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Long-term Impacts of Annual Cattle Manure and Fertilizer on Soil Quality Under Corn-Soybean Rotation in Eastern South Dakota

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LONG-TERM IMPACTS OF ANNUAL CATTLE MANURE AND FERTILIZER ON SOIL QUALITY UNDER CORN-SOYBEAN ROTATION IN EASTERN SOUTH DAKOTA

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

LONG-TERM IMPACTS OF ANNUAL CATTLE MANURE AND FERTILIZER ON SOIL QUALITY UNDER CORN-SOYBEAN ROTATION IN EASTERN SOUTH DAKOTA

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Dairy and beef manure have been used to enhance soil quality; however, their impacts under long-term application in corn-soybean rotation need to be evaluated. Nutrient based recommended rates of manure applications on soils are important and also need to be monitored. This study, therefore, was conducted at two long-term sites to assess the impacts of manure and inorganic fertilizer application rates on some of the soil quality indicators and greenhouse gas emissions (GHGs) in a corn (*Zea mays* L.) - soybean (*Glycine max* L.) rotation system located at Beresford and Brookings in Eastern South Dakota. Study treatments included: three manure [phosphorus (P) based recommended manure application rate, nitrogen-based recommended manure application rate (N), nitrogen-based double of recommended manure application rate (2N)], and two fertilizers; recommended fertilizer (F) and (HF) high fertilizer and a control (CK) with no manure management. Soil samples were extracted in four replicates under randomized complete block design from 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm depths to analyze selected soil quality indicators, and intact core samples were taken from 0-10 and 10-20 cm depths to measure soil hydrological properties in 2015. Soil GHG fluxes were observed once a week from June 2015 through October 2015 and May 2016 to August

2016 depending on the climatic conditions. Results showed that manure maintained the soil pH for 0-10 cm depth and inorganic fertilizer decreased it compared to the control treatment at either site. Manure improved soil organic carbon (SOC), total nitrogen (TN), soil aggregate stability (WAS), soil water retention (SWR), water infiltration (q_s) but decreased the soil bulk density (BD) in comparison with inorganic fertilizer and control.

The CO_2 fluxes were significantly impacted by manure application, whereas, there were insignificant impacts on CH_4 flux. Soil surface nitrous oxide (N_2O) fluxes were significantly impacted by inorganic fertilizer in 2016, whereas, there were non-significant differences in 2015. Air temperature and soil moisture content were strongly correlated with soil CO_2 fluxes. As a result, this study concluded that manure produced better soil quality by improving soil properties and developing better soil structure, whereas, manure also increased soil surface GHGs emission. The rate of manure application is consequently important for use in agriculture to offer better environmental quality.

CHAPTER 1

INTRODUCTION

Soil organic carbon (SOC) is the long-term studied parameter due to its direct or indirect impacts on soil quality (Franzluebbers, 2002). The SOC is the source of energy for soil microbial activities and processes (Reeves, 1997). Therefore, the addition of soil organic amendments is important for enhancing the soil quality. The addition of organic materials such as manure improves SOC and hence reduces soil compaction, erosion, degradation and also improves soil structure (Celik, Gunal, et al., 2010).

Livestock manure generally decreases the soil bulk density and increases total porosity, soil water retention, macro and microporosities and infiltration (Rasoulzadeh and Yaghoubi, 2014, Zhang, Yang, et al., 2006). Organic manure which originated from livestock is very helpful to improve soil productivity and quality, and also challenges soil degradation by improving soil nutrients especially SOC in the agricultural fields (Domingo-Olivé, Bosch-Serra, et al., 2016, Jones, Panagos, et al., 2012). Manure is the only available source of organic nutrient in considerable amounts to enrich SOC (Dunjana, Nyamugafata, et al., 2012, Zingore, Delve, et al., 2008). The application of manure as soil amendment can improve soil properties and provide various additional benefits to enrich soil quality and crop productivity (Lal, 2006). However, some studies reported insignificant changes in bulk density, water infiltration and available water due to the application of manure (Asada, Yabushita, et al., 2012, Blanco-Canqui, Hergert, et al., 2015). Livestock manure is a very important management to enhance productivity and quality of soil and also decreases soil degradation by SOC addition. However, if manure application and rate not managed properly, it can negatively impact to soils and environment. Manure is responsible for the significant amount of total greenhouse gas emissions (Bennetzen, Smith, et al., 2016, Liang, Lal, et al., 2013).

Inorganic fertilizer is the most commonly amendment used by the producers for enhancing the crop production. However, inorganic fertilizer addition might impact soil properties (Bronick and Lal, 2005). Some inorganic fertilizers may increase crop production but not soil hydrological parameters (Dunjana, Nyamugafata, et al., 2014). Soil fertility degradation related to declining in pH, organic matter and exchangeable cations in the soil (Lawal and Girei, 2013) and GHGs emission especially N_2O (Kim, Rafique, et al., 2014) might be the result of inorganic fertilizer application. The long-term application of inorganic fertilizer may not keep SOC content sustainable in the soil (Hati, Swarup, et al., 2008), and NH_4^+ concentration of N fertilizers and role of dispersing organic agents by moving into the soil aggregates and colloids might be a possible reason of reduction for aggregate stability (Haynes and Naidu, 1998). The addition of chemical fertilizers can impact soil physical properties (Bronick and Lal, 2005). Further, application of inorganic fertilizer can reduce the pH of the soil (Eghball, 2002). A review study conducted by Guo, Liu, et al. (2010) also reported that plots received inorganic fertilizer decreased the soil pH compared to manure application at the top soil depth. Therefore, manure can be alternative option to inorganic fertilizers if the rate and application of manure in soils can be managed properly.

Study Objectives

Manure management practices based on the nutrient content are significant to improve crop productivity and mitigate soil surface GHG emissions. Therefore, the purpose of this study was to understand influences of organic manure and inorganic fertilizer on soil quality and GHGs emissions. Thus study was divided into three separate objectives and those are listed below as:

Study 1 To assess the impacts of manure and inorganic fertilizer applications on selected soil quality parameters in the long-term reduced-tillage corn-soybean rotation.

Study 2 To study the influences of manure and inorganic fertilizer applications on soil hydrological properties in long-term reduced-tillage corn-soybean rotation.

Study 3 To investigate the impacts of long-term manure and inorganic fertilizer application on soil surface greenhouse gas (GHG) fluxes in long-term reduced-tillage corn-soybean rotation.

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CHAPTER 2

LITERATURE REVIEW

Understanding the impacts of agricultural management practices on soil quality indicators is very crucial (Peukert, Griffith, et al., 2016). It is important to determine the influences of alternative management systems and soil amendments such as animal manure and inorganic fertilizers on soils and crop productivity (Haynes and Naidu, 1998). Soil amendments such as manures and inorganic fertilizer impact soils and crop yield by influencing especially the soil organic carbon (Reeves, 1997). The application of manure as soil amendment can improve soil properties and provide various additional benefits to enhance the soil quality (Domingo-Olivé, Bosch-Serra, et al., 2016, Jones, Panagos, et al., 2012, Lal, 2006). The present review will focus on investigating the impacts of manure and inorganic fertilizer application on soil quality indicators.

2.1. Manure Management in Agroecosystems

Addition of manure to soils can improve soil organic matter (SOM) in both temperate and tropical regions (Khaleel, Reddy, et al., 1981, Lal and Kang, 1982). Some of the benefits of manure additions include: increase in soil microbial communities, microbial biomass (McGill, Cannon, et al., 1986), earthworm populations (Standen, 1984) and enzyme activities (Dick, Rasmussen, et al., 1988). Improved soil microbial community enhances soil properties such as soil aggregation, porosity (Haynes and Naidu, 1998), nutrients and crop yield (Sharpley, Chapra, et al., 1994). Addition of manure to agricultural soils is an important economic practice to manage organic wastes, however, higher rate of manure application can be environmental concerns such as heavy metal accumulation (van der Meer, 1987), surface crusting due to detrimental effects, decreased hydraulic conductivity, increased detachment (Mazurak, Chesnin, et al., 1975, Olsen, Hensler, et al., 1970, Weil and Kroontje, 1979), higher soil salinity (Epstein, Taylor, et al., 1976), pollution of groundwater (Haynes and Naidu, 1998) and greenhouse gas emissions (especially ammonia and nitrous oxide) (Nkoa, 2014). The high monovalent cations (Na+ and particularly K+) concentration in the animal based amendments and $NH4^+$ content (due to mineralization of organic waste N) are the initial reasons of soil structural breakdown by dispersion of soil colloids (Haynes and Naidu, 1998). The phosphorus loss from manure applied soils can deteriorate the water quality of streams (Sharpley, Chapra, et al., 1994). Therefore, an optimum rate of manure application is very important.

The type and amount of bedding material, time of accumulation, water amount and quality, location in the storage and length of storage before application are variables which can affect manure quality at the time of application (Sharpley, Chapra, et al., 1994) and can result in a wide range of manure nutrient concentration (Edwards and Daniel, 1992). Over application of nutrients might create a harmful situation. For instance, it has been reported that high P inputs can impair the quality of water bodies (Sharpley, Chapra, et al., 1994). Due to a wide variation of nutrient concentrations, the application rates should be based on manure analysis (Igo, Sims, et al., 1991) and it is recommended that the P and N content in the soil should also be examined as soon as possible before application of manure to the soils (Sharpley, Chapra, et al., 1994). To maximize application of organic material and minimize environmental risk, the optimum amount of manure is important to be used (Asada, Yabushita, et al., 2012).

Application of organic manure to soils at recommended rates to supply nutrients is a traditional agricultural practice (Haynes and Naidu, 1998) and beneficial for soil physical properties (Low, 1954). Nutrient content of manure is important in calculating land application rates and determining treatment techniques. The characteristics to determine manure application rates suggested that manure application rates should be based on P or N (Sharpley, Chapra, et al., 1994). Since the N ratio to P in the manure is much lower than in grain, this can lead to over application of P because more P will be applied than is needed by the crop and also N/P ratio of manure is lower than crop requirements. There is a need to comply with the South Dakota Department of Environment and Natural Resources (DENR) rules (February, 2003) pertaining to manure application rates that are based on nitrogen and phosphorus (Gelderman, Gerwing, et al., 2006). Manure application is dependent on crop nutrient needed, available soil nutrients and manure nutrient contents. Therefore, it can be summarized that application of manure should be at recommended rates and nutrient based according to analysis of soil and manure under consideration of yield and environmental risks.

2.2. Inorganic Fertilizer Application in Soils

Mineral fertilizers are used to manage nutrient concentration in the soil for enhancing the crop production. These inorganic fertilizers in the long-term increase the crop yield which is associated with the increase in SOM and soil biological activities (Haynes and Naidu, 1998). Addition of P as an inorganic fertilizer, sometimes increase the water holding capacity, develops soil physical structure and increases the crop production (Lutz, Pinto, et al., 1966), however, it does not always produce reliable economic returns (Yeoh and Oades, 1981). Applications of inorganic fertilizer including Na^+ which favor the dispersion of soil colloids (Haynes and Naidu, 1998). Inorganic fertilizer can contribute to negative effects such as lowering the soil pH and soil moisture, and increasing the accumulated $NH4^+$ levels (Haynes and Naidu, 1998). Intensive mineral fertilization can be costly, and enhance the nitrate pollution and loss of carbon in the soil. In addition, inorganic fertilizers from agricultural lands might be negatively impacting the human health (Campbell and Campbell, 2005). Therefore, there is strong need to explore for alternatives or application of these fertilizers in the right amount without negatively impacting the soils and the environment.

2.3. Manure and Inorganic Fertilizer Impacts on Soils

2.3.1. Soil Organic Matter (SOM)

Globally, over the last 160 years, there has been a wide area of research examining the influences of fertility practices on SOC because changes in SOC needs long duration of years to be detectable (Ludwig, Geisseler, et al., 2011). Organic matter is a major parameter to crop growth and productivity not only directly by providing nutrients but also indirectly by modifying soil properties (Darwish, Persaud, et al., 1995, Ding, Han, et al., 2012, Lal, Follett, et al., 1999) and it eases global warming, delivers “win–win” advantages (Lal, 2004). For example, decline in SOM causes compaction, negatively impacts water holding properties, aggregation, porosity and hence contributes to erosion (Barik, 2011). Soil aggregate stability is strongly correlated with SOC (Celik, Gunal, et al., 2010, Mikha, Hergert, et al., 2015). It has been reported that SOC is also strongly related with soil physical properties (Hati, Swarup, et al., 2007), such as decreased soil compaction, stabilized soil structure and soil more resistant to erosion (Martınez and Zinck, 2004). Soil quality is an important perspective for sustainable agriculture (Lawal and Girei, 2013). Livestock manure holds about 15% C content (Blanco-Canqui, Hergert, et al., 2015). Manure application and benefits to increase SOC and soil fertility is well documented (Miller, Sweetland, et al., 2002). Therefore, any nutrient management practice which can improve SOM in the complex and dynamic soil system is important.

Organic manure influences on SOC is well documented (Bottinelli, Menasseri-Aubry, et al., 2013, Mikha, Hergert, et al., 2015, Rasoulzadeh and Yaghoubi, 2014) under different soils and cropping systems (Agbede, Ojeniyi, et al., 2008, Barik, 2011, Ibrahim, Hassan, et al., 2011, Shirani, Hajabbasi, et al., 2002). Soil fertility strategies which can increase SOM assist to sustain crop productivity at higher levels (Bandyopadhyay, Misra, et al., 2010). However, the highest improvements in soil properties are associated with the addition of manure (Mellek, Dieckow, et al., 2010). The SOM amount accrued can differ significantly contingent to its decomposition rate (Haynes and Naidu, 1998). Inorganic fertilizers application does not directly increase SOC, indicating that by itself application of inorganic fertilizers is not a significant practice to influence SOC sequestration (Liang, Chen, et al., 2012). It is obvious, inorganic fertilizers are more commonly used soil fertility practice in comparison with manure in modern farming but it is not as effective as manure application in terms of increases in SOC level.

Consequently, comparison of inorganic fertilizer and organic manure is important for sustainable agriculture (Blanco-Canqui, Hergert, et al., 2015).

2.3.2. Soil Bulk Density and Soil Penetration Resistance

Soil bulk density is one of the soil properties that indicate the degree of soil compaction. For sustainable agricultural management to improve soil properties, soil resilience or resistance against compaction is important. Addition of the manure to croplands is an important management strategy to minimize soil degradation and increased soil productivity. Long-term manure practices can be strongly associated with changes in SOC and soil physical properties (Blanco-Canqui, Hergert, et al., 2015). Duration of manure addition is one of the controllers affecting manure impacts on soil properties (Sweeten and Mathers, 1985). Addition of manure has been reported to decrease bulk density associated with SOM (Celik, Ortas, et al., 2004, Hati, Mandal, et al., 2006, Hou, Wang, et al., 2012, Mandal, Chandran, et al., 2013, Shirani, Hajabbasi, et al., 2002), but it is also been reported insignificant changes in bulk density (Iordache and Borza, 2012), while long-term studies frequently indicate improvement in soil quality parameters (Blanco-Canqui, Hergert, et al., 2015). This highlights the need for long-term experiments to assess changes in soil parameters. The more rate and level of manure increase, the more decrease will be monitored in bulk density (Rasoulzadeh and Yaghoubi, 2014).

As it is for manure, inorganic fertilizer impacts on soil properties is also important (Blanco-Canqui, Hergert, et al., 2015). Inorganic fertilization does not significantly influence bulk density (Celik, Gunal, et al., 2010, Xin, Zhang, et al., 2016). Indeed, inorganic fertilizers are more widely used than cattle manure in modern agriculture. Knowledge and comparison of the impacts of inorganic fertilizers and animal manure on soil properties are vital for the management of soil resources and long-term sustainability of cropping systems. Long-term experiments (>50 yr) of manure and N fertilizer applications can provide valuable information on the extent to which such applications can modify soil physical properties (Blanco-Canqui, Hergert, et al., 2015).

2.3.3. Soil Aggregate Stability and Structure

Soil aggregation is vital in agriculture due to impacts on, plant growth and the environment; therefore, addition of organic substances perform important roles in improving soil properties (Celik, Gunal, et al., 2010). Decline in soil aggregates and hence in soil structure limit plant root growth (Darwish, Persaud, et al., 1995). It has been reported by many studies explain a strong correlations among soil aggregate stability, soil structure, SOM (Haynes and Naidu, 1998) and erosion (Tebrügge, 2003) indicated that SOC explains for 70 to 90% of the variability in stable aggregates (Bottinelli, Menasseri- Aubry, et al., 2013). Organic matter addition such as manure application has been monitored as improving soil aggregation and hence soil structure (Busari and Salako, 2015, Dunjana, Nyamugafata, et al., 2012, Kukal and Bawa, 2014, Leroy, Herath, et al., 2008, Liu, Li, et al., 2013, Wortmann and Shapiro, 2008). Addition of heavy manure application alters the soil redox circumstances by developing soil aggregation and structure and also produced the oxidizing and anoxic states in inter or intra aggregate pores (Asada, Yabushita, et al., 2012).

On the other hand, mineral fertilizers do not significantly develop soil aggregate stability and structure (Khalid, Tuffour, et al., 2014). Inorganic fertilizer addition means only enriching nutrient availability in the soil, however, some problems appear related to the use as exclusive soil amendment source (Lawal and Girei, 2013). Phosphoric fertilizers and phosphoric acid can favor aggregation by the formation of Al or Ca phosphate binding agents whilst where fertilizer $NH4^{+}$ accumulates in the soil at high concentrations, dispersion of clay colloids can be favored (Haynes and Naidu, 1998).

2.3.4. Water Infiltration

Improved steady state infiltration rate which is significantly increased ($P < 0.05$) by fertility management compared with the control, contributes to greater absorption of rainfall and lower surface runoff (Dunjana, Nyamugafata, et al., 2014). Decreased soil compaction is highly associated with higher soil water infiltration and water-holding capacity (Dexter, 2004). Increases in SOM produce an increase in soil quality indicators like infiltration rate, water holding capacity, structure. (Rasoulzadeh and Yaghoubi, 2014) stated that SOM is important for soil structural stability, aiding the infiltration of air and water, promoting water retention, and reducing erosion.

Organic amendments, such as manure, generally increase infiltration compared to control (without manure) (Busari and Salako, 2015, Miller, Beasley, et al., 2015). Organic wastes can improve soil hydraulic properties such as infiltration rate and hydraulic conductivity whereas, the inorganic fertilizer alone did not show any significant improvement (Khalid, Tuffour, et al., 2014).

2.3.5. Water Retention and Pore Size Distribution

Soil water retention describes the relation between wetness and water potential of soil and has impacts on soil redox conditions (Asada, Yabushita, et al., 2012). Soil organic carbon has significant positive correlation with water retention at field capacity (Hati, Swarup, et al., 2007), total porosity, saturated hydraulic conductivity and hence bulk density (Fares, Abbas, et al., 2008). Soil compaction impacts have been monitored as decreasing macro porosity and water infiltration but also increase in bulk density, and soil strength (Dexter, 2004). Addition of organic amendments such as manure improves soil structure, water retention capacity (Bhagat and Verma, 1991, Hati, Mandal, et al., 2006), pore size distribution, soil water transmission (Fares, Abbas, et al., 2008), aggregation, water-holding capacity, hydraulic conductivity, total porosity, resistance to water and erosion but decreases bulk density and compaction (Leroy, Herath, et al., 2008). However, some reports state little or no effect on soil water retention (Miller, Sweetland, et al., 2002). Manure addition as a soil fertility practice reflects more benefits than chemical fertilizers due to manure potential to moderate soil physical condition such as improvement in water holding capacity, aeration, drainage, friability and microbial activities (Goladi and Agbenin, 1997). However, manure amount is associated with important differentiations in these parameters (Mellek, Dieckow, et al., 2010, Miller, Sweetland, et al., 2002).

Due to its impacts as increasing in biomass production and C input, N fertilization can positively influence soil water retention and compatibility (Blanco-Canqui, Hergert, et al., 2015). However, some studies show insignificant increases in any of the parameters by addition of inorganic fertilizers to soil (Khalid, Tuffour, et al., 2014).

2.4. Manure and Inorganic Fertilizer Impacts on Soil Surface GHGs

Greenhouse gas (GHG) emissions play an important role to global warming, stratospheric ozone depletion and also regulate the earth's atmospheric temperature and altered precipitation regimes (Rafique, Kumar, et al., 2014). Agricultural activities add importance to global GHG emissions, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3), which are the main GHG which cause global warming (Houghton, Ding, et al., 2001). Concentrations of the three most important long-lived greenhouse gases, CO_2, CH_4 and N_2O have increased dramatically over the past 255 years in the atmosphere (Marble, Prior, et al., 2011). Concerns about the global warming and dependence on foreign fossil fuels in the United States, which is second highest worldwide GHGs emitter where China is first (Kumar, Nakajima, et al., 2014), triggered a search for more sustainable sources of energy (Marble, Prior, et al., 2011). It is essential to assess GHG emissions at chronological and spatial scales to intend the way to decrease environmental degradation (Liang, Lal, et al., 2013). There is growing interest such as GRACE net in decreasing the potential threat of global warming and enhance soil carbon sequestration by decline of GHG release into the atmosphere (Moss, Jouany, et al., 2000) without reducing the economic viability of initiatives (Sejian, Lal, et al., 2011).

Multiple studies observed major differences in GHGs in the summer period due to drought conditions, reduced precipitation and higher temperatures. The water-filled pore space (WFPS) in soil determines by precipitation impacts GHG fluxes and the soil aeration. Complex interactions in soil C, drainage, moisture, returned C, gas diffusivity, temperature, and soil biological activity impacts GHG (Dijkstra, Prior, et al., 2012, Wagle and Kakani, 2014). Rising atmospheric GHGs add an increase to the atmospheric temperature and hence global warming (Newsroom, 2006). The relief and differentiation in CO_2 and CH_4 from small amount of carbon due to SOM produce pertinent atmospheric GHGs variability because SOM has more organic carbon than is in the atmosphere and global flora (Lehmann and Kleber, 2015). Therefore, agricultural management impacts GHG emission (Poch, Hopmans, et al., 2006) due to SOC concentration (Osher, Matson, et al., 2003). Nitrate increase rates of denitrification processes under anaerobic conditions (Myrold, 1998). Soil organic carbon serves as substrate to soil microorganisms that generate CO_2 in aerobic conditions (Davidson, Verchot, et al., 2000). Higher WFPS and lower porosity reduce aerobic conditions and restrict CO_2 diffusivity and microbial access to substrate (Beare, Gregorich, et al., 2009). The combination of lower SOC, lower porosity, high bulk density, and higher WFPS resulted in lower CO_2 fluxes in the shoulder compared to the foot slope during the growing season (Mbonimpa, Hong, et al., 2015).

It has been reported that fertilization (N and P) has mixed effects on soil surface GHGs emissions. Soil surface GHG (CH_4, N_2O and CO_2) emissions from soils are sensitive to climate change and land management practices (Rafique, Kumar, et al., 2014). Soil CH_4 fluxes are a result of microbial processes which exhibit two behaviors; uptake and release (Mbonimpa, Hong, et al., 2015). Both methanogens and CH_4-oxidizing bacteria are present in solid manure (Sejian, Samal, et al., 2015). The CH_4 is oxidized mainly by aerobic bacteria (Sejian, Samal, et al., 2015). Methanogens occur only under strict anaerobic conditions where it is coupled to other processes involved in the breakdown of manure organic matter (Sejian, Samal, et al., 2015). Principal factors affecting CH_4 emissions from manure are the amount of manure produced and the portion of the manure that decomposes anaerobically (Mbonimpa, Hong, et al., 2015). The soil surface N_2O emissions are the major contributor to the global agricultural emissions (Li, Watson, et al., 2013). Globally, manure production and use contribute more N_2O to the atmosphere than synthetic fertilizer N (Li, Watson, et al., 2013). However, to meet the nutritional needs of a growing human population, more N inputs to agriculture are likely needed for enhancing the productivity (Li, Watson, et al., 2013). The use of N fertilizers and animal manures are the main anthropogenic sources, estimated at about 24% of annual N_2O emissions (Kim, Rafique, et al., 2014). It has been suggested that N fertilizer use, land use and its management, and climate are the major controlling factors of N_2O emissions from agricultural lands (Kim, Rafique, et al., 2014). Increases in N_2O concentrations add to the greenhouse effect and ozone depletion (Kim, Rafique, et al., 2014). In a 100-year time horizon, the global warming potential of N_2O is 298 times than that of carbon dioxide (CO_2) and 12 times that of methane (CH_4) (Kim, Rafique, et al., 2014). Almost 90% of global N_2O emissions are a result of the microbial processes of nitrification and denitrification of nitrogen (N) compounds in soils (Li, Watson, et al., 2013). Nitrification does not occur under anaerobic conditions (Sejian, Samal, et al., 2015). Denitrification is transformation of nitrites and nitrates to N_2O and dinitrogen (N_2) (Li, Watson, et al., 2013). Soil with a history of manure application had a much higher propensity for N_2O production than does non-manured soil (Graham, van Es, et al., 2013). In summary, the production and emission of N_2O from managed manures require the presence of either nitrites or nitrates in an anaerobic environment preceded by aerobic conditions necessary for the formation of these oxidized forms of N (Sejian, Samal, et al., 2015).

Carbon dioxide is lost from agricultural soils by respiration and decomposition of soil organic matter (Rafique, Kumar, et al., 2014). Soil CO_2 fluxes are generated from autotrophic metabolism of plant roots and associated mycorrhizae, and heterotrophic respiration from soil organisms (Mbonimpa, Hong, et al., 2015). Soil organic carbon serves as substrate to soil microorganisms that generate CO_2 in aerobic conditions (Mbonimpa, Hong, et al., 2015). Carbon dioxide emissions per unit product were the least contributor to GHG emission (Sejian, Rotz, et al., 2011). While CO_2 receives the most attention as a factor relative to global warming, the CH_4 and N_2O also cause significant radiative forcing (Sejian, Lal, et al., 2011). Variations in climatic factors strongly affect the GHG balance in agricultural systems (Rafique, Kumar, et al., 2014). The GHGs fluxes increase by reduced precipitation and increased temperatures (Mbonimpa, Hong, et al., 2015). Precipitation determines the water filled pore space (WFPS) in soil which impacts GHG fluxes by influencing the oxygen status of the soil (Rafique, Kumar, et al., 2014). Agricultural GHG emissions are complex and heterogeneous due to the combined effect of meteorological drivers as well as land management and soil properties (Mbonimpa, Hong, et al., 2015). Not only it is necessary to reduce GHGs emissions but also it is needed to return the GHGs to the soil and sustain normal condition of the nature. This might be possible with management practices because soil and land management practices influence the organic carbon (SOC) content of the soils, and hence influence the GHG emissions (Kumar, Nakajima, et al., 2014). Improved livestock and grassland management, and soil nutrient management can be strategies to deliver on both mitigation and improved local livelihoods, and create further resilience to climate change (Bennetzen, Smith, et al., 2016). However, uncertainty still remains about overall implications of fertilization rate, climate and soil conditions on GHG emissions (Mbonimpa, Hong, et al., 2015). Its effective biomass productivity and carbon (C) sequestration potential are also believed to reduce greenhouse gases (GHGs) (Mbonimpa, Hong, et al., 2015). The nature of the N cycle and its interaction with the C cycle demands a holistic approach for addressing gaseous emissions and mitigation research by developing suitable abatement strategies for manure management (Sejian, Samal, et al., 2015).

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CHAPTER 3

LONG-TERM ANNUAL LIVESTOCK MANURE APPLICATION IMPACTS ON SELECTED SOIL QUALITY INDICATORS UNDER A CORN-SOYBEAN ROTATION IN SOUTH DAKOTA

ABSTRACT

Manure can be used to enhance soil fertility and crop yield. However, an optimum rate of manure application is very important to avoid any environmental impacts. This study was conducted to assess the long-term impacts of manure and inorganic fertilizer rates on some of the soil quality indicators such as SOC, total nitrogen (TN), aggregate stability, pH and electrical conductivity (EC) under corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation system at two sites of South Dakota. Study treatments included: three manure [phosphorus based recommended manure application rate (P), nitrogen-based recommended manure application rate (N), nitrogen-based double of recommended manure application rate (2N)], two fertilizers [recommended fertilizer (F) and high fertilizer (HF)], and a control (CK) with no manure application]. Soil samples were extracted in 4 replicates from 0-10, 10-20, 20-30 and 30-40 cm depths in 2015 to analyze selected soil quality indicators. Results showed that manure maintained (no impact) the soil pH for 0-10 cm depth, whereas, inorganic fertilizer decreased it compared to the control treatment at either site. Further, manure (2N) significantly increased SOC for every studied depth increment from 0-40 cm compared to that of inorganic fertilizer at either site. A similar trend was observed for the TN but differeneces were not always signifcant. Manure (6.95) significantly increased pH by 6.6 and 23% compared to that of fertilizer (6.52) for the 0-10 cm depth at Brookings and Beresford, respectively, sites.

Manure increased EC (1556 μs cm^{-1}) by 120% compared to fertilizer (708 μS cm^{-1}) for 0-10 cm depth. On average, manure significantly increased WAS by 7.2 and 5.6% compared to that of fertilizer for the 0-10 cm depth for Brookings and Beresford, respectively, sites. Data from this study concluded that manure improved soil properties compared to that of inorganic fertilizer, however, further research is needed to monitor the water quality and environmental impacts associated with different rates of manure application.

Keywords: Manure, inorganic fertilizer, corn-soybean rotation, soil organic carbon, total nitrogen, pH, and EC.

INTRODUCTION

Soil quality reflects the living and dynamic nature of the soil (Karlen, Mausbach, et al., 1997, Shukla, Lal, et al., 2006), and the concept of soil quality addresses biological, chemical and physical components that are important in sustaining biological productivity, environmental quality and plant and animal health (Karlen, Mausbach, et al., 1997, Reeves, 1997, Shukla, Lal, et al., 2006). Soil quality parameters are altered by various soils and crop management practices and thus used to evaluate the effects of alternative management systems, soil amendments such as animal manure, inorganic fertilizers, on soils and crop production. Soil is the largest terrestrial organic carbon pool (Stockmann, Adams, et al., 2013). Soil organic carbon is the major soil quality indicator which strongly impacts physical, chemical and biological properties of soils, therefore, this parameter is the most studied attribute for long-term research (Shukla, Lal, et al., 2006, Stockmann, Adams, et al., 2013). The SOC is the energy source for various soil microbial activities and chemical processes (Reeves, 1997). There are various other soil quality indicators such as plant available water capacity, infiltration rate, aggregate formation and stability, bulk density and soil strength that are also associated with the SOC (Franzluebbers, 2002). Soil amendments such as manures and inorganic fertilizer impact soils and crop yield by impacting the carbon concentration in the soil (Reeves, 1997). Organic manure which originated from livestock is very helpful to improve soil productivity and quality, and also challenges soil degradation by improving soil nutrients especially SOC in the agricultural fields (Domingo-Olivé, Bosch-Serra, et al., 2016, Jones, Panagos, et al., 2012). Manure is an available source of organic nutrient in considerable amounts to enrich SOM (Dunjana, Nyamugafata, et al., 2012, Zingore, Delve, et al., 2008). The application of manure as soil amendment can improve soil properties and provide various additional benefits to enrich soil quality and crop productivity (Lal, 2006).

The application of manure is one of the organic practices for enhancing the crop yield and improving soil quality. The application of inorganic fertilizer also impacts soils and crop productivity. However, long-term application of inorganic fertilizer may not keep SOC content sustainable in the soil (Hati, Swarup, et al., 2008). The NH_4^+ concentration of N fertilizers and role of dispersing organic agents by moving into the soil aggregates and colloids might be a possible reason of reduction for aggregate stability (Haynes and Naidu, 1998). The addition of chemical fertilizers can impact soil physical properties (Bronick and Lal, 2005). Eghball (2002) reported that application of inorganic fertilizer reduced the pH of the soil. A review study conducted by Guo, Liu, et al. (2010) also reported that plots received inorganic fertilizer decreased the soil pH compared to manure application at the top soil depth.

Manure management practices based on nutrient contents are significant to improve productivity in the agroecosystems and benefit economically and environmentally. Therefore, we hypothesized that different application of manure rates and inorganic fertilizer rates based on phosphorous (P) and nitrogen (N) concentrations could improve soil quality indicators. Therefore, the specific objective of this study was to assess the impacts of manure and inorganic fertilizer applications on selected soil quality indicators in the long-term corn-soybean rotation at two different locations of South Dakota.

MATERIALS AND METHODS

Sites Description

The experimental sites were located at two different locations; Beresford and Brookings in South Dakota. The Brookings site was established in 2008 (7-yr) at South Dakota State University Felt Research Farm near Brookings (44º 22’ 07.15” N and 96º 47’ 26.45” W) on well drained silty loam Vienna soil (Fine-loamy, mixed, frigid Udic Haploborolls). The Beresford site was initiated in 2003 (12-yr) near Beresford (43o 02’ 33.46” N and 96º 53’ 55.78” W) at the Southeast Research Farm of the South Dakota State University in Clay County on silty loam Egan soil (Fine-silty, mixed, mesic Udic Haplustolls). These sites were initiated to study the effect of manure and mineral fertilizer application rates on crop production and soil properties. The plots at Beresford site were established in nearly flat areas with the slope and elevation of <1%, and 390 m, respectively. This site was characterized by a humid continental climate having relatively humid summers and cold, snowy winters with a mean annual air temperature of -13.6°C in the winter and 29.5°C in the summer, respectively. The mean annual precipitation was about 678 mm. The plots at Brookings site are nearly flat with the slope of <1% and elevation of this site were 518 m, and this site was characterized by a humid continental climate having relatively humid summers and cold, snowy winters with a mean annual air temperature of -15.8°C in the winter and 27.8°C in the summer, respectively. The mean annual precipitation was about 637 mm.

Study Treatments

The experiment had three manure application rates; recommended phosphorus-based manure (P), recommended nitrogen-based manure (N), and two times of recommended nitrogen-based manure (2N), and two different fertilizer application rates; recommended fertilizer (F), high fertilizer application (HF), and control (CK). The cropping sequence was corn (*Zea mays* L.)- soybean (*Glycine max* L.) rotation system for each location. There are total 24 plots at either site, and all the treatments are laid out in a randomized complete block design with four replicates. The dimensions of each plot are 4.6 m (wide) by 20 m (length) in size at Beresford, and 6 m by 18 m at Brookings.

The manure was applied in the spring in a manual application and incorporated by disk at 6-cm deep for 1 to 3 days before planting at either site. Manure of the study was analyzed by South Dakota Agricultural Laboratories. Fertilizer treatments for 179.3 kg ha^{-1} yield goal for corn and 44.8 kg ha^{-1} for soybean were used for both the sites; however, no nutrient recommendation of fertilizer for soybean was used. Dairy manure with 31.5% moisture and beef manure with 21.9% moisture for Brookings and Beresford sites, respectively, were used in this study. Dairy manure contained 6 g kg^{-1} total nitrogen, 2.7 g kg^{-1} NH_4-N, 3.3 g kg^{-1} Organic-N, 3.2 g kg^{-1} available N, 2.5 g kg^{-1} P_2O_5 and 4.2 g kg^{-1} K_2O concentrations. Beef manure contained 10.6 g kg^{-1} total nitrogen, 1.3 g kg^{-1} NH_4-N, 9.3 g kg^{-1} Organic-N, 5.6 g kg^{-1} available nitrogen, 8.5 g kg^{-1} P_2O_5 and 9.9 g kg^{-1} concentrations. Annually, P-based recommended rate of manure treatment include N (90 kg ha^{-1})-P (30 kg ha^{-1})-K (39 kg ha^{-1}) where N-based recommended manure rate included N (131 kg ha^{-1})-P (56 kg ha^{-1})-K (93 kg ha^{-1}), two times N-based recommended manure rate N (261 kg ha^{-1})-P (111 kg ha^{-1})-K (187 kg ha^{-1}) at Brookings site. Beresford site included N (51 kg ha^{-1})-P (52 kg ha^{-1})-K (82 kg ha^{-1}) for P treatment, N (122 kg ha^{-1})-P (111 kg ha^{-1})-K (155 kg ha^{-1}) for N treatment and N (243 kg ha^{-1})-P (222 kg ha^{-1})-K (310 kg ha^{-1}) for 2N treatment. On the other hand, F (inorganic fertilizer) treatment included N (41 kg ha^{-1})-P (19 kg ha^{-1})-K (23 kg ha^{-1}) and HF included N (75 kg ha^{-1})-P (60 kg ha^{-1})-K (71 kg ha^{-1})-Zinc (7 kg ha^{-1})-S (25 kg ha^{-1}) at the Brookings site, wheras, F included N (43 kg ha^{-1})-P (16 kg ha^{-1})-K (4 kg ha^{-1}) and HF included N (85 kg ha^{-1})-P (46 kg ha^{-1})-K (39 kg ha^{-1})-Zinc (6 kg ha^{-1})-S (25 kg ha^{-1}) for Beresford site from 2003 to 2015.

Soil Sampling and Analysis

Soil samples were collected from 0-10, 10-20, 20-30, and 30-40 cm depths at either site using a push probe auger in summer of 2015. A total of 4 replicated samples per plot were collected, and these soil samples were composited for each plot and sieved and passed through 2 mm sieve pending analysis.

Wet aggregate stability of the soil for the 0-10 and 10-20 cm depths was measured using the procedure of Kemper and Rosenau (1986). Soil samples were sieved to obtain 1-2 mm aggregates and air-dried aggregates were pre-moistened to saturation in a vaporization chamber and placed on a 0.25 mm screen. Soil samples were immersed in deionized water for 3 minutes and then subjected to an oscillating movement in water for 3 minutes in an apparatus designed according to specifications outlined in Kemper and Rosenau (1986). Wet stable aggregates for 0-10 and 10-20 cm depths were described as the percentage of stable aggregates retained on the screen compared to the initial sample mass corrected for air-dry moisture and sand content.

The pH of the soil is a measure of the concentration of the hydrogen ion (H^+) concentrations. Soil pH was determined using a suspension sample with soil (air-dried) to the water (soil: water) ratio of 1:1 procedure, and measured with an Orion star pH and EC meter. Electrical conductivity (EC) was measured with 1:2 of soil: water ratio using electronic pH and EC meter. The method outlined by Stetson, Osborne, et al. (2012) was used to determine carbon (C) and nitrogen (N) concentrations after removing visible crop residues and sieved through a 0.5 mm. Total C (TC) and nitrogen (TN) were analyzed by combustion using a Tru-Spec-CHN analyzer (LECO Corporation, St. Joseph, MI). Soil inorganic carbon (SIC) was measured using 1M 10 ml of HCI addition to the one gram of the 0.5 mm sieved soil samples. The loss of the weight from the initial weight of the total was given as SIC. Soil organic carbon (SOC) was calculated by subtracting SIC from TC and expressed in g kg^{-1}.

Statistical Analysis

A statistical test was performed to determine the impacts of treatments on soil properties under different levels of manure and inorganic fertilizer applications. An estimate for the least significant difference (Duncan's LSD) among treatments was obtained using the Mixed procedure in SAS 9.3 (Institute, 2012). Treatments were considered as fixed effects and replications as random effect. The differences among treatments were calculated at the significant level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Soil pH and EC

Soil pH and EC data for 0-10, 10-20, 20-30 and 30-40 cm depth under all the treatments for Brookings and Beresford sites are shown in Table 1. Treatments significantly impacted the soil pH only at 0-10 cm depth for either site. Soil pH was not significantly influenced by the treatments at either site beyond 10 cm depth. It was also significantly different for *Manure vs. Fertilizer* contrast only for 0-10 cm depth. Soil pH ranged from 6.38 to 7.61 at Brookings and 5.51 to 6.97 at Beresford site and was slightly lower at the Beresford compared to that of Brookings site. Data showed that the plots received 2N manure application rate had the highest pH and those received HF treatment had the lowest pH at the 0-10 cm depth for Brookings site. A similar trend was observed for the Beresford site. The 2N treatment (7.05) increased the soil pH by 5.9 and 10.5%, respectively, compared to F (6.66) and HF (6.38) treatments at Brookings. Similarly, the 2N treatment increased pH by 22 and 27% compared to F and HF at Beresford site. The plots received F treatment had a greater pH compared to the plots those received HF at Brookings site. The HF treatment had significantly lower pH compared to all other treatments at either site. On an average, manure (6.95) significantly increased pH by 6.6 and 23% compared to that of fertilizer (6.52) for the 0-10 cm depth at Brookings and Beresford, respectively, sites. Significant differences on soil pH due to manure and inorganic fertilizer treatments were not observed beyond 10 cm depth at either site.

Data from this study showed that manure application for longer duration increased the pH at the surface 0-10 cm depth. However, manure did not impact the pH beyond 10 cm depth, indicating that manure maintained the pH of the soil beyond 10 cm depth. In general, fertilizer decreased the soil pH. Eghball (2002) reported that manure maintained the soil pH, and fertilizer lowered it from an experiment that includes crop yield goal depended on manure, compost and fertilizer application to a silty loam textured soil in Nebraska. A review study conducted by Guo, Liu, et al. (2010) reported that plots received inorganic fertilizer application for 20 years in 7 locations, and those received for 25 years in 8 locations in China decreased the soil pH compared to manure application at the top soil depth. Similarly, Liang, Chen, et al. (2012) reported that soil pH decreased in the 0-20 cm depth with the application of inorganic fertilizer for 15 years compared to manure under winter wheat-summer maize crop rotation on a silty loam textured soil in China. Various researchers (e.g., Guo, Liu, et al., 2010, Liang, Chen, et al., 2012, Wang and Yang, 2003) reported that the decrease in soil pH could be attributed to the H^- release by roots and nitrification and acidification processes stimulated by continuous application of inorganic fertilizer for a longer duration. Manure impacts on soil pH depend on sources of manure and characteristics of complex and dynamic soil system (Liang, Chen, et al., 2012). Manure contains various constituents such as organic acids, carbonates, bicarbonates and large amounts of soluble nutrients (Salter and Schollenberger, 1939). Manure decreases the pH because of the organic acid present in the manure and increases the pH because of the presence of carbonates and bicarbonates, and carboxyl and phenolic hydroxyl (Liang, Chen, et al., 2012).

The data reported that treatments significantly impacted the EC at all the soil depths under either site (Table 2). The higher manure rate (2N) significantly increased the EC compared to all other treatments for 0-10, 10-20, 20-30 and 30-40 cm depths at Brookings site. The highest EC was observed under 2N treatment (2010 µS/cm) which was significantly higher than N (1508 µS/cm) by 33%, P (1149 µS/cm) by 75%, F (754 µS/cm) by 167%, HF (662 µS/cm) by 204% and CK (719 µS/cm) by 180% at the 0-10 cm depth for Brookings. Similar trends were observed for Beresford site. Significant differences were observed for contrast *Manure* vs. *Fertilizer* at all the soil depths under both the sites. On an average, manure treatments significantly increased EC by 120, 50, 34 and 19% compared to fertilizer treatments in the 0-10 (1556 vs. 708 µS/cm), 10-20 (880 vs. 587 µS/cm), 20-30 (861 vs. 641 µS/cm), and 30-40 (827 vs. 694 µS/cm) cm depths at Brookings, respectively. A similar trend was alsoobserved at the Beresford site. In addition, EC was significant for the contrasts *P vs. 2N* at 0-10, 10-20, 20-30 and 30-40 cm depths for either site.

A study conducted by Eigenberg, Doran, et al. (2002) reported that plots received higher manure application on Crete silty loam soil under irrigated field of silage corn and winter cover crop in Nebraska, increased the soil EC compared to lower manure and compost treatments. Similarly, Eghball (2002) reported that increasing manure rate also increased the soil EC with the application of P and N-based manure compare to compost application under continuous corn crop on a clay loam textured soil in Nebraska.

Soil Organic Carbon

Data for SOC concentrations (g kg^{-1}) under different manure and inorganic fertilizer application rates for Brookings and Beresford sites in the 0-10,10-20, 20-30, and 30-40 cm depths are shown in Figure 1. Data showed that treatments significantly impacted the SOC for all the soil depths for either site. Additionally, SOC was also significant for the contrasts *P vs. 2N* and *Manure vs. Fertilizer* for all soil depths, except at 10-20 cm depth for *Manure vs. Fertilizer* at Brookings. The highest SOC concentrations were observed under 2N manure application (38.3 g kg^{-1}) treatment which was significantly higher than N (24%; 30.9 g kg^{-1}), P (39% higher; 27.6 g kg^{-1}), F fertilizer application (60% higher; 24.0 g kg^{-1}), HF fertilizer (48% higher; 25.8 g kg^{-1}) and CK (64% higher; 23.3 g kg^{-1}) treatments at the 0-10 cm depth (Table 2). Similar trends were observed for other depths of Brookings and Beresford site. Averaged across all the manure treatments, manure (32.3 g kg^{-1} and 28.6 g kg^{-1}) significantly increased SOC by 29 and 25% compared to that of fertilizer (24.9 g kg^{-1} and 22.9 g kg^{-1}) for the 0-10 cm depth at Brookings and Beresford, respectively, sites. Similar trend was observed for other depths.

Liang, Chen, et al. (2012) showed that farmyard manure application for 15 years increased SOC by 56.2, 46.3, and 14% higher for 0-10, 10-20, and 20-30 cm depths, respectively, compared to control (without any application) on a silty loam textured soil under winter wheat-summer maize rotation under a semi-humid climate in China. Similarly, Xin, Zhang, et al. (2016) also reported that SOC contents under manure application under annual rotation of winter wheat-summer maize for 23 years were 138% higher compared to mineral fertilizer and compost manure application on a sandy loam textured soil. In addition, Barik (2011) reported from a greenhouse study with different rates of barnyard manure and sugar beet pulp for six months that higher application of manure statistically (P<0.01) increased the SOM. In addition, the higher application rate of manure produced the higher SOM content (Barik, 2011).

Bandyopadhyay, Misra, et al. (2010) reported that fertilizer did not impact SOC on a clay texture soil under a soybean-wheat rotation in a hot sub-humid climate in India. Celik, Gunal, et al. (2010) studied the impacts of manure and fertilizer application in winter wheat and corn rotation on a clay-loam soil in Mediterranean climate in Turkey for 13 years and reported that the application of manure increases SOC compared to fertilizer treatments. Similar findings were also reported by Shirani, Hajabbasi, et al. (2002) on silty clay loam soil under corn in Iran. Hati, Mandal, et al. (2006) from a study that included farmyard manure and inorganic fertilizer application on a deep heavy clay soil under soybean and a hot sub-humid climate in India reported that SOC increased for 0-15 cm depth from an initial level which was 41% higher than that of fertilizer application. Dunjana, Nyamugafata, et al. (2012) reported that cattle manure and inorganic fertilizer applied on clay and sandy soils under corn, groundnut, sweet potato and sunflower under a sub-tropical climate in Zimbabwe for seven consecutive years lower SOC concentration in the soil under organic and high inorganic fertilizer applications. In general, manure application increases SOC compared to inorganic (chemical) fertilizer and hence enhances the crop growth due to leaf shedding and higher root biomass production (Bandyopadhyay, Misra, et al., 2010, Hati, Mandal, et al., 2006, Xin, Zhang, et al., 2016).

Total Soil Nitrogen

Total nitrogen (TN; g kg^{-1}) data for 0-10, 10-20, 20-30 and 30-40 cm depths under all the treatments for Brookings and Beresford sites are presented in Table 3. Data showed that treatments significantly impacted total soil N (TN) at 0-10 cm ($P<0.0008$) and 30-40 cm depth ($P<0.05$) for Brookings site, at 0-10 cm ($P<0.0001$) and 10-20 cm ($P<0.05$) depths for Beresford site. However, TN data showed non-significant impact by the treatments for 10-20 and 20-30 cm depths at Brookings and beyond 20 cm depth at Beresford site (Table 3). Additionally, TN was also significantly different for contrasts *P vs. 2N* and *Manure vs. Fertilizer* for 0-10 cm depth for Brookings site, and 0-10 and 10-20 cm (only *Manure* vs. *Fertilizer*) depth for Beresford site. The range of TN was from 0.11 g kg^{-1} to 3.45 g kg^{-1} at Brookings and 1.23 g kg^{-1} to 3.17 g kg^{-1} at Beresford site. Plots under 2N treatment had the highest TN concentrations, whereas, those under control had the lowest at 0-10 cm depth for Brookings site. The similar trend was observed for 0-10 cm and 10-20 cm depths for Beresford site. The soil under application of 2N treatment (3.45 g kg^{-1}) was represented as the highest increased value, which is 50% higher than F (2.30 g kg^{-1}) and 31% higher than HF (2.63 g kg^{-1}) treatments at 0-10 cm depth in Brookings. Similarly, plots those received 2N manure rate increased TN (3.17 g kg^{-1}) content by 42% higher than F (2.23 g kg^{-1}) and 43% higher than HF (2.22 g kg^{-1}) at 0-10 cm depth for Beresford site. Also, TN for 10-20 cm depth for Beresford under 2N treatment was 2.17 g kg^{-1} which was 14% higher than F (1.91 g kg^{-1}) and 14% than HF

(1.92 g kg^{-1}). Higher manure application rate increased the TN in comparison to lower rates of manure at either site. On an average, manure treatments significantly increased TN content by 19 and 27% compared to fertilizer treatments for the 0-10 cm depth at Brookings and Beresford. In addition, manure (2.06 g kg^{-1}) significantly increased TN content by 7% in comparison with fertilizer (1.92 g kg^{-1}) at 10-20 cm depth for Beresford site. Data from this study showed that manure application for longer duration increased the TN content at the 0-10 and 10-20 cm depths; however, manure did not impact the TN beyond 20 cm depth.

A study conducted by Liang, Chen, et al. (2012) on silty loam soil under wheat and corn rotation and semi-humid climate in China for 15 years reported that soil fertility practices significantly impacted the TN content; manure increased the TN contents by 43.9% (0-10 cm) and 29.1% (10-20 cm) compared to that of control (no manure application). A similar finding was observed in our study for both the study locations. Similarly, Blair, Faulkner, et al. (2006) from the Broad balk Wheat Experiment in UK established in 1849 studied the farmyard manure, inorganic fertilizer and wheat straw applications on an Aquic/Typic Paleudalf for wheat crop under a cool temperate climate, and reported that manure increased TN contents by 151% compared to that of control, whereas, inorganic fertilizer did not impact TN contents. Liang, Chen, et al. (2012) concluded that inorganic fertilizer did not impact TN contents compared to that of control. This may be partially attributed to the fact that a part of applied mineral N lost because of ammonia volatilization (44.1% of applied N), leaching (14.8%), and denitrification (4.4%) as documented by Ju, Xing, et al. (2009) in the wheat-maize cropping systems on the North China Plain. In contrast, manure increases TN due to the slow release of N which reduces the N losses, and higher biological N-sequestration stimulated by the manure (Kundu, Bhattacharyya, et al., 2007).

Wet Aggregate Stability

Wet aggregate stability (WAS, %) data for 0-10 and 10-20 cm depths under treatments for Brookings and Beresford sites are shown in Table 4. Treatments significantly impacted the WAS at 0-10 depth for Brookings and Beresford site. The WAS was not significantly influenced by the treatments beyond 10 cm depth at either site. The WAS was also significantly different for *P vs. 2N* contrast at 0-10 cm depth for either site whereas *Manure vs. Fertilizer* contrast for 0-10 cm depth in Brookings and for 0-10 and 10-20 cm depths in Beresford site was significant (Table 4). Wet aggregate stability ranged from 84.6 to 98.6% at Brookings and 88.9 to 96.7% at Beresford site. Data showed that the plots received 2N manure application rate had the highest (98.6%) WAS and those received HF treatment had the lowest (87.39%) WAS at the 0-10 cm depth for Brookings site. Similar trends of WAS were observed for both depths at both sites.

The 2N treatment increased WAS by 11 and 13%, respectively, compared to F (89.2%) and HF (87.4%) treatments at 0-10 cm for Brookings. The plots received HF treatment decreased the WAS compared to the plots those received F at Brookings site. The HF treatment had significantly lower WAS results compared to all other treatments at either site. On an average, manure (94.7% and 94.3%) significantly impacted WAS by 7.2 and 5.6% compared to that of fertilizer (88.3% and 89.3) for the 0-10 cm depth for Brookings and Beresford, respectively, sites. Data from this study showed that manure application for longer duration increased the WAS at the surface 0-10 cm depth. However, manure did not impact the WAS beyond 10 cm depth for either site.

Aggregate stability helps in the development of soil structure, and the other soil physical properties (Celik, Gunal, et al., 2010, Xin, Zhang, et al., 2016). Celik, Gunal, et al. (2010) reported that SOC is generally the major contributing factor affecting aggregate stability according to a study where these researchers studied the manure and fertilizer applications under a clay-loam soil for winter wheat-corn rotation in Mediterranean climate in Turkey for 13 years. In addition, Barik (2011) reported from a greenhouse study with different rates of barnyard manure and sugar beet pulp for six months that higher application of manure statistically increased aggregate stability; for instance, 5 and 7.5% manure application resulted 31.4 and 43.6% aggregate stability which is significantly higher than 0 and 2.5% manure application resulted in 11.6 and 17.4% aggregate stability. Dunjana, Nyamugafata, et al. (2012) studied a cattle manure and inorganic fertilizer treatments which showed that the cattle manure application significantly impacted aggregate stability on clay and sandy soils under corn, groundnut, sweet potato and sunflower in a sub-tropical climate in Zimbabwe for seven consecutive years. The relationship between the SOC and the stable aggregation showed 81% correlation as reported by Bandyopadhyay, Misra, et al. (2010) according to the study that included inorganic fertilizer and farmyard manure on a clay texture soil under soybean–wheat rotation and hot sub-humid climate in India. Hati, Mandal, et al. (2006) from a study included farmyard manure and inorganic fertilizer application on a deep heavy clay soil under soybean and a hot sub-humid climate in India indicated that organic matter increase soil aggregation due to the binding between clay minerals and quartz particles by polysaccharides. Higher manure addition to the soil improves aggregate stability (Barik, 2011). Continuous application of inorganic fertilizer especially those form NH_4^+ reduce aggregate formation and stability by dispersing soil colloids and secondary particles (Haynes and Naidu, 1998). Intensive and heavy cultivation can disrupt the soil aggregates of 0.25-2 mm size if these are not protected by the organic matter (Beare, Hendrix, et al., 1994). Intensively tilled soils with low organic matter can form weak structural stabilities reported by Shirani, Hajabbasi, et al. (2002) on silty clay loam soil under corn in Iran.

CONCLUSIONS

A long-term study was conducted at two different locations in South Dakota to assess the impacts of manure and inorganic fertilizers on selected soil quality indicators that include pH, EC, SOC, TN, and water stable aggerates under corn-soybean rotation at two different long-term sites. The following conclusions can be drawn from this study, and those are mentioned below as:

1. The application of manure did not impact the soil pH, rather it maintained it as compared to that of control treatment, however, inorganic fertilizer decreased the soil pH as compared to manure and control treatments.
2. Manure application increased the SOC for all the soil depths at either site as compared to inorganic fertilizer and control treatments. A similar trend was observed for the TN. However, differences were not always significant for the TN concentrations.
3. Manure increased the soil EC in comparison to inorganic fertilizer and control, respectively.

4. Manure applications increased water stable aggregation, whereas, fertilizer application tend to decrease WAS.

It can be concluded from this study that the application of higher manure rate helps in improving the soil quality indicators as compared to that of inorganic fertilizer in corn-soybean cropping systems of South Dakota. However, future study is strongly encouraged that can assess the economics and environmental impacts (water quality, greenhouse gas emissions) associated with different application rates of manure on soils.

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Table 3.1. Soil pH (pH) for 0-10, 10-20, 20-30 and 30-40 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

Treatments	**Brookings**				**Beresford**			
	Depths (cm)							
Depths	**0-10**	**10-20**	**20-30**	**30-40**	**0-10**	**10-20**	**20-30**	**30-40**
	pH							
P[††]	6.91[ba†]	6.97[a]	7.25[a]	7.57[a]	6.87[a]	5.99[a]	6.32[a]	6.67[a]
N	6.90[ba]	6.96[a]	7.25[a]	7.44[a]	6.95[a]	6.24[a]	6.34[a]	6.57[a]
2N	7.05[a]	7.04[a]	7.29[a]	7.54[a]	7.02[a]	6.75[a]	6.40[a]	6.73[a]
F	6.66[b]	6.90[a]	7.26[a]	7.61[a]	5.76[cb]	5.59[a]	6.02[a]	6.32[a]
HF	6.38[c]	6.97[a]	7.32[a]	7.56[a]	5.51[c]	5.91[a]	6.30[a]	6.73[a]
CK	6.86[ba]	7.10[a]	7.30[a]	7.52[a]	6.27[b]	5.86[a]	6.03[a]	6.31[a]
	Analysis of Variance (*P*>*F*)							
Treatment	0.001	0.52	0.97	0.33	<.0001	0.09	0.5	0.11
P vs. 2N	0.29	0.54	0.67	0.66	0.58	0.05	0.07	0.77
Manure vs. Fertilizer	0.01	0.23	0.59	0.16	0.001	0.08	0.32	0.33

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate; F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 3.2 Soil electrical conductivity (EC; µS/cm) for 0-10, 10-20, 20-30 and 30-40 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

Treatments	**Brookings**				**Beresford**			
	----------Depths (cm)----------							
Depths	**0-10**	**10-20**	**20-30**	**30-40**	**0-10**	**10-20**	**20-30**	**30-40**
	---------- EC (µS/cm)----------							
P[††]	1149[c†]	734[cb]	738[cb]	749[cb]	768[b]	369[cb]	367[ba]	451[ba]
N	1508[b]	828[b]	783[b]	777[b]	934[a]	478[b]	423[a]	409[bc]
2N	2010[a]	1078[a]	1062[a]	954[a]	1083[a]	749[a]	522[a]	584[a]
F	754[d]	575[c]	651[cd]	653[d]	321[c]	183[c]	184[c]	244[d]
HF	662[d]	599[c]	631[d]	736[cbd]	359[c]	307[cb]	408[a]	479[ba]
CK	719[d]	616[c]	622[d]	667[cd]	437[c]	265[cb]	240[bc]	297[dc]
	Analysis of Variance (*P*>*F*)							
Treatment	<.0001	0.0004	<.0001	<.0001	<.0001	0.0009	0.003	0.001
P vs. 2N	<.0001	0.001	<.0001	0.0003	0.0005	0.002	0.05	0.06
Manure vs. Fertilizer	<.0001	0.0012	<.0001	0.008	0.0001	0.01	0.05	0.05

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate; F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 3.3 Total soil nitrogen (TN; g kg^{-1}) for 0-10, 10-20, 20-30 and 30-40 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

Treatments	**Brookings**				**Beresford**			
	--------------------------------Depths (cm)--------------------------------							
Depths	**0-10**	**10-20**	**20-30**	**30-40**	**0-10**	**10-20**	**20-30**	**30-40**
	---------------------- TN (g kg^{-1})----------------------							
P[††]	2.52[cb†]	2.04[a]	1.63[a]	1.17[a]	2.50[c]	2.01[ba]	1.71[a]	1.32[a]
N	2.80[b]	2.01[a]	1.62[a]	1.30[a]	2.76[b]	2.00[ba]	1.73[a]	1.34[a]
2N	3.45[a]	2.03[a]	1.66[a]	1.49[a]	3.17[a]	2.17[a]	1.69[a]	1.34[a]
F	2.30[c]	2.00[a]	1.68[a]	1.17[a]	2.23[d]	1.91[b]	1.65[a]	1.29[a]
HF	2.63[cb]	1.96[a]	1.64[a]	1.45[a]	2.22[d]	1.92[b]	1.65[a]	1.23[a]
CK	2.24[c]	1.93[a]	1.55[a]	1.24[a]	2.12[d]	1.85[b]	1.72[a]	1.36[a]
	Analysis of Variance ($P>F$)							
Treatment	0.0008	0.87	0.97	0.06	0.0001	0.05	0.98	0.83
P vs. 2N	0.0008	0.94	0.84	0.95	0.0001	0.11	0.86	0.85
Manure vs. Fertilizer	0.01	0.41	0.85	0.16	0.0001	0.02	0.54	0.13

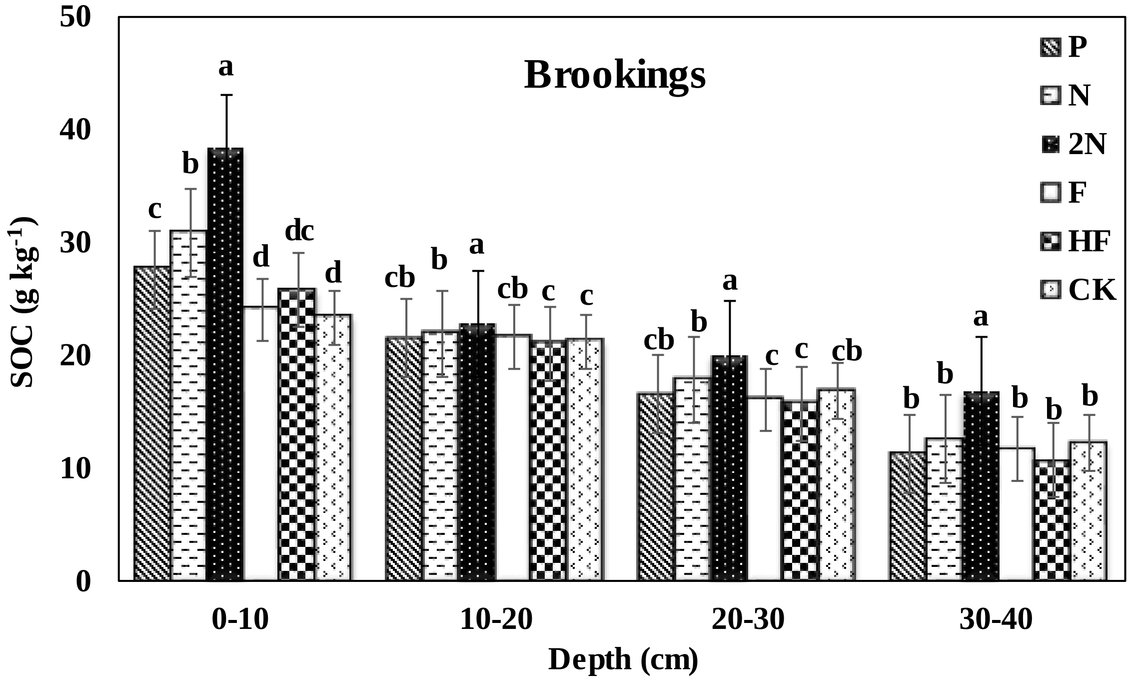
[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.

[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate; F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 3.4. Wet aggregate stability (WAS, %) for 0-10 and 10-20 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

Treatments	**Brookings**		**Beresford**	
	---------------Depths (cm)-------------------			
Depths	**0-10**	**10-20**	**0-10**	**10-20**
	---------- WAS (%) --------------			
P[††]	91.90[bc†]	90.12[a]	92.86[bac]	92.31[a]
N	93.51[ba]	92.28[a]	93.29[ba]	92.15[a]
2N	98.59[a]	92.40[a]	96.73[a]	92.85[a]
F	89.22[bc]	89.11[a]	89.36[c]	89.20[a]
HF	87.39[c]	84.55[a]	89.14[c]	88.93[a]
CK	90.11[bc]	90.41[a]	92.42[bc]	90.52[a]
	Analysis of Variance (*P*>*F*)			
Treatment	0.01	0.5	0.01	0.08
P vs. 2N	0.02	0.6	0.05	0.7
Manure vs. Fertilizer	0.02	0.2	0.001	0.01

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate; F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.



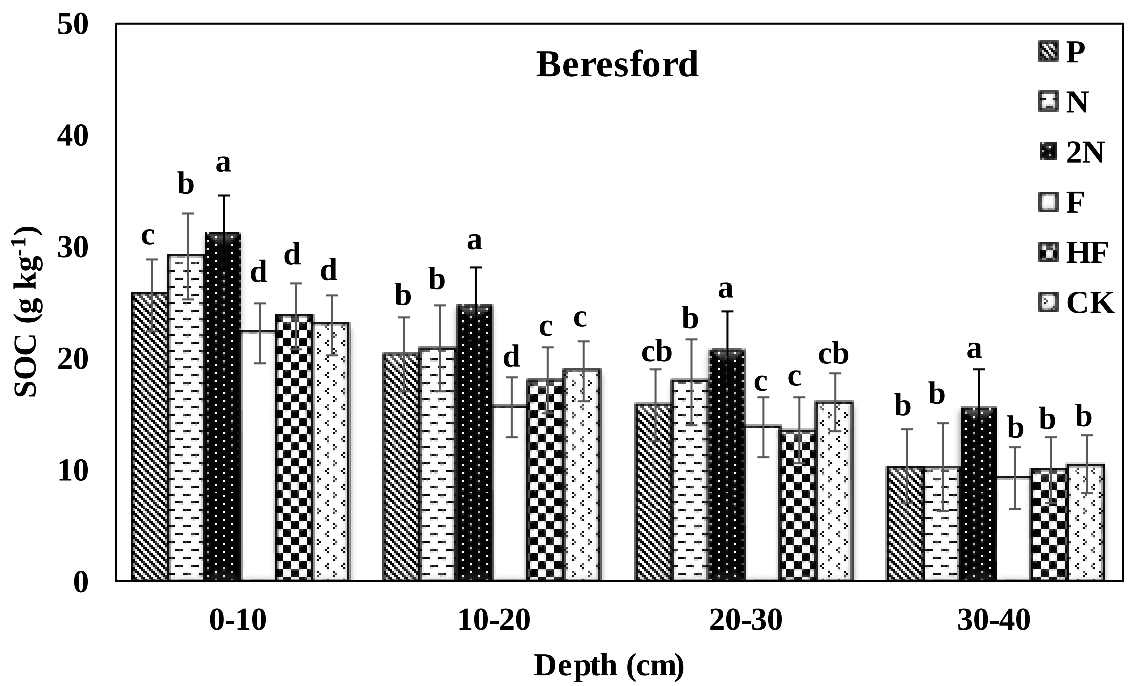


Figure 3.1 Soil organic carbon (g kg^{-1}) for 0-10, 10-20, 20-30 and 30-40 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

CHAPTER 4

RESPONSE OF LONG-TERM CATTLE MANURE APPLICATION ON SOIL HYDROLOGICAL PROPERTIES UNDER CORN-SOYBEAN ROTATION OF TWO LOCATIONS IN EASTERN SOUTH DAKOTA

ABSTRACT

Manure improves soil organic carbon (SOC) and impacts soil hydrological properties such as soil water retention (SWR), pore-size distribution (PSD) and water infiltration (q_s) thatare crucial for crop production. The present study was conducted with the specific objective to investigate the impacts of different rates of manure and inorganic fertilizers on soil hydrologic properties at two long-term experimental sites located at Beresford and Brookings in South Dakota. Study treatments included two fertilizers [recommended fertilizer (F) and high fertilizer (HF)], and three manure [phosphorus-based recommended manure application rate (P), nitrogen-based recommended manure application rate (N), and nitrogen-based double of recommended manure application rate (2N)], and a control (CK) under reduced-tilled corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation. Dairy and beef manure were used at Brookings and Beresford, respectively. Results of this study showed that manure application improved the soil properties as compared to those of inorganic fertilizer applications. Average manure application reduced the soil bulk density by 17% compared to those inorganic fertilizer applications at 0-10 cm depths for Beresford sites. Water infiltration (q_s) was increased by 49 to 75% under manure application compared to inorganic fertilizer applied plots for either site. Manure tended to positively impact water retention and porosity but not always significantly. Data from this study concluded that manure improved soil hydrological properties in comparison with those of inorganic fertilizer. However, further investigation

is needed that can focus on the environmental impacts associated with the higher rates of manure application in comparison with those of inorganic to make recommendations to producers.

Keywords: Manure, inorganic fertilizer, water infiltration, bulk density, corn-soybean rotation

INTRODUCTION

Soil management practices need to have the perspective of improving crop production, soil properties, hydrological properties for enhancing the food security (Avery and Abernethy, 1995, Conway and Barbier, 2013). However, these practices when used inappropriately can negatively impact soils and crop production. Such activities that involve continuous tillage and imbalanced use of chemical fertilizers led to soil degradation, reduced water infiltration (q_s), and enhanced soil erosion (Lawal and Girei, 2013). Soil amendments such as cattle manure generally decrease soil bulk density and increase total porosity, soil water retention, macro and microporosity and water infiltration rate (q_s) (Rasoulzadeh and Yaghoubi, 2014, Shi, Zhao, et al., 2016, Xin, Zhang, et al., 2016). Manure modifies soil properties (Lawal and Girei, 2013), however, changes in these properties are associated with the amount of manure applied (Asada, Yabushita, et al., 2012, Bottinelli, Menasseri- Aubry, et al., 2013, Fares, Abbas, et al., 2008, Khalid, Tuffour, et al., 2014). Some studies reported insignificant changes in bulk density, water infiltration (q_s) and available water under application of manure (Asada, Yabushita, et al., 2012, Blanco-Canqui, Hergert, et al., 2015).

Soil structure can be negatively impacted by a long-term lack of phosphorus (P) and disproportionate contribution of nitrogen (N) (Xin, Zhang, et al., 2016). Application of manure not only reduces soil compaction, erosion, and soil degradation but also develops the soil structure by binding the soil particles (Celik, Gunal, et al., 2010). The addition of organic amendments such as manure is important for agricultural practices to ameliorate problems that occur due to declining of SOM (Celik, Gunal, et al., 2010, Celik, Ortas, et al., 2004, Lawal and Girei, 2013). The balanced application of organic and mineral fertilizers to agricultural soil have been viewed as an excellent way to recycle nutrients and organic matter that can support crop production and maintain or improve soil quality indicators such as bulk density, infiltration rate, soil moisture retention capacity and soil structure (Khalid, Tuffour, et al., 2014, Lawal and Girei, 2013).

Inorganic fertilizer and manure are one of the main sources of the nutrients for crop growth, and use of these soil amendments are beneficial for sustainability (Blanco-Canqui, Hergert, et al., 2015). Long-term inorganic fertilizer application can modify soil properties, for instance, inorganic N-fertilizer improved the macropore density, macropore volume, and unsaturated hydraulic conductivity of a clayey soil (Dunjana, Nyamugafata, et al., 2014). In contrast, some studies showed that inorganic fertilizer may enhance crop yield but not hydrological properties of soil (Dunjana, Nyamugafata, et al., 2014). However, use of inorganic fertilizers may produce problems such as soil fertility degradation by reducing pH, organic matter and exchangeable cations in the soil (Lawal and Girei, 2013). The use of organic manure can improve soil physical properties and is useful in improving soil fertility (Lawal and Girei, 2013). For instance, manure improves

SOM, total porosity, water holding capacity, and decreases bulk density in comparison to inorganic fertilizer (Blanco-Canqui, Hergert, et al., 2015, Khalid, Tuffour, et al., 2014, Shi, Zhao, et al., 2016). However, combined applications (manure and inorganic fertilizer) sometimes showed better performance on soil physical properties (Lawal and Girei, 2013).

The previous studies have explained the recommended application rate of manure and fertilizer impacts on soil properties. However, the recommended rates of manure and inorganic fertilizer applications based on the nutrient content such as phosphorus and nitrogen are important to investigate for improved crop productivity without negatively impacting the environment. Therefore, the present study was conducted with the specific objective to evaluate the influences of manure and inorganic fertilizer applications on soil hydrological properties in long-term reduced-tilled corn-soybean rotation in South Dakota.

MATERIALS AND METHODS

Experimental Sites and Study Treatments

Two experimental sites were established at two different locations; Beresford and Brookings in South Dakota. The research plots were initiated in 2003 at Beresford site and 2008 at Brookings to study the effect of manure and inorganic fertilizer application rates on crop production and soil properties. The Brookings site is located at South Dakota State University Felt Research Farm near Brookings (44º 22’ 07.15” N and 96º 47’ 26.45” W) on well drained Vienna soil (Fine-loamy, mixed, frigid Udic Haploborolls). Dimensions for each plot at this site are 6 m by 18 m. The plots are nearly flat with the slope of <1% with elevation of 518 m. The experimental areas were observed with humid continental climate having relatively humid summers and cold, snowy winters with a mean air temperature of 27.8°C in the summer and -15.8°C in the winter, respectively. The mean annual precipitation was about 637 mm. The Beresford (43° 02' 33.46" N and 96° 53' 55.78" W) site is located at the Southeast Research Farm of the South Dakota State University in Clay County on Egan soil (Fine-silty, mixed, mesic Udic Haplustolls). The plots at this site were established on nearly flat areas with the slope and elevation of <1%, and 390 m, respectively. The experimental site was observed with humid continental climate having relatively humid summers and snowy winters with a mean air temperature of 29.5°C in the summer and -13.6°C in the winter, respectively. The mean annual precipitation was about 678 mm. Dimensions for each plot at Beresford site are 4.6 m (wide) by 20 m (length).

Study treatments at either sites included: two fertilizers [recommended fertilizer (F) and high fertilizer (HF)], and three manure [phosphorus based recommended manure (P), nitrogen based recommended manure (N), and nitrogen based double of recommended manure application rate (2N)], and a control (CK) with no manure application. The P concentrations of the soil, P content of manure and amount of the P needed to reach the desired yield goal were used to calculate P recommended application rate by using a tool developed by South Dakota Department of Environment and Natural Resources. A similar calculation was used for N recommended application rate. Similarly, both the P and Nitrate-N soil tests were used for the fertilizer treatments to make the P and N recommendations for the fertilizer treatment. The manure was applied in the spring and incorporated using disk for 6-cm before planting at either site. Manure samples were analyzed at South Dakota Agricultural Laboratories. At both the sites, fertilizer treatments for 179.3 kg ha^{-1} yield goal for corn and 44.8 kg ha^{-1} for soybean were applied; however, there is no nutrient recommendation of fertilizer for soybean (Gelderman, Gerwing, et al., 2006). Dairy manure with 31.5% moisture and beef manure with 21.9% moisture for Brookings and Beresford sites, respectively, were used in this study. Dairy manure contained 6 g kg^{-1} total nitrogen, 2.7 g kg^{-1} NH_4-N, 3.3 g kg^{-1} organic -N, 3.2 g kg^{-1} available N, 2.5 g kg^{-1} P_2O_5 and 4.2 g kg^{-1} K2O concentrations. Beef manure contained 10.6 g kg^{-1} total nitrogen, 1.3 g kg^{-1} NH_4-N, 9.3 g kg^{-1} organic -N, 5.6 g kg^{-1} available nitrogen, 8.5 g kg^{-1} P_2O_5 and 9.9 g kg^{-1} concentrations. Annually, P-based recommended rate of manure treatment include N (90 kg ha^{-1})-P (30 kg ha^{-1})-K (39 kg ha^{-1}) where N-based recommended manure rate included N (131 kg ha^{-1})-P (56 kg ha^{-1})-K (93 kg ha^{-1}), two times N-based recommended manure rate N (261 kg ha^{-1})-P (111 kg ha^{-1})-K (187 kg ha^{-1}) at Brookings site.In addiiton, Beresford site included N (51 kg ha^{-1})-P (52 kg ha^{-1})-K (82 kg ha^{-1}) for P treatment, N (122 kg ha^{-1})-P (111 kg ha^{-1})-K (155 kg ha^{-1}) for N treatment and N (243 kg ha^{-1})-P (222 kg ha^{-1})-K (310 kg ha^{-1}) for 2N treatment. On the other hand, F inorganic fertilizer treatment included N (41 kg ha^{-1})-P (19 kg ha^{-1})-K (23 kg ha^{-1}) and HF included N (75 kg ha^{-1})-P (60 kg ha^{-1})-K (71 kg ha^{-1})-Zinc (7 kg ha^{-1})-S (25 kg ha^{-1}) at the Brookings site when F included N (43 kg ha^{-1})-P (16 kg ha^{-1})-K (4 kg ha^{-1}) and HF included N (85 kg ha^{-1})-P (46 kg ha^{-1})-K (39 kg ha^{-1})-Zinc (6 kg ha^{-1})-S (25 kg ha^{-1}) for Beresford site from 2003 to 2015, annually.

Soil Sampling

Intact core samples were collected from 0-10 and 10-20 cm depths using the core sampler of 5 cm diameter and 5 cm height to measure soil bulk density, soil water retention (SWR), and pore size distribution (PSD) from both the sites in summer of 2015. Soil cores were collected from each plot, labeled, trimmed from both ends, sealed in plastic zip-lock bags and transported to the laboratory. These cores were stored at 4°C pending analysis.

Soil Bulk Density, Soil Water Retention, and Pore Size Distribution

Soil bulk density (ρ_b) was determined using the core method (Grossman and Reinsch, 2002) for the 0-10 and 10-20 cm depths under all treatments at both the sites. Soil was removed from the intact core and was oven-dried at 105°C for 48 hr to get the oven-dried weight of the soil, and then bulk density was determined by dividing the oven-dried mass with the volume of the core. Soil water retention (SWR) for 0-10 and 10-20 cm depths was measured for every treatment. The cheese cloth was fixed at the bottom of the soil core, and then these were saturated with water by capillarity for 24 to 48 hours, depending on the sampling depth of these cores. The SWR was measured at 0, -0.4, -0.1, -2.5, -5.0, -10.0, -30.0 kPa matric potentials using tension and pressure plated extractors (Klute and Dirksen, 1986). Soil water content (g g^{-1}) was determined gravimetrically by oven-drying the soil samples at 105°C for 48 hr. This gravimetric moisture content (*w*) was converted to volumetric moisture content (θ; m^3 m^{-3}) by multiplying *w* with the soil bulk density and dividing with the density of water. Note that density of water was used as 1000 kg m^{-3} for calculating the θ. The pore size distribution of soil for 0-10 and 10-20 cm depth was calculated using capillary rise equation from the SWR data (Jury, Gardner, et al., 1991). Four categories of pore sizes were estimated including macro-pores having (>1000 μm equivalent cylindrical diameter, end), coarse mesopores having (60- to 1000-μm ecd), fine mesopores having (10- to 60-μm ecd), and micro-pores having (<10 μm ecd).

Water Infiltration Rate

Water infiltration (q_s) rates were measured with a double-ring infiltrometer (ring of 20 cm height, 30-cm outer, and 20 cm inner diameters) using a constant-head method (Reynolds, Elrick, et al., 2002). Two infiltration measurements were conducted in four replicated plots (two for each plot) until the steady state was achieved.

Statistical Analysis

A statistical analysis was performed to estimate the impacts of treatments on soil hydrological properties due to different rates of manure and chemical fertilizer applications. The significant differences among treatments were obtained using the Mixed procedure in SAS 9.3 (Institute, 2012). Treatments were considered as the fixed impacts and replications as the random effect at significant level of α=0.05. Single degree-of-freedom contrasts were also determined and were conducted as follows: *Manure* vs. *Fertilizer*, and *P* vs. *2N* (P-based manure application rate vs. two times N based recommended application rate of manure).

RESULTS AND DISCUSSION

Soil Bulk Density

Soil Bulk Density (*ρ*b; Mg m^{-3}) data for 0-10 and 10-20 cm depths for either site are presented in Table 1. Data showed that treatments significantly impacted the *ρ*b for the 0-10 cm depth on either site. However, treatments did not impact the *ρ*b beyond 10 cm depth. High manure rate (2N) significantly lowered the *ρ*b compared to other manure applications and fertilizer applications at either site. The lowest *ρ*b was observed under 2N treatment (0.87 Mg m^{-3}) which was significantly lower than N (1.07 Mg m^{-3}) by 19%, P (1.13 Mg m^{-3}) by 24%, CK (1.20 Mg m^{-3}) by 28%, F (1.22) by 29% and HF (1.23 Mg m^{-3}) by 30% at the 0-10 cm depth (Table 1). In 10-20 cm depth at the Brookings site, the 2N (1.22 Mg m^{-3}) was significantly lowered in *ρ*b by 6, 7,8, 8, and 10%, respectively, compared to (HF; 1.30 Mg m^{-3}, N; 1.32 Mg m^{-3}, P; 1.33 Mg m^{-3}, CK; 1.33 Mg m^{-3}, F; 1.36 Mg m^{-3}). Similar trends were observed at the Beresford site. On an average, *ρ*b under manure treatments at 0-10cm depth (1.02 Mg m^{-3}) was significantly decreased by 17%, compared to fertilizer treatment (1.23 Mg m^{-3}) for Brookings site. A similar trend was observed at 10-20 cm depth for Beresford site. Also, *ρ*b was significant for the contrasts Manure only at 0-10 cm depth for either site, whereas, it was significant for 0-10 and 10-20 cm depths for P vs. 2N.

Soil *ρ*b indicates soil compaction and can be affected by tillage and fertilization (Xin, Zhang, et al., 2016). Organic amendments usually decrease soil *ρ*b due to the dilution effect caused by the mixing of the added lighter organic material with denser mineral fractions of the soil (Shepherd, Harrison, et al., 2002). In the present study, manure applications for 7 (Brookings) to 12 (Beresford) years decreased soil *ρ*b compared to the fertilizer treatments. Xin, Zhang, et al. (2016) reported that application of manure under annual rotation of winter wheat-summer maize for 23 years decreased ρb compared to that of control, which attributed to higher SOM content due to the production of microbial decomposition from organic amendments, and soil particle binding agents, better aggregation, dilution impacts of organic amendments, developed root growth on a sandy loam textured soil in China. Similarly, Bandyopadhyay, Misra, et al. (2010) supported that manure application decreased ρb owing to higher SOM content, better aggregation and more developed root growth on a clay texture soil under a soybean-wheat rotation in a hot sub-humid climate in India. Celik, Gunal, et al. (2010) also studied the impacts of manure and fertilizer application in winter wheat-corn rotation on a clay-loam soil in a Mediterranean climate in Turkey for 13 years and reported that the application of manure decreased ρb compared to that of fertilizer and control treatments. Similar trends were observed by Shirani, Hajabbasi, et al. (2002) on a silty clay loam soil under corn in Iran. The application of manure and chemical fertilizer on a dark loamy soil under maize in China observed the decrease in bulk density with manure application (Hou, Wang, et al., 2012). In another study with poultry manure application on a tilled Dormont silt soil under Kentucky bluegrass, Mandal, Chandran, et al. (2013) documented that the ρb for the surface layer was lower compared to that of subsurface depths in all the treatments in Virginia.

Soil Water Retention

The SWR (m^3 m^{-3}) data for 0-10 and 10-20 cm depths under all the treatments are shown in Table 2-a and Table 2-b. Treatments significantly impacted the WR at -2.5, -5 and -10 kPa potentials in the 0-10 cm depth, and 0 and -0.4 kPa at the 10-20 cm depths for the Brookings site. The SWR was also significantly different for *Manure vs. Fertilizer* contrast at -0.4, -1, -2.5, -5, -10 and -30 kPa at 0-10 cm depth for Brookings site. Water retention ranged from 0.44 m^3 m^{-3} to 0.64 m^3 m^{-3} for 0-10 cm depth at Brookings and 0.45 m^3m^{-3} to 0.65 m^3 m^{-3} for 0-10 cm depth at Beresford site. Data showed that the plots received 2N manure application rate had the highest (0.64 m^3 m^{-3}) SWR and those received HF treatment had the lowest (0.59 m^3 m^{-3}) SWR for 0 kPa at the 0-10 cm depth for Brookings site. Similar trends were observed for other pressure points for 0-10 cm depth for both sites. Treatments were significantly different under 0 and -0.4 kPa at 10-20 cm depth at the Brookings site. Also, there were significant contrasts for Manure and Fertilizer under 0 and -0.4 kPa at 10-20 cm depth at the Brookings site. Data was ranged from 0.45 m^3 m^{-3} to 0.64 m^3 m^{-3} for 10-20 cm depth at Brookings site and 0.44 m^3 m^{-3} to 0.62 m^3 m^{-3} for 10-20 cm depth at Beresford site. Trends monitored from Beresford were similar to those monitored from Brookings site for 10-20 cm depth as well. On an average, manure (0.61, 0.59, 0.57, 0.55, 0.53, 0.51 m^3 m^{-3}) significantly impacted SWR by 11, 11, 14, 12, 13 and 13% compared to that if fertilizer (0.55, 0.53, 0.50, 0.49, 0.47, 0.45 m^3 m^{-3}) for -0.4, -1, -2.5, -5, -10 and -30 kPa at the 0-10 cm depth at Brookings site. A similar trend was represented at 0-10 cm depth for Beresford site, too. Data from this study showed that manure application for longer duration increased the WR at the surface 0-10 cm for all tensions and at 10-20 cm depth for 0 and -0.4 kPa. However, manure did not impact the WR at beyond -1 kPa and 10 cm depth for either site. These statements indicate that manure had a positive effect on the WR of the soil at 0-10 cm depth.

Miller, Beasley, et al. (2015) conducted a study that included an application of composted manure and stockpiled manure on irrigated barley, and reported that higher organic carbon and number of smaller pores produced greater SWR on a clay loam Dark Brown Chernozemic soil in Alberta. The SWR is associated with bulk density, texture and organic matter (Miller, Beasley, et al., 2015). As we observed from this study that manure significantly impacted SWR at some matric potentials for surface and subsurface depths. Blanco-Canqui, Hergert, et al. (2015) reported that manure application increased SWR positively and was correlated with SOC content on a Tripp very fine sandy loam under reduced-tilled and irrigated corn, sugar beet, potato and alfalfa in Nebraska, whearas, inorganic fertilizer did not impact SWR. The present study was conducted under the corn and soybean rotation and managed with the reduced tillage system which leave higher residue on the surface compared to tilled system that can be helpful in improving the soil hydrological properties such as SWR. Similarly, Blanco-Canqui, Stone, et al. (2009) mentioned that long-term application of manure might produce greater benefits to increase SWR under conservation tillage due to the higher surface residue cover and lower soil disturbance.

Pore Size Distribution

Pore size distribution (PSD; $m^3\ m^{-3}$) data for 0-10 and 10-20 cm depths under all the treatments for Brookings and Beresford sites are presented in Table 3a and 3b. Data shows that treatments did not impact PSD at 0-10 cm depth for either site. However, 2N manure numerically performed better than fertilizer treatments for Macropores, Fine Mesopores, and Micro pores; whereas, N manure application had the highest observation for Coarse Mesopores compared to fertilizer treatments at 0-10 cm depth at the Brookings site. Similar trends were also observed for Fine mesopores and Micropores at 0-10 cm depth in the Beresford site. Data from this study showed that manure treatments did not show any significant differences for fertilizer and control treatments whereas fertilizer was also not significantly impacted on PSD compare to control.

Dunjana, Nyamugafata, et al. (2012) reported that cattle manure and inorganic fertilizer application for seven consective years showed non-significant differences between fertilizer and manure compared to control for macropores and coarse mesopores on clay and sandy soils under corn, groundnut (*Arachis hypogaea L.*), sweet potato (*Ipomoea batatas L.*) and sunflower (*Helianthus annuus L.*) under a sub-tropical climate in Zimbabwe. It was reported that field type might be an important factor on pore size distribution and these observations suggested variability related to macropores at local scale (Watson and Luxmoore, 1986). Also, Xin, Zhang, et al. (2016) reported that the addition of manure did not impact microporosity.

Water Infiltration

Water infiltration (q_s) data under all the treatments for the Brookings and Beresford sites are shown in Table 4. Treatments significantly impacted the q_s for either site. The q_s was significantly different for *Manure, P vs. 2N and Manure vs. Fertilizer* contrasts. The q_s ranged from 225 mm hr^{-1} to 412 mm hr^{-1} at Brookings and 143 mm hr^{-1} to 329 mm hr^{-1} at the Beresford site. The q_s of the soil was slightly lower at the Beresford compared to that of Brookings site. Data showed that the plots received 2N manure application rate had the highest q_s and those received HF treatment had the lowest q_s for the Brookings site. It was also observed plots with 2N manure had the highest q_s, whereas, those received F treatment had the lowest q_s at Beresford site. The 2N treatment (412 mm hr^{-1}) increased the q_s by 71 and 83%, compared to F (241 mm hr^{-1}) and HF (225 mm hr^{-1}) treatments at Brookings, respectively. Similarly, the 2N treatment increased q_s by 130 and 85% compared to F and HF at Beresford site, respectively. There was no significant difference between F and HF fertilizer treatments. On an average, manure (347 and 281 mm hr^{-1}) significantly increased q_s by 49 and 75% compared with fertilizer (233 and 160 mm hr^{-1}) for Brookings and Beresford, respectively. Data from the study showed that manure application for longer duration increased the q_s. Also, significant differences in q_s were not observed between fertilizer and control. However, in general, fertilizer decreased the soil q_s.

Fertility x field type interaction might be significant for explaining in higher infiltration rate because of more porosity linked with retention of organic material (Dunjana, Nyamugafata, et al., 2014). Dunjana, Nyamugafata, et al. (2014) reported a study conducted with cattle manure and inorganic fertilizer application on clay and sandy soils under corn, groundnut, sweet potato and sunflower and a sub-tropical climate in Zimbabwe indicated infiltration rate on the clay soil reported as significantly ($P < 0.05$) increased due to fertility and organic fertility on sandy soils ($P<0.05$). However, it was also reported as insignificant impacted ($P>0.05$) under inorganic fertilizer on the sandy soil by Dunjana, Nyamugafata, et al. (2014). Meek, Graham, et al. (1982) reported an high rate manure application on a variety of crops such as water-grass, sorghum, lettuce, barley and cotton indicated that application of manure-impacted the infiltration rate slightly between crops but strongly during the cropping season on a Holtville silty clay

(Typic Torrifluvents) soil in an irrigated desert region for 9 years (1971-1979) in California. It was also reported that a 1% increase in organic matter lowered the infiltration time by 31% by Meek, Graham, et al. (1982). Walia, Walia, et al. (2010) reported that application of manure increased water infiltration in comparison to that of chemical fertilizers for 14 different treatments including dairy manure, wheat cut straw, dreen manure with *Sesbania aculeate,* nitrogen, phosphorus, and potassium fertilizer application under rice–wheat system in the Punjab, India perhaps owing to improvement in soil physical properties such as bulk density and soil structure.

CONCLUSIONS

A long-term study was initiated at two different sites in eastern South Dakota to examine the influences of cattle manure and synthetic fertilizers on selected soil hydrological parameters that include the soil bulk density, soil penetration resistance, water infiltration, water retention and pore size distribution.

Results of this study showed that manure lowered the bulk density at 0-10 cm depth compared to fertilizer and control. An opposite trend was monitored for water infiltration indicated that manure increased water infiltration rate compared to fertilizer application. Manure tended to increase the SWR compared to the control at both sites; however, differences were not always significant. There was a trend for manure application to increase micropores and fine mesopores at the Brookings site compared to other applications; where control and high fertilizer increased the macropores and coarse pores distribution at 10-20 cm depths; however, the differences were not statistically significant. Manure also increased the distribution of micropores and coarse mesopores at the Beresford site where control was observed to have more macropores and fine-mesopores. The significant differences were observed at10-20 cm depth of fine mesopores where the control showed the highest levels.

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Table 4.1 Soil bulk density (BD; Mg m^{-3}) for the 0-10 and 10-20 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

	Brookings		**Beresford**	
Treatments	-------------------Depths (cm) --------------------------			
Depths	**0-10**	**10-20**	**0-10**	**10-20**
	------------BD (Mg m^{-3})---------------------			
P[††]	1.13[b†]	1.33[ba]	1.10[bc]	1.34[a]
N	1.07[b]	1.30[b]	1.08[c]	1.26[a]
2N	0.87[c]	1.21[c]	1.06[c]	1.24[a]
F	1.27[a]	1.36[a]	1.22[a]	1.32[a]
HF	1.27[a]	1.30[b]	1.20[ba]	1.35[a]
CK	1.29[a]	1.38[a]	1.22[a]	1.32[a]
	Analysis of Variance (*P*>*F*)			
Treatment	<.0001	<.0001	0.008	0.2
P vs. 2N	0.0001	<.0001	0.4	0.06
Manure vs. Fertilizer	0.0005	0.003	0.008	0.2

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at *P*<0.05.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 4.2-a Soil water retention (SWR; $m^3\ m^{-3}$) for 0-10 and 10-20 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Brookings location of South Dakota.

	Brookings Location													
Treatments	Depth (cm)													
Depths	**0-10**							**10-20**						
	Pressure (kPa)													
Pressure	**0**	**-0.4**	**-1**	**-2.5**	**-5**	**-10**	**-30**	**0**	**-0.4**	**-1**	**-2.5**	**-5**	**-10**	**-30**
	WR ($m^3\ m^{-3}$)													
P[††]	0.61^{ba†}	0.60^{a}	0.58^{a}	0.55^{b}	0.53^{b}	0.51^{a}	0.50^{a}	0.59^{ba}	0.57^{ba}	0.56^{a}	0.54^{a}	0.53^{a}	0.51^{a}	0.50^{a}
N	0.63^{a}	0.63^{a}	0.62^{a}	0.60^{a}	0.58^{a}	0.56^{a}	0.53^{a}	0.59^{ba}	0.58^{ba}	0.57^{a}	0.55^{a}	0.54^{a}	0.52^{a}	0.50^{a}
2N	0.64^{a}	0.62^{a}	0.60^{a}	0.57^{ba}	0.55^{ba}	0.53^{a}	0.51^{a}	0.64^{a}	0.62^{a}	0.60^{a}	0.59^{a}	0.57^{a}	0.56^{a}	0.54^{a}
F	0.58^{b}	0.53^{cb}	0.51^{cb}	0.48^{c}	0.46^{c}	0.44^{b}	0.43^{b}	0.56^{b}	0.54^{b}	0.53^{a}	0.51^{a}	0.50^{a}	0.49^{a}	0.47^{a}
HF	0.53^{c}	0.50^{c}	0.48^{c}	0.46^{c}	0.44^{c}	0.43^{b}	0.42^{b}	0.64^{a}	0.63^{a}	0.62^{a}	0.59^{a}	0.57^{a}	0.55^{a}	0.53^{a}
CK	0.57^{b}	0.54^{b}	0.52^{b}	0.50^{c}	0.48^{c}	0.46^{b}	0.45^{b}	0.56^{b}	0.54^{b}	0.52^{a}	0.50^{a}	0.48^{a}	0.47^{a}	0.45^{a}
	Analysis of Variance ($P>F$)													
Treatments	0.001	<.0001	<.0001	<.0001	<.0001	0.0001	0.001	0.04	0.04	0.06	0.07	0.08	0.08	0.1
P vs. 2N	0.2	0.3	0.3	0.4	0.4	0.4	0.7	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Manure vs. Fertilizer	0.001	<.0001	<.0001	<.0001	0.0001	0.0002	0.0009	*0.8*	0.8	0.8	0.6	0.5	0.6	0.5

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 4.2-b Soil water retention (SWR; $m^3 m^{-3}$) for 0-10 and 10-20 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford location of South Dakota.

	Beresford location													
Treatments	Depth (cm)													
Depths	**0-10**							**10-20**						
	Pressure (kPa)													
Pressure	**0**	**-0.4**	**-1**	**-2.5**	**-5**	**-10**	**-30**	**0**	**-0.4**	**-1**	**-2.5**	**-5**	**-10**	**-30**
	WR ($m^3 m^{-3}$)													
P††	$0.62^{b\dagger}$	0.61^{b}	0.59^{b}	0.58^{a}	0.55^{ba}	0.54^{ba}	0.52^{a}	0.53^{a}	0.53^{a}	0.51^{a}	0.51^{a}	0.49^{a}	0.48^{a}	0.47^{a}
N	0.64^{a}	0.64^{a}	0.62^{a}	0.59^{a}	0.55^{ba}	0.53^{bac}	0.50^{ba}	0.61^{a}	0.59^{a}	0.57^{a}	0.55^{a}	0.53^{a}	0.52^{a}	0.50^{a}
2N	0.64^{ba}	0.63^{a}	0.61^{a}	0.59^{a}	0.57^{a}	0.55^{a}	0.52^{a}	0.62^{a}	0.61^{a}	0.60^{a}	0.58^{a}	0.57^{a}	0.56^{a}	0.54^{a}
F	0.59^{d}	0.58^{c}	0.57^{cb}	0.55^{b}	0.53^{b}	0.50^{c}	0.46^{b}	0.58^{a}	0.58^{a}	0.57^{a}	0.56^{a}	0.55^{a}	0.54^{a}	0.51^{a}
HF	0.61^{dc}	0.60^{bc}	0.58^{c}	0.57^{ba}	0.55^{ba}	0.53^{bac}	0.49^{ba}	0.60^{a}	0.60^{a}	0.59^{a}	0.58^{a}	0.57^{a}	0.56^{a}	0.54^{a}
CK	0.61^{c}	0.61^{b}	0.59^{b}	0.58^{a}	0.54^{ba}	0.51^{bc}	0.48^{ba}	0.56^{a}	0.54^{a}	0.52^{a}	0.51^{a}	0.50^{a}	0.48^{a}	0.44^{a}
	Analysis of Variance (*P*>*F*)													
Treatments	0.001	0.0008	<.0001	0.04	0.3	0.1	0.1	0.4	0.4	0.4	0.4	0.4	0.4	0.3
P vs. 2N	0.1	0.02	0.004	0.3	0.5	0.6	0.9	0.08	0.09	0.09	0.1	0.1	0.1	0.1
Manure vs. Fertilizer	0.0002	0.0005	0.0007	0.0005	0.05	0.01	0.02	0.7	0.6	0.5	0.3	0.2	0.2	0.3

†Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at *P*<0.05.
††P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 4.3-a Soil pore size distribution (SPSD; m^3 m^{-3}) for 0-10 and 10-20 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

Treatments	**Brookings Location**							
	---Depths (cm)---							
Depths	**0-10**				**10-20**			
Pore sizes	**Macropores (>1000 µm)**	**Coarse Mesopores (60-1000 µm)**	**Fine Mesopores (10-60 µm)**	**Micropores (<10 µm)**	**Macropores (>1000 µm)**	**Coarse Mesopores (60-1000 µm)**	**Fine Mesopores (10-60 µm)**	**Micropores (<10 µm)**
	---SPSD (m^3 m^{-3}) ---							
P[††]	0.02[bc†]	0.07[a]	0.03[a]	0.50[a]	0.017[a]	0.040[a]	0.030[a]	0.50[a]
N	0.01[c]	0.05[a]	0.05[a]	0.53[a]	0.013[a]	0.040[a]	0.033[a]	0.50[a]
2N	0.03[bsc]	0.07[a]	0.04[a]	0.51[a]	0.019[a]	0.045[a]	0.030[a]	0.54[a]
F	0.05[a]	0.08[a]	0.03[a]	0.43[a]	0.018[a]	0.045[a]	0.035[a]	0.47[a]
HF	0.03[bc]	0.06[a]	0.02[a]	0.42[a]	0.014[a]	0.06[a]	0.040[a]	0.53[a]
CK	0.03[ba]	0.06[a]	0.14[a]	0.35[a]	0.023[a]	0.06[a]	0.030[a]	0.45[a]
	Analysis of Variance (P>F)							
Treatment	0.01	0.2	0.4	0.07	0.9	0.5	0.7	0.1
P vs. 2N	0.2	0.8	0.9	0.9	0.9	0.7	1	0.1
Manure vs. Fertilizer	0.07	0.7	0.8	0.2	0.9	0.4	0.2	0.5

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at *P*<0.05.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 4.3-b Soil pore size distribution (SPSD; $m^3\ m^{-3}$) for 0-10 and 10-20 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford locations of South Dakota.

Beresford Location								
Treatments	---Depths (cm)---							
Depths	**0-10**				**10-20**			
Pore sizes	**Macropores (>1000 µm)**	**Coarse Mesopores (60-1000 µm)**	**Fine Mesopores (10-60 µm)**	**Micropores (<10 µm)**	**Macropores (>1000 µm)**	**Coarse Mesopores (60-1000 µm)**	**Fine Mesopores (10-60 µm)**	**Micropores (<10 µm)**
	--- SPSD ($m^3\ m^{-3}$)---							
P[††]	0.01[a]	0.06[a]	0.04[c]	0.51[a]	0.007[a]	0.03[a]	0.03[cb]	0.47[a]
N	0.008[a]	0.09[a]	0.05[c]	0.50[a]	0.01[a]	0.07[a]	0.03[cb]	0.50[a]
2N	0.009[a]	0.06[a]	0.05[ba]	0.52[a]	0.009[a]	0.05[a]	0.02[c]	0.54[a]
F	0.008[a]	0.06[a]	0.07[a]	0.46[a]	0.005[a]	0.03[a]	0.04[b]	0.51[a]
HF	0.008[a]	0.06[a]	0.05[ba]	0.49[a]	0.005[a]	0.03[a]	0.04[cb]	0.54[a]
CK	0.007[a]	0.06[a]	0.06[a]	0.48[a]	0.01[a]	0.05[a]	0.06[a]	0.44[a]
	Analysis of Variance (P>F)							
Treatment	0.3	0.5	0.01	0.09	0.2	0.2	0.005	0.3
P vs. 2N	0.2	0.7	0.04	0.9	0.7	0.2	0.4	0.1
Manure vs. Fertilizer	0.08	0.2	0.04	0.01	0.2	0.06	0.1	0.3

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 4.4 Water infiltration rate (qs, mm hr^{-1}) as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

Treatment	**Brookings**	**Beresford**
	---Infiltration rate (qs, mm hr^{-1})---	
P[††]	304[bc][†]	250[bc]
N	326[ba]	264[ba]
2N	412[a]	329[a]
F	241[bc]	143[d]
HF	225[c]	178[dc]
CK	245[bc]	179[dc]
	Analysis of Variance (P > F)	
Treatment	0.01	0.001
P vs. 2N	0.04	0.04
Manure vs. Fertilizer	0.001	0.001

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.

[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

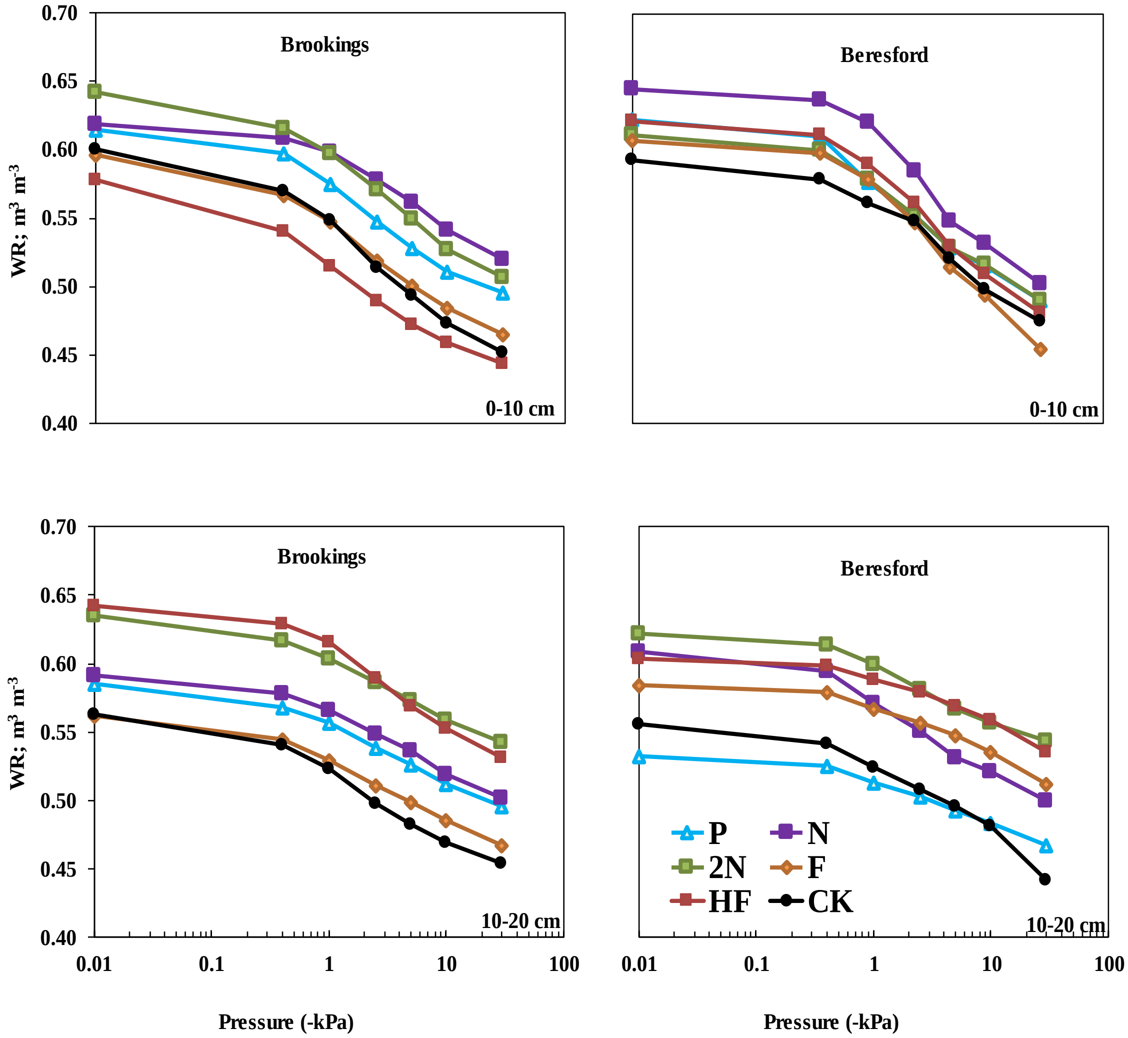

Figure 4.1 Soil water retention (WR; m^3 m^{-3}) for the 0-10 and 10-20 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

CHAPTER 5

RESPONSE OF SURFACE GHG FLUXES TO LONG-TERM MANURE AND INORGANIC FERTILZIER APPLICATION IN CORN AND SOYBEAN ROTATION

ABSTRACT

This study was conducted to investigate the impacts of dairy manure and inorganic fertilizer on carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) fluxes from soils managed under corn-soybean rotation. The study site was established under silty loam soil, and the treatments included three manure application rates [phosphorus based recommended rate (P), nitrogen based recommended rate (N) and two times recommended nitrogen rate (2N)], two inorganic fertilizer levels [recommended fertilizer (F) and high rate of fertilizer (HF)] and control (CK) replicated four times. Soil GHG fluxes were observed once a week from June 05, 2015 through October 08, 2015 depending on the climatic conditions. The CO_2 fluxes were significantly impacted by manure application. There were not any significant impacts from manure and inorganic fertilizer application on CH_4 fluxes. Nitrous oxide fluxes were significantly impacted by inorganic fertilizer in 2016 whereas non-significant differences on N_2O were monitored between manure and inorganic fertilizer in 2015. The CO_2 flux from plots under CK treatment was 119 kg ha^{-1} day^{-1} while under 2N manure application was 707 kg ha^{-1} day^{-1} in 2015. However, for 2016 were from 99 kg ha^{-1} day^{-1} under CK treatment to 266 kg ha^{-1} day^{-1} under 2N manure application. This indicated that variation of CO_2 flux in 2015 was higher than variation in 2016. Even though the highest flux was observed under 2N manure application in 2015, those under CK treatment (19.10 g ha^{-1} d^{-1}) impacts were the highest observations in 2016. Results from this study also conclude that, air temperature, and soil moisture content strongly impacted soil CO_2 fluxes, whereas soil moisture impacted the direction of CH_4 fluxes. Nitrous oxide was strongly impacted by inorganic fertilizer application whereas impacts were for shorter relative to timing of manure application.

Keywords: Greenhouse gas emissions (GHG), manure, inorganic fertilizer, corn-soybean rotation, reduced tillage

INTRODUCTION

Agricultural emissions are an important contributing factor to global warming and stratospheric ozone depletion, and thus, help in regulating the earth's surface temperature and precipitation regimes (Sejian, Samal, et al., 2015). Agricultural soils, covering 37% of the earth's land surface, are responsible for 18% of the global GHGs emissions (Massé, Talbot, et al., 2011). Concentrations of the three most important greenhouse gases (GHG) namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), have increased dramatically over the past 255 years in the atmosphere (Marble, Prior, et al., 2011). Soil and crop management practices have significantly contributed to these GHG emissions. Agricultural production and livestock manure are responsible for significant amounts of GHG emissions (Bennetzen, Smith, et al., 2016, Kumar, Nakajima, et al., 2014, Sejian, Samal, et al., 2015). The US dairy industry produces approximately 2% of the total US GHG emissions that come from the feed, cattle and manure management, and climatic factors at the farm level (Cortus, Jacobson, et al., 2015). GHG emissions from animal production include CH_4 from livestock manures, and

N_2O, from land applied manures and grazed lands (Kebreab, Clark, et al., 2006). Therefore, there is an urgent need for the livestock industry to adopt environmentally sustainable production practices (Massé, Talbot, et al., 2011).

Animal manure as a fertilizer can contribute significantly to GHG emissions. In addition, manure stored in confinement barns, manure applied to land for crop nutrients (Cortus, Jacobson, et al., 2015), and manure from grazing animals contribute significant amount of emissions (Sejian, Samal, et al., 2015, Zhu, Dong, et al., 2011). Manure contains complex organic compounds, which are broken down by bacteria resulting in the production of CO_2 under aerobic and CH_4 under anaerobic conditions (Sejian, Samal, et al., 2015). In contrast, inorganic fertilizers (N and P) are reported to have a mixed impact on GHG emissions. For example, Schmer, Liebig, et al. (2012) reported that in the Northern Great Plains, the N fertilizer did not impact CO_2 and CH_4 emissions. Nitrogen fertilizer usage may have important consequences for direct and indirect N_2O emissions (Kim, Rafique, et al., 2014). Therefore, optimization of N rate is critical to avoid N related pollution (GHG emissions) and to support carbon sequestration (Mbonimpa, Hong, et al., 2015).

Greenhouse gas emissions from soils are sensitive to climate change and land management practices (Rafique, Kumar, et al., 2014). Emission of methane (CH_4) by livestock is a major cause of global warming (Sejian, Rotz, et al., 2011). Methane is the single largest source of GHG emission from dairy farms (Sejian, Rotz, et al., 2011). Principal factors affecting CH_4 emissions from manure are the amount of manure produced and the portion of the manure that decomposes anaerobically (Sejian, Samal, et al., 2015). The N_2O emissions from soil application of manure and fertilizer are also a major contributor to the global agricultural emissions (Li, Watson, et al., 2013, Sejian, Samal, et al., 2015). Globally, manure production and use contribute more N_2O emissions to the atmosphere than does synthetic fertilizer N (Davidson, 2009). However, to meet the nutritional needs of a growing human population, more N inputs to agriculture are likely needed (Davidson, 2012). The use of N fertilizers and animal manures contributing about 24 % of annual N_2O emissions (Kim, Rafique, et al., 2014). It has been suggested that N fertilizer use, land use and its management are the major controlling factors of N_2O emissions from agricultural lands (Kim, Rafique, et al., 2014). The soil with a history of manure application had a much higher propensity for N_2O emission than the non-manured soil (Graham, van Es, et al., 2013). Similarly, manure and inorganic fertilizer also strongly impact the soil surface CO_2 emissions. The latter are generated from autotrophic metabolism of plant roots and associated mycorrhizae, and heterotrophic respiration from soil organisms (Ryan and Law, 2005) . Soil organic carbon serves as substrate to soil microorganisms that generate CO_2 in aerobic conditions (Davidson, Verchot, et al., 2000). In addition to soil amendments, climatic fluctuations also strongly affect the GHG balance in agricultural systems (Rafique, Kumar, et al., 2014). Agricultural GHG emissions are complex and heterogeneous due to the combined effect of meteorological drivers as well as land management and soil properties (Rafique, Kumar, et al., 2014). The GHGs fluxes impacted by climatic fluctuations especially with changes in precipitation and temperature (Mbonimpa, Hong, et al., 2015). Precipitation determines the water filled pore space (WFPS) in soil which impacts GHG fluxes by influencing the oxygen status of the soil (Rafique, Kumar, et al., 2014).

Improved livestock and grassland management, and soil nutrient management can be strategies to mitigate emissions and create further resilience to climate change (Bennetzen, Smith, et al., 2016). However, uncertainty still remains about overall implications of fertilization rate, climate and soil conditions on GHGs emissions (Mbonimpa, Hong, et al., 2015). Therefore, the present study was conducted to assess the impacts of long-term manure and inorganic fertilizer application on soil surface GHG emissions under corn-soybean rotation systems, and compared these emissions with that from control treatment with no manure and inorganic fertilizer.

MATERIALS AND METHODS

Experimental Site and Experimental Design

The experimental site was located at the South Dakota State University Felt Research Farm (44^o 22' 07.15" N and 96^o 47' 26.45" W) in Brookings County, South Dakota (SD). Soil type was Vienna soil (Fine-loamy, mixed, frigid Udic Haploborolls). The experimental plots were established in a corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation system, and treatments were laid out in a randomized complete block design with four replications. The individual plot was of 6 m × 18 m in size and managed under a reduced tillage system. Soils of the study site were well drained, and site was established on nearly flat areas with the slope of less than 1% with the elevation of about 518 m. The experimental areas were characterized with a continental climate having relatively humid summers and cold, snowy winters.

Treatments

The study site included three different manure application rates (i) manure rate ascertained based on the Phosphorous requirement (P), (ii) recommended manure rate based on nitrogen requirement (N), (iii) two times prescribed nitrogen rate (2N), and two distinctive fertilizer application rates: (iv) suggested fertilizer rate (F), and (v) high rate of fertilizer application (HF), and (vi) control. For manure and inorganic fertilizer application, the crop yield goal of 180 kg ha^{-1} for corn and 44.8 kg ha^{-1} for soybean was used. The manure and fertilizer were applied in the spring in a manual application and incorporated by disking at 20 cm before planting. Soybean was mechanically planted in the spring and was harvested in the fall.

Sampling and Analysis

The PVC static chambers (25 cm diameter x 15 cm height) were installed in every plot to monitor soil surface GHG fluxes. A chamber was installed between rows in each plot throughout the season. Gas samples were taken once a week depending on weather conditions from June to October 2015 and May to October 2016. In addition to soil surface GHG flux monitoring, soil temperature and moisture data for 0-5 cm depth was also collected with a thermometer at every chamber throughout all sampling times. Gas samples were collected at 0, 20 and 40 minutes' intervals using 10-ml syringe. These samples were taken via a chamber septum and transferred to a 10-ml, argon-filled vials. Concentrations of CO_2, CH_4, and N_2O were measured with 2-3 days of sampling using a Gas Chromatograph (Shimadzu 14B with a CombiPal AOC-500 auto sampler, 2-ml injection loop, a 1/8" stainless-steel Porapack Q (80/100 mesh) column, a Haysep-D column (columns operated at 60°C), and a flame ionization detector and a lepton capture detector each at 260°C)]. Daily flux of gases was estimated from the concentration in the chamber headspace over 40 min collection period. Daily flux *(F*, mass of g gas ha^{-1} day^{-1}) was computed as:

$$F = \left(\frac{\Delta g}{\Delta t}\right)\left(\frac{V}{A}\right)k$$

where Δg/Δt is the rate of gas change (CH_4, CO_2 or N_2O) concentration inside the chamber (mg CH_4-C, CO_2-C or mg N_2O-N m^{-2} min^{-1}); V is the chamber volume (m^3); A is the surface area circumscribed by the chamber (m^2) and *k* is the time conversion factor (1440 min day^{-1}). Gas fluxes were calculated from the time vs. concentration data using linear regression or, the algorithm of (Hutchinson and Mosier, 1981, Ussiri and Lal, 2009) when the time vs. concentration data were curvilinear. A positive value of *F* corresponds to a net emission of gas from the soil to the atmosphere, and a negative *F* value corresponds to a net transfer of gas from atmosphere into the soil. These data were used to calculate the cumulative emissions over the experimental period by linear interpolation of data points between two successive sampling events and numerical integration of underlying area using the trapezoid rule (Ussiri and Lal, 2009, Whittaker and Robinson, 1967).

During each sampling date, surface (0-5 cm) soil moisture samples were obtained approximately 20 cm away from each chamber and soil water content was measured volumetrically by a HH2 moisture sensor (Delta-T-Devices, Cambridge, England). Data for soil properties are presented in (Table 1). Water Field Pore Size was calculated by using equation (Mbonimpa, Hong, et al., 2015) below;

$$WFPS = \frac{\theta}{Soil\ porosity} * 100$$

where θ is the volumetric moisture content ($m^3\ m^{-3}$). Soil porosity ($m^3\ m^{-3}$) was calculated using a particle density value of 2.65 Mg m^{-3}, and soil bulk density measured from the field using core method.

Statistical Analysis

Statistical analysis was performed to determine the impacts of treatments on GHG emissions (CO_2, CH_4, N_2O) under different levels of manure and chemical fertilizer applications. The least significant difference is estimated (Duncan's LSD) among treatments using the 'Mixed procedure in SAS 9.3 (Institute, 2012). Treatments were considered fixed effects and replications as a random effect. In addition, contrasts were also determined as follows: *Manure vs. Fertilizer*, and *P vs. 2N* (P-based manure application rate versus two times N based recommended application rate of manure).

RESULTS

Climate and Soil Properties

The average daily precipitation and air temperature for the sampling period were 3.53 mm and 19.5°C, respectively (Fig. 1). The long-term (8 years) average annual precipitation and minimum and maximum temperature were 367 mm, -15.8°C, and 27.8 °C, respectively. Annual precipitation in 2015 and 2016 was 2.3% and 18.9% higher than the long-term annual average precipitation. Average temperature also influences the soil temperature; it was positively correlated with soil temperature in 2015 (R^2 = 0.48), and 2016 (R^2 = 0.16).

Data on selected soil properties show that the manure applications significantly influenced soil properties for the 0–7.5 cm depth (P< 0.05; Table 1). For the 0–10 cm depth, soil pH at 2N manure (pH = 7.1) was more alkaline compared to that under HF inorganic fertilizer (pH = 6.4). The SOC and TN concentrations at this depth were 48% and 35%, respectively, higher at the 2N (38.3 and 3.5 g kg $^{-1}$) compared to those at the HF (25.8 and 2.6 g kg^{-1}). A similar trend was observed for WAS, where it was 13% higher at 2N than HF. Results also indicated that soil BD was 18% lower in the 2N as compared to that in the HF for the 0–7.5 cm depth.

Soil moisture content (θ), Soil temperature (°C) and Water filled pore space (WFPS, %)

Soil moisture content (θ; m^3 m^{-3}) on a volumetric basis (measured at the time of gas sampling), on an average, was higher under the 2N manure treatment for the 0–5 cm compared to other treatments (Fig. 1). Moisture content was associated with temperature and precipitation. A decline in temperature and precipitation for both 2015 and 2016 concurs with a severe decline in θ under all treatments. A similar trend was observed when there was an increase in the temperature and precipitation. No moisture and gas samples were collected from October 2015 to May 2016 due to low temperature (Fig. 1). There was not any significant difference on soil temperature observed but it was significantly associated with precipitation and air temperature (Fig. 1).

The water filled pore space (WFPS) was lower at the 2N manure application than the inorganic fertilizer application and control (Fig. 2). The WFPS was significantly affected by 2N manure application with lower WFPS than the lower manure rates and inorganic fertilizer applications. Monthly variations in the WFPS resemble those of θ throughout the sampling period (2015 and 2016). The WFPS was lower during days with low precipitation, and low temperature. Further, the trend of WFPS showed a reduction from middle of August to October 2015 and a trend with continuous increase from beginning of May until August 2016 (Fig. 2).

Daily average of CO_2, CH_4 and N_2O fluxes

Daily average soil surface CO_2 fluxes were higher under the 2N manure application (Fig. 3). Higher fluxes occurred in wet and warm periods of the year. Daily soil CO_2 flux peaks coincide with that of temperature and precipitation. These fluxes started increasing from May onwards, peaked in July and started decreasing until around September. The largest difference in the soil CO_2 fluxes was observed in June 27 of 2015 between the 2N manure application (70.29 kg ha^{-1} day^{-1}) and control (8.27 kg ha^{-1} day^{-1}), where the peak of CO_2 fluxes was 470% higher under the 2N manure application than the HF inorganic fertilizer application. In contrast, the minimum difference (-11%) between 2N manure and HF was observed on September 22, 2015 (Fig. 3). The CO_2 peak was observed from soils at the 2N manure application on 27 June, 2015 (70.29 kg CO_2-C ha^{-1} day^{-1}) and it was 2.7 times higher than that on 30 June 2016 (25.83 kg CO_2- C ha^{-1} day^{-1}), whereas CO_2 peak at the HF inorganic fertilizer was 2.1 times higher in 2016 (25.83 kg CO_2-C ha^{-1} day^{-1}) compared to 2015 (12.31 kg CO_2-C ha^{-1} day^{-1}; Fig. 3).

Methane fluxes under all the treatments varied with climatic conditions (Fig. 3). The summer months of 2015 exhibited alternating episodes of release and uptake.

Sharper changes were observed under 2N manure application than under inorganic fertilizer applications and control. Higher manure application impacts CH_4 flux more than lower manure application. The 2N manure exhibited higher differences between uptake (10.3 g ha^{-1} day^{-1}) and release (3.4 g ha^{-1} day^{-1}) of CH_4 in June and October 2015, respectively (Fig. 3). However, under HF inorganic fertilizer application, August 2015 exhibited highest CH_4 uptake (4.191 g ha^{-1} day^{-1}) and June 2016 exhibited the highest release (5.0 g ha^{-1} day^{-1}). Some days also exhibited opposite trends in release and uptake of CH_4 between manure and fertilizer applications. The N rate from manure application impacted daily soil CH4 fluxes; however, it was not always significant. The soil CH_4 release was higher with the high N rate compared to that with the low and medium manure N rate applied plots (Fig. 3).

Daily average soil surface N_2O fluxes were higher under the 2N manure application in 2015 (Fig. 3). Higher fluxes occurred in wet and warm periods of the year. Daily soil N_2O flux peaks coincide with that of temperature and precipitation. These fluxes started increasing from May onwards, peaked in June and started decreasing until around September. The largest difference in the soil N_2O fluxes was observed on June 21 of 2015 between the 2N manure application (129.3 g ha^{-1} day^{-1}) and HF inorganic fertilizer (12.2 g ha^{-1} day^{-1}), where the peak of N_2O fluxes was 9.6 times higher at the 2N manure application than the HF treatment. In contrast, the minimum difference (8%) between 2N manure and HF was observed on September 15, 2015 (Fig. 3). The N_2O peak was also observed under the 2N manure application on June 21, 2015 (129.3 g ha^{-1} day^{-1}). On the other hand, there were two different peaks in 2016. Before till June 2, 2016 and after July 15 2016, there was a peak observed under N manure application (34.7 g ha^{-1}

day^{-1}). However, HF inorganic fertilizer application was observed as highest treatment for N_2O fluxes from 16 June 2016 to 15 July 2016 when compared to all other treatments. The peak point was observed on July 15th 2016 which indicated that HF inorganic fertilizer was highest impacted treatment (196.9 g ha^{-1} day^{-1}) on GHG emissions as compared to the other treatments. This might be due to fertilizer application was between 2 June 2016 and 6 June 2016. It is evident that inorganic fertilizer impacts continue for 21 days after application (Hensen, Skiba, et al., 2013). The N_2O flux under HF inorganic fertilizer treatment was 784 times higher than those under 2N manure treatment on July 15, 2016.

Monthly average of CO_2, CH_4 and N_2O fluxes

Monthly soil CO_2 fluxes were influenced by treatments in 2015 and 2016 ($P < 0.05$; Table 3). Monthly soil CO_2 fluxes were higher under 2N manure application compared to that under lower manure application rates and fertilizer applications ($P < 0.05$; Table 3) except on August 2015 and May 2016 where CO_2 fluxes were the highest under the N manure application treatment. The highest fluxes were observed in June 2015 under 2N manure application (375.48 kg CO_2-C ha^{-1} day^{-1}). These fluxes under 2N manure application in June and July 2015 were 3.04 and 2.6 times higher compared to those in June and July of 2016, respectively (Table 3). Similar trend was observed under N and P manure applications as well. The inorganic fertilizer rates did not have any significant influence on soil CO_2 fluxes for either years except July 2015. The HF inorganic fertilizer applications (113.39 kg CO_2-C ha^{-1} day^{-1}) in August 2015 had 14.1 times higher impacts on CO_2 flux compare to those (8.04 kg CO_2-C ha^{-1} day^{-1}) in August of 2016. In addition, overall values under all treatments for soybean crop in 2015 were higher than those for corn in 2016. On the other hand, HF fertilizer applied plots were 1.4 times higher for corn in June 2016 compare to those for soybean in June 2015. A similar trend was observed from plots under F fertilizer application.

Monthly soil CH_4 fluxes were not impacted either by manure or inorganic fertilizer applications, except in June 2015 where, 2N manure application slightly influenced CH_4 fluxes (Table 2). The 2N manure applied plots (30.75 g ha^{-1} day^{-1}) were 99% higher than N manure application (15.44 g ha^{-1} day^{-1}), 1109% higher than P manure application (2.54 g ha^{-1} day^{-1}), 1285% higher than HF inorganic fertilizer application (2.22 g ha^{-1} day^{-1}) and 1596% higher than control (1.81 g ha^{-1} day^{-1}) whereas F fertilizer impacted plots showed -0.95 g ha^{-1} day^{-1} flux. Higher observations were observed under manure treatments for June-July in 2015 where temperature was higher; however, fertilizer showed higher impacts on CH_4 for September.

Monthly N_2O fluxes were impacted by treatments in 2015 and 2016 ($P<0.05$; Table 4). For July 2015 ($P<0.03$), these fluxes under 2N manure treatment (65.70 g ha^{-1} d^{-1}) were higher than those under N (40%; 46.78 g ha^{-1} d^{-1}), P (1620%; 3.82 g ha^{-1} d^{-1}), HF (3709%;8.76 g ha^{-1} d^{-1}), F (9267%;3.92 g ha^{-1} d^{-1}) and CK (278.58 times;0.24 g ha^{-1} d^{-1}). Similarly, manure applications emitted higher fluxes in comparison with fertilizer applications and control for 2015. Monthly soil N_2O fluxes were higher under 2N manure application compared to lower manure application rates and fertilizer applications except June-July 2016 where HF fertilizer application (391.66 g ha^{-1} day^{-1}, June and 197.93 g ha^{-1} day^{-1}, July) was the highest impacted treatment. For June 2016 ($P<.0001$), HF inorganic fertilizer applicate plots (391.66 g ha^{-1} day^{-1}) were higher than those under F

(6.88 times; 56.97 g ha^{-1} d^{-1}), N (9.51 times; 41.20 g ha^{-1} d^{-1}), 2N (14.85 times; 26.36 g ha^{-1} d^{-1}), P (22.42 times; 17.47 g ha^{-1} d^{-1}) and CK (2264.41 times; 0.17 g ha^{-1} d^{-1}). Similarly, HF fertilizer treatment (197.93 g ha^{-1} d^{-1}) was 631.42 times higher than highest manure application (2N; 0.31 g ha^{-1} d^{-1}) and all other treatments for July 2016 ($P<0.048$). However, this trend was not observed in August 2016. The 2N manure treatment was 8 times higher in June 2015 than those in June 2016, HF fertilizer applicate plots in June 2016 were 7 times lower than those in June 2015.A similar finding were presented; whereas, 2N manure treatment was 209 times higher in July 2015 than those in July 2016, HF fertilizer applicate plots in July 2016 were 114.75 times lower than those in July 2015.

Annual and total Soil Surface CO_2, CH_4 and N_2O Fluxes

Data showed that the treatment significantly impacted soil CO_2 fluxes throughout the sampling period (Table 5). Annual CO_2 fluxes were higher under 2N manure application (707 and 266 kg ha^{-1} day^{-1}) than N manure (366 kg ha^{-1} day^{-1}% and 204 kg ha^{-1} day^{-1}%) and P manure (290 kg ha^{-1} day^{-1}% and 172 kg ha^{-1} day^{-1}%) applications in 2015 and 2016, respectively. On the other hand, HF inorganic fertilizer application rate (243 kg ha^{-1} day^{-1}) was 60% higher than F fertilizer application (151 kg ha^{-1} day^{-1}) in 2015; whereas, F (164 kg ha^{-1} day^{-1}) was 4% higher than HF (157 kg ha^{-1} day^{-1}) in 2016. In addition, the highest rate of manure application (2N) was 191% and 69% higher impacting CO_2 flux in comparison with the highest inorganic fertilizer application (HF) and also 496% and 169% than control treatment (CK;119 and 99 kg ha^{-1} day^{-1}) in 2015 and 2016. The CO_2 flux from plots under CK treatment was 119 kg ha^{-1} day^{-1} while under

2N manure application was 707 kg ha^{-1} day^{-1} in 2015. However, for 2016 were from 99 kg ha^{-1} day^{-1} under CK treatment to 266 kg ha^{-1} day^{-1} under 2N manure application. This indicated that variation of CO_2 flux in 2015 was higher than variation in 2016. Also, higher manure produced higher CO_2 fluxes compare to lower manure rates and fertilizer rates whereas there are no differences between inorganic fertilizer (F and HF) rates.

Data showed that the treatment did not significantly impacted soil CH_4 fluxes for sampling periods in 2015 and 2016 (Table 5). Plots under 2N manure treatment (42.57 g ha^{-1} day^{-1}) were higher impacted than those under F (12.76 g ha^{-1} d^{-1}), P (11.32 g ha^{-1} d^{-1}), HF (11.00 g ha^{-1} d^{-1}) whereas N (-8.18 g ha^{-1} d^{-1}) and CK (-37.88 g ha^{-1} d^{-1}) were monitored in 2015. Even though the highest flux was observed under 2N manure application in 2015, those under CK treatment (19.10 g ha^{-1} d^{-1}) impacts was the highest observation in 2016. The trend in 2015 clearly showed that 2N manure had higher impacts on CH_4 fluxes but differences were not significant.

Data showed that the treatment significantly impacted soil N_2O fluxes throughout the sampling period (Table 5). 2N manure application (306 g ha^{-1} d^{-1}) performed higher than all other treatments whereas F (8 g ha^{-1} d^{-1}) was the lowest observation in 2015. The 2N manure treatment impacted plots were higher than those under N manure application (197 g ha^{-1} d^{-1}), HF (118 g ha^{-1} d^{-1}), P (30 g ha^{-1} d^{-1}), CK (17 g ha^{-1} d^{-1}) and F (8 g ha^{-1} d^{-1}) in 2015.However, differences were not statistically significant. In contrast, HF fertilizer (594 g ha^{-1} d^{-1}) applied plots were higher than those under impacts of N manure application (90.35 g ha^{-1} d^{-1}), F (80.75 g ha^{-1} d^{-1}), 2N (75.67 g ha^{-1} d^{-1}), P (26.55 g ha^{-1} d^{-1}) and CK (1.42 g ha^{-1} d^{-1}) in 2016 ($P<0.0003$). The year 2015 had soybean crop on stand so the impacts from inorganic fertilizer treatment were only from long term whereas manure was applied continuously every year. However, there was fertilizer application in 2016. This changes indicates that fertilizer application strongly impact N_2O flux and continuous application of fertilizer might produce much more N_2O emission.

DISCUSSION

Soil Properties

Higher SOC and TN concentrations, moisture content, and soil CO_2 fluxes were observed under manure application compared to those under inorganic fertilizer application. This was attributed to the fact that addition of manure increase soil nutrients and organic matter in comparison with that of inorganic fertilizer and control. Higher SOC in manure application is often associated with lower bulk density (Schmer, Liebig, et al., 2011). Similar findings were observed in this study. Celik, Gunal, et al. (2010) reported that bulk density under manure application was 26.7% lower compared to that under inorganic fertilizer application, indicating that soil structure for root growth was better under manure application which also supported by higher WAS under manure application. The higher SOC concentration is also associated with the higher aggregation. Soil pH was higher (pH = 7.05) under manure application in comparison to those under inorganic fertilizer application (pH = 6.38). This indicates that manure in soils helps to maintain soil pH (Eghball, 2002). The influence of fertility practices is associated with various factors including antecedent soil nitrogen, type of fertilizer, time of application, soil series and local climate (Lee, Doolittle, et al., 2007, Makaju, Wu, et al., 2013).

Soil Surface GHG Fluxes

Manure addition can impact CO_2 emissions by improving soil properties. In addition, SOC may indirectly impact CO_2 emission associated with other soil properties. For instance, higher WFPS and bulk density associated with lower porosity decline aerobic conditions (Beare, Gregorich, et al., 2009). It also reported by Mbonimpa, Hong, et al. (2015) that the combination of lower SOC, lower porosity, high bulk density, and higher WFPS resulted in lower CO_2 fluxes in N rates (inorganic fertilizer applied plots). Data from this study show that the CO_2 fluxes were correlated with temperature and precipitation. Similarly, Wagle and Kakani (2014) also reported that seasonal CO_2 fluxes are correlated with temperature and moisture. Warm and moist conditions are one of the reasons for higher CO_2 fluxes due to higher microbial activity (Smith, Martino, et al., 2008). Soil microbial activity increases under aerobic conditions, and reduces with the decline in oxygen availability (Linn and Doran, 1984). Soil and air temperature strongly impact soil surface GHGs fluxes. Differences in soil and air temperature might be a reason for increase or decrease in GHGs fluxes.

Manure and inorganic fertilizer applications did not have any significant impact on soil surface CH_4 fluxes. The inorganic fertilizer applications to the soil did not necessarily translate into higher CH_4 release possibly due to lower SOC which serves as substrate to methanogens. Inorganic fertilizer applications did not show any significant impacts on soil CH_4 fluxes partially due to their low impact on soil moisture content. In general, well-developed soil structure and higher aeration under the manure treatments might be another reason for non-significant CH_4 emissions. Changes in CH_4 fluxes might be due to differentiation of moisture and temperature. The temperature is related to other environmental conditions such as precipitation and WFPS which are local and dominant determined factors (Curry, 2009). Soil porosity and temperature promote soil microbial activities (Scott, Jenerette, et al., 2009). The differences in CH_4 fluxes between 2015 and 2016 data may be associated with climate, soil conditions and crop. The present study indicates that soil CO_2 fluxes were strongly correlated with manure application whereas inorganic fertilizer did not impact CO_2 fluxes. However, CH_4 fluxes were not impacted by both manure and inorganic fertilizer applications. Some studies reported that there is a strong correlation between CH_4 and CO_2 due to similar source or process (Bjerg, Zhang, et al., 2012, Ngwabie, Jeppsson, et al., 2011, Wu, Zhang, et al., 2012) such as enteric fermentation and ruminant respiration (Hamilton, DePeters, et al., 2010).

Soil surface N_2O flux does not have strong correlation with other gases because the mechanisms and sources are different (Joo, Ndegwa, et al., 2015). Soil N can be lost through denitrification, and leaching (Mbonimpa, Hong, et al., 2015). Soil moisture content might be associated with a rise in denitrification rates and hence N_2O emissions. Baggs, Stevenson, et al. (2003) studied on N_2O emissions under inorganic N fertilizer and crop residues application on a silt loam soil in UK and reported that N_2O emissions went up more with increased in NH_4NO_3 fertilizer (200 kg N ha^{-1}) application in comparison with the residues. Baggs, Stevenson, et al. (2003) also mentioned that higher emission continued for the first 23 days after application of inorganic fertilizer. This statement supports the impacts of inorganic fertilizer on N_2O emission in 2016. In addition, Eichner (1990) studied an experiment between 1979 and 1987 that included 104 fields to estimate worldwide N_2O emission and reported that N_2O emission is associated with type and quantity of fertilizer. Petersen (1999) studied N_2O emissions under liquid manure (anaerobically digested slurry), and inorganic fertilizers in spring barley, and reported that increase in the soil moisture content or NO_3^- availability had no significant effect on accumulated N_2O losses; however, nitrification and denitrification are affective processes that influence N_2O emission. Petersen (1999) also mentioned that anaerobic digestion of slurry potentially could reduce N_2O fluxes by 1.2 to 2.5%. Davidson (2009) mentioned that soil microbial production is the main source of N_2O which increased with nitrogen fertilizer application. Davidson (2009) also reported that to reduce atmospheric N_2O sources, manure management is important to consider. In addition, climate is important factor on N_2O emissions. It has been reported that climatic conditions might significantly enhance estimation of CH_4 and N_2O emissions from animal manure (Sommer, Petersen, et al., 2004). Higher manure and inorganic fertilizer applications have higher impacts on N_2O emission compare to lower rates of manure and inorganic fertilizer. This statement is supported by Meng, Ding, et al. (2005) with the application of manures and fertilizers for three different rates (300 kg N ha^{-1} $year^{-1}$, 150 g N_2O-N ha^{-1} $year^{-1}$ and 856 g N_2O-N ha^{-1} $year^{-1}$).

CONCLUSION/SUMMARY

A long-term study was conducted at one site in South Dakota to monitor the influences of organic manure and inorganic fertilizers on GHG emissions that include methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). Results from this study showed that soil temperature and moisture which are associated with climatic conditions, were significantly correlated with overall GHG emissions. The WFPS was higher under inorganic fertilizer application and the WFPS and gas fluxes were significantly correlated. The manure and fertilizer applications did not show significant impacts on CH_4 emission as compared to the control. Soil surface CO_2 was significantly impacted by manure application compared to inorganic fertilizer application and control, whereas there were significant impacts of inorganic fertilizer on CO_2emission. Soil surface N_2O fluxes were impacted by both manure and inorganic fertilizer however inorganic fertilizer impacts were higher than manure especially in 2016.

Data from this study conclude that higher manure rates result in higher emissions, however, soil surface N_2O fluxes were higher with the inorganic fertilizer, therefore, and manure can be an option for improving the soil organic matter content and lowering the GHG emissions as compared to inorganic fertilizer.

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Table 5.1 Soil Properties for 0-7.5 cm depth as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Brookings locations of South Dakota.

Treatments	**Soil Parameters**				
	SOC[†††] g kg^{-1}	**TN** g kg^{-1}	**pH**	**BD** Mg m^{-3}	**WAS** g g^{-1}
P[††]	27.6[c†]	2.5[cb]	6.9[ba]	1.13[b]	91.9[bc]
N	30.9[b]	2.8[b]	6.9[ba]	1.07[b]	93.5[ba]
2N	38.3[a]	3.5[a]	7.1[a]	0.87[c]	98.6[a]
F	24.0[d]	2.3[c]	6.7[b]	1.27[a]	89.2[bc]
HF	25.8[dc]	2.6[cb]	6.4[c]	1.27[a]	87.4[c]
CK	23.3[d]	2.2[c]	6.9[ba]	1.29[a]	90.1[bc]
	Analysis of variance				
Treatment	<.0001	0.0008	0.001	<.0001	0.01
P vs. 2N	<.0001	0.0008	0.3	0.0001	0.02
Manure vs. Fertilizer	<.0001	0.01	0.01	0.0005	0.02

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at P<0.05.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.
[†††]SOC, Soil organic carbon; TN, Total nitrogen; pH, Soil pH; BD, Soil bulk density; WAS, Water aggregate stability.

Table 5.2 Monthly CH_4 Fluxes as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Brookings locations of South Dakota.

Treatments	2015 June	2015 July	2015 August	2015 September	2015 October	2016 May	2016 June	2016 July	2016 August
	g CH_4-C ha^{-1} d^{-1}								
P[††]	2.5[a†]	4.4[a]	3.6[a]	0.5[a]	0.3[a]	12.5[a]	-0.8[a]	0.8[a]	3.1[a]
N	15.4[a]	2.7[a]	3.4[a]	-9.6[a]	-20.1[a]	14.7[a]	0.04[a]	0.3[a]	0.2[a]
2N	30.8[a]	9.8[a]	0.7[a]	8.0[a]	-6.7[a]	6.3[a]	-1.9[a]	0.05[a]	0.3[a]
F	-0.9[a]	0.3[a]	-2.7[a]	15.3[a]	0.8[a]	0.7[a]	0.04[a]	-1.5[a]	-0.07[a]
HF	2.2[a]	0.4[a]	10.5[a]	-2.1[a]	-0.08[a]	-0.04[a]	-9.9[a]	0.1[a]	0.02
CK	1.8[a]	-7.8[a]	0.2[a]	-32.5[a]	0.4[a]	3.8[a]	-0.5[a]	16.0[a]	-0.2[a]
Analysis of variance									
Treatment	0.3	0.4	0.9	0.5	0.8	0.4	0.5	0.2	0.4
P vs. 2N	0.06	0.5	0.8	0.8	0.7	0.5	0.8	0.9	0.1
Manure vs. Fertilizer	0.01	0.4	0.9	0.8	0.2	0.05	0.3	0.8	0.2

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 5.3 Monthly CO_2 Fluxes as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Brookings locations of South Dakota.

Treatments	2015 June	2015 July	2015 August	2015 September	2015 October	2016 May	2016 June	2016 July	2016 August
	kg CO_2-C ha^{-1} d^{-1}								
P[††]	127.6[b†]	56.4[a]	88.0[a]	13.7[b]	4.1[a]	38.9[ba]	100.6[a]	22.4[a]	10.4[a]
N	122.5[b]	94.7[a]	132.1[a]	16.6[b]	0.2[a]	81.7[a]	111.5[a]	1.09[a]	10.3[a]
2N	375.5[a]	137.3[a]	130.2[a]	55.6[a]	8.5[a]	69.9[a]	123.6[a]	52.8[a]	19.3[a]
F	61.4[b]	30.4[a]	34.2[a]	21.7[b]	3.5[a]	21.5[b]	93.8[a]	38.9[a]	9.5[a]
HF	68.2[b]	39.2[a]	113.4[a]	20.1[b]	1.8[a]	15.9[b]	95.8[a]	37.6[a]	8.04[a]
CK	44.4[b]	5.1[a]	51.0[a]	17.6[b]	0.6[a]	16.7[b]	45.7[a]	36.0[a]	0.3[a]
Analysis of variance									
Treatment	0.0001	0.12	0.3	0.04	0.3	0.04	0.2	0.1	0.7
P vs. 2N	0.0002	0.1	0.4	0.005	0.3	0.2	0.4	0.1	0.5
Manure vs. Fertilizer	0.004	0.0002	0.06	0.2	0.5	0.01	0.4	0.2	0.2

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 5.4 Monthly N_2O Fluxes as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Brookings locations of South Dakota.

	2015					2016			
Treatments	**June**	**July**	**August**	**September**	**October**	**May**	**June**	**July**	**August**
	g N_2O ha^{-1} d^{-1}								
P[††]	17.5[a†]	3.8[bc]	1.2[a]	1.7[a]	6.0[a]	7.8[b]	17.5[b]	1.3[b]	0.02[a]
N	61.2[a]	46.8[ba]	67.8[a]	21.4[a]	0.2[a]	45.4[b]	41.2[b]	0.1[b]	3.6[a]
2N	213[a]	65.7[a]	24.1[a]	1.6[a]	1.5[a]	44.8[b]	26.4[b]	0.3[b]	4.2[a]
F	3.1[a]	0.7[c]	0.1[a]	1.3[a]	2.5[a]	2.0[a]	57.0[b]	21.7[b]	0.05[a]
HF	53.0[a]	1.7[bc]	60.2[a]	0.1[a]	2.7[a]	4.6[a]	391.7[a]	197.9[a]	0.06[a]
CK	7.7[a]	0.2[c]	3.9[a]	3.0[a]	1.8[a]	0.1[b]	0.2[b]	1.1[b]	0.05[a]
	Analysis of variance								
Treatment	0.3	0.03	0.5	0.2	0.8	0.04	<.0001	0.048	0.6
P vs. 2N	0.05	0.01	0.6	0.9	0.3	0.05	0.9	0.9	0.2
Manure vs. Fertilizer	0.2	0.001	0.9	0.2	0.9	0.008	0.0006	0.06	0.06

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 5.5 Annual GHGs Fluxes as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Brookings locations of South Dakota.

Treatments	**-----CH_4----** g ha^{-1} d^{-1}		**----CO_2----** kg ha^{-1} d^{-1}		**----N_2O----** g ha^{-1} d^{-1}	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
	-------------------------Annual Emissions-------------------					
P[††]	11.3[a†]	15.6[a]	290[b]	172[bc]	30[a]	26.6[b]
N	-8.2[a]	15.2[a]	366[b]	204[ba]	197[a]	90.4[b]
2N	42.6[a]	4.6[a]	707[a]	266[a]	306[a]	75.7[b]
F	12.8[a]	-0.9[a]	151[b]	164[bc]	8[a]	80.8[b]
HF	11.0[a]	-9.7[a]	243[b]	157[bc]	118[a]	594[a]
CK	-37.9[a]	19.1[a]	119[b]	99[c]	17[a]	1.4[b]
	Analysis of variance					
Treatment	0.3	0.3	0.006	0.01	0.2	0.0003
P vs. 2N	0.4	0.5	0.007	0.03	0.04	0.6
Manure vs. Fertilizer	0.9	0.2	0.0004	0.1	0.09	0.006

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.

[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

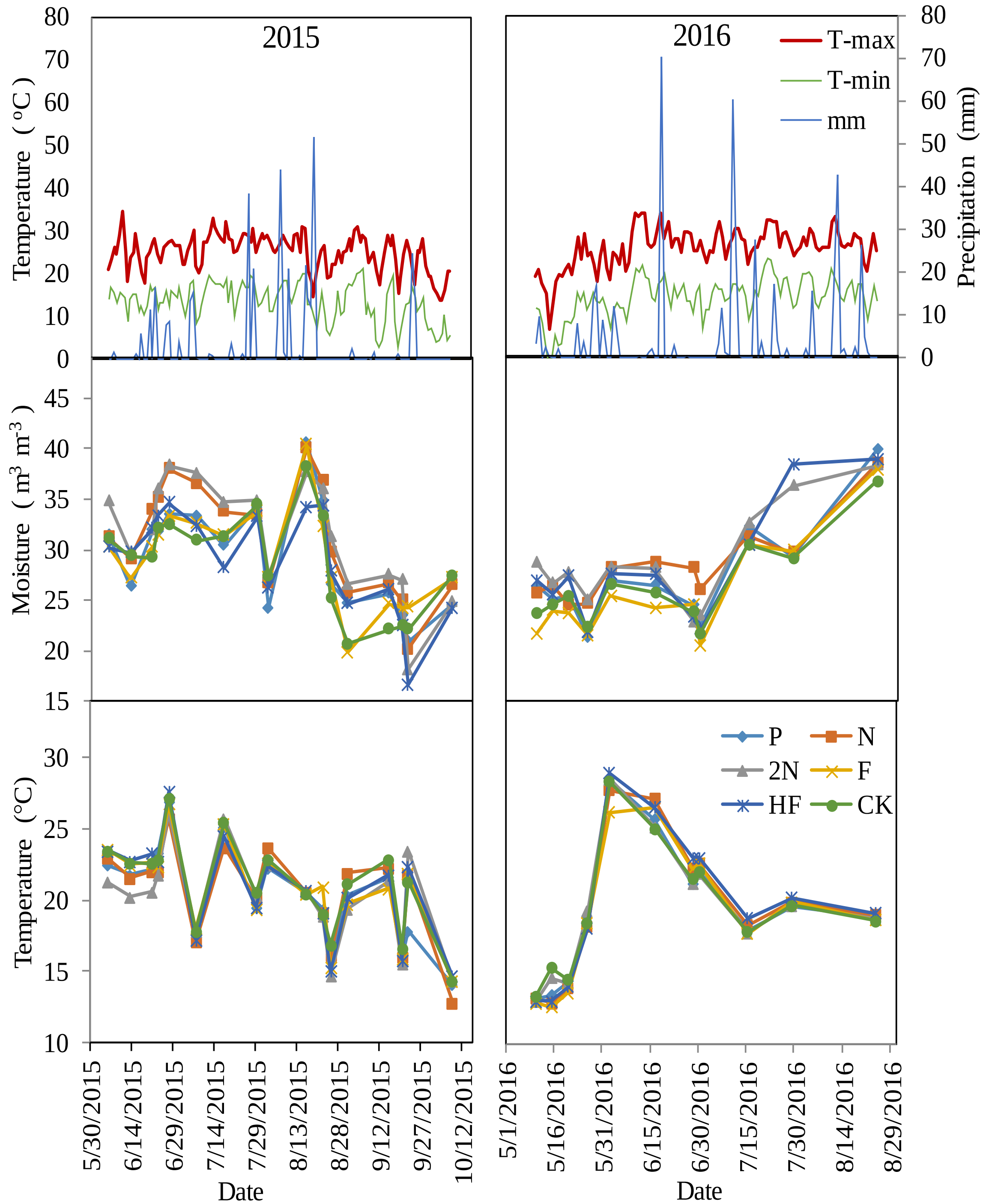

Figure 5.1 Soil Moisture and Soil Temperature as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation and Climate at Brookings locations of South Dakota.

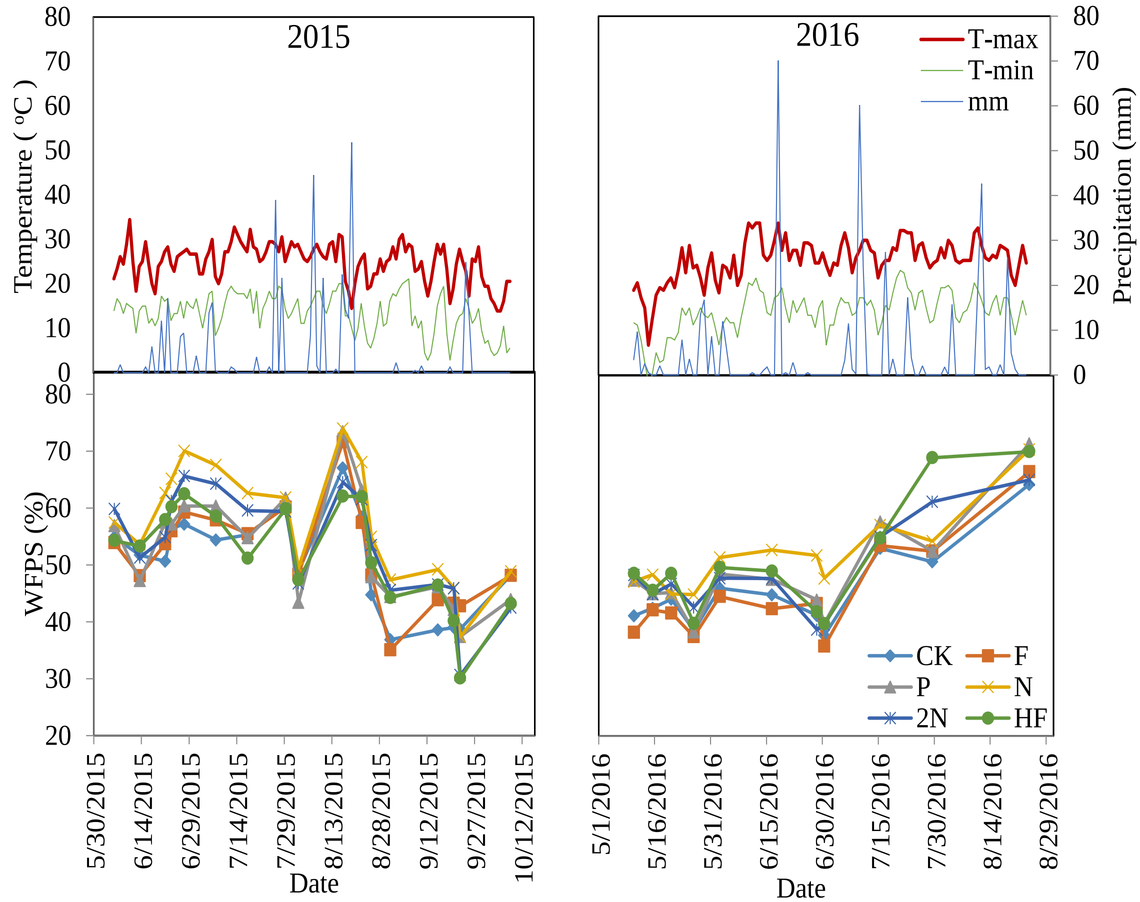

Figure 5.2 Water Filled Pore Space as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation and Climate at Brookings locations of South Dakota.

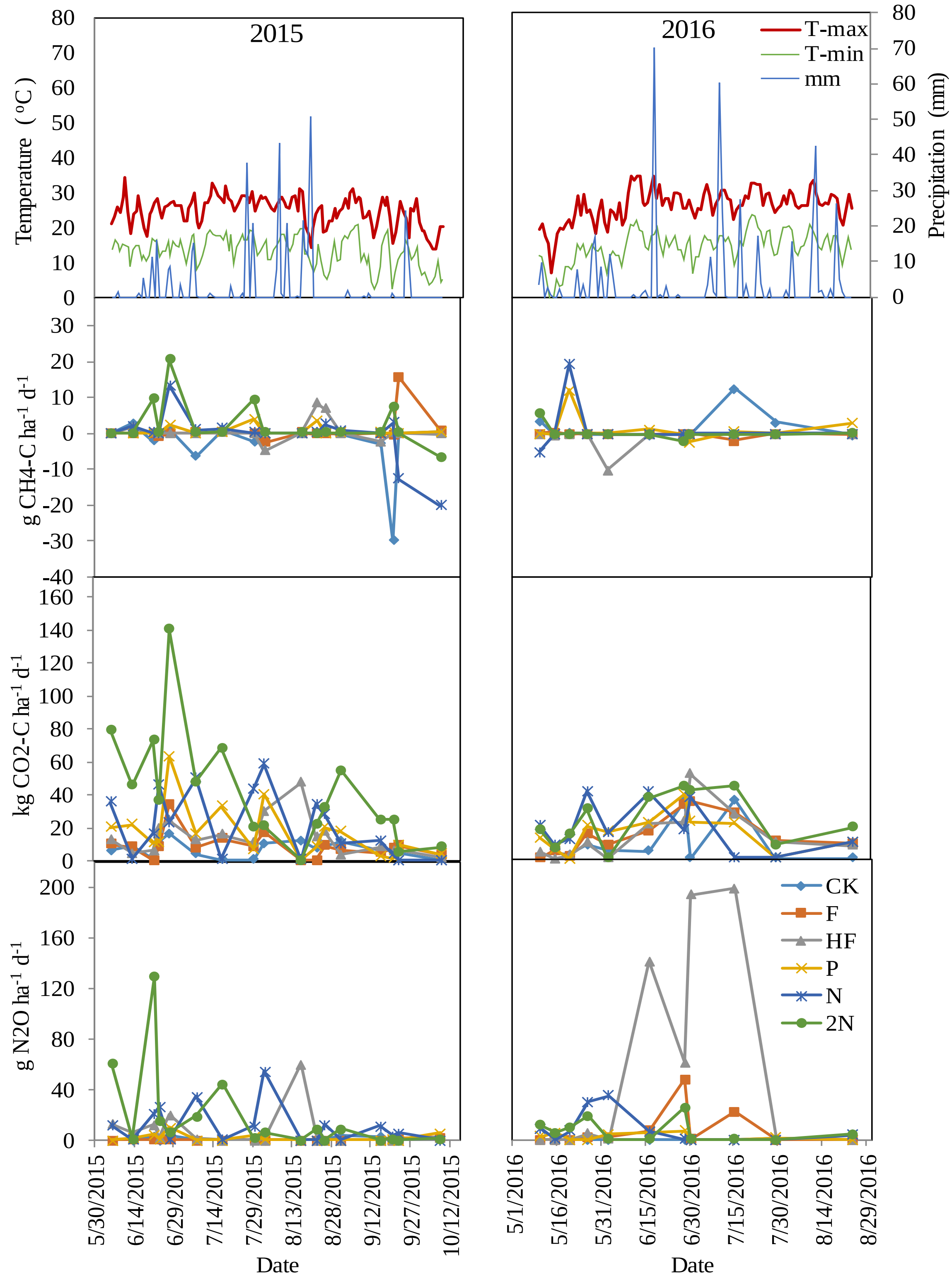

Figure 5.3 Daily average GHGs fluxes as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation and Climate at Brookings locations of South Dakota.

CHAPTER 6

CONCLUSIONS

The present study was conducted at two different sites of Eastern South Dakota to examine the long-term influences of cattle manure and inorganic fertilizers on selected soil quality indicators that include pH, EC, SOC, TN, and water stable aggerates, soil hydrological parameters, and soil surface GHG emissions that include methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) under corn-soybean rotation at two different long-term sites. The following conclusions can be drawn from this study:

Study 1 – Long-term annual livestock manure application impacts on selected soil quality indicators under a corn-soybean rotation in South Dakota.

(i) The application of manure did not impact soil pH, rather it maintained it as compared to that of control treatment. However, inorganic fertilizer decreased the soil pH as compared to manure and control treatments.

(ii) Manure application increased the SOC for all the soil depths at either site as compared to inorganic fertilizer and control treatments. A similar trend was observed for the TN, however, differences were not always significant. A similar trend was also observed for EC that showed manure increased the soil EC in comparison to inorganic fertilizer and control. In addition, a higher rate of manure application increased the soil EC.

(iii) In general, manure applications increased water stable aggregation (WAS), whereas, fertilizer application decreased the WAS.

It can be concluded from this study that the application of manure helped in improving the soil quality indicators as compared to that of inorganic fertilizer in corn-soybean cropping systems of South Dakota. However, future study is strongly encouraged to assess the economics and environmental impacts (water quality) associated with different application rates of manure on soils.

Study 2 – Response of long-term cattle manure application on soil hydrological properties under corn-soybean rotation of two locations in eastern South Dakota.

(i) The application of manure lowered the bulk density at 0-10 cm depth compared to fertilizer and control treatments.

(ii) Manure increased the water infiltration compared to that of inorganic fertilizer application treatment.

(iii) Manure tended increase to the soil water retention (SWR) compared to control at both sites, however, differences were not always significant.

(iv) Manure application increased micropores and fine mesopores at the Brookings site compared to that of other applications compared to control and fertilizer treatments. However, differences were not always statistically significant. Manure also increased the distribution of micropores and coarse mesopores at the Beresford site.

Study 3 – Response of surface GHG fluxes to long-term manure and inorganic fertilizer application in corn and soybean rotation.

(i) Results from this study showed that soil temperature and moisture impacted the soil surface GHG emissions.

(ii) The manure and fertilizer applications did not show significant impacts on CH_4 emissions as compared to that of control treatment.

(iii) Soil surface CO_2 emission was significantly impacted by manure application compared to that of inorganic fertilizer application and control treatments, whereas, there were not any significant impacts of inorganic fertilizer on CO_2 emissions.

(iv) Soil surface N_2O fluxes were impacted by both manure and inorganic fertilizer applications; however, inorganic fertilizer impacts were higher than manure especially in 2016.

Data from this study conclude that higher manure rate produce higher emissions, however, soil surface N_2O fluxes were higher with the inorganic fertilizer; therefore, manure as compared to inorganic fertilizer is an option for improving the soil organic matter content and lowering the GHG emissions.

APPENDICES AND SUPPORTING MATERIALS

SUPPORTING MATERIALS

S1. Mean Manure nutrient analysis, Average Treatments, and Nutrients applied at Brookings and Beresford, SD, 2003-2015.

Mean Manure nutrient analysis

Manure	**Moist**	**Total N**	**NH4-N**	**Organic-N**	**Avail N**	**P2O5**	**K2O**
	--%--	----------Kg/t----------					
Beef	21.9	10.6	1.3	9.3	5.6	8.5	9.9
Dairy	32.5	6	2.7	3.3	3.2	2.5	4.2

Average Treatments and Nutrients applied.

Sites	**CK**			**F**			**P**			**N**			**2N**			**HF**				
	Manure applied1 (ton/a)																			
Beresford	0			0			4.18			9.75			19.5			0				
Brookings	0			0			8.23			18.66			33.79			0				
	----------N-P2O5-K2O----------															-N-P2O5-K2O-Zn-S-				
Beresford	0	0	0	0	0	0	51	52	82	122	111	155	243	222	310	0	0	0	0	0
Brookings	0	0	0	0	0	0	90	30	39	131	56	93	261	111	187	0	0	0	0	0
	Fertilizer applied (lb/a)																			
	----------N-P2O5-K2O----------															-N-P2O5-K2O-Zn-S-				
Beresford	0	0	0	43	16	4	0	0	0	0	0	0	0	0	0	85	46	39	6	25
Brookings	0	0	0	41	19	23	0	0	0	0	0	0	0	0	0	75	60	71	7	25

S 2. Soil organic carbon (SOC, g kg^{-1}) for 0-10, 10-20, 20-30 and 30-40 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

Treatments	**Brookings**				**Beresford**			
	Depths (cm)							
Depths	**0-10**	**10-20**	**20-30**	**30-40**	**0-10**	**10-20**	**20-30**	**30-40**
	SOC (g kg^{-1})							
P[††]	27.57[c†]	21.52[cb]	16.54[cb]	11.31[b]	25.56[c]	20.28[b]	15.72[cb]	10.24[b]
N	30.89[b]	21.91[b]	17.83[b]	12.56[b]	29.07[b]	20.85[b]	17.82[b]	10.14[b]
2N	38.29[a]	22.79[a]	19.97[a]	16.80[a]	31.20[a]	24.81[a]	20.88[a]	15.62[a]
F	24.03[d]	21.62[cb]	16.08[c]	11.70[b]	22.22[d]	15.56[d]	13.75[c]	9.21[b]
HF	25.78[dc]	21.05[c]	15.74[c]	10.67[b]	23.64[d]	17.91[c]	13.45[c]	9.95[b]
CK	23.34[d]	21.19[c]	16.85[cb]	12.26[b]	22.90[d]	18.78[c]	15.98[cb]	10.40[b]
	Analysis of Variance ($P>F$)							
Treatment	<.0001	0.0003	0.0001	<.0001	<.0001	<.0001	0.0004	0.0003
P vs. 2N	<.0001	0.0006	0.0001	<.0001	<.0001	<.0001	0.0012	0.0001
Manure vs. Fertilizer	<.0001	0.0593	0.0002	0.0002	<.0001	<.0001	0.003	0.0158

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate; F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

S3. The soil C: N ratio for 0-10, 10-20, 20-30 and 30-40 cm depths as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Beresford and Brookings locations of South Dakota.

Treatments	**Brookings**				**Beresford**			
	--------Depths (cm)--------							
Depths	**0-10**	**10-20**	**20-30**	**30-40**	**0-10**	**10-20**	**20-30**	**30-40**
	-------- C:N Ratio --------							
P[††]	10.92[a†]	10.58[a]	10.17[a]	9.74[a]	10.21[a]	10.11[b]	9.35[b]	8.00[b]
N	11.07[a]	10.91[a]	11.14[a]	9.63[a]	10.52[a]	10.44[ba]	10.33[b]	7.79[b]
2N	11.11[a]	11.39[a]	12.50[a]	11.09[a]	9.87[a]	11.61[a]	13.11[a]	12.38[a]
F	10.47[a]	10.84[a]	9.70[a]	9.96[a]	9.99[a]	8.17[c]	8.39[b]	7.27[b]
HF	10.11[a]	10.73[a]	9.69[a]	9.12[a]	10.54[a]	9.38[bc]	8.22[b]	8.25[b]
CK	10.42[a]	10.98[a]	11.03[a]	9.85[a]	10.82[a]	10.21[b]	9.26[b]	7.76[b]
	Analysis of Variance (*P>F*)							
Treatment	0.4	0.7	0.3	0.6	0.1	0.001	0.001	0.002
P vs. 2N	0.7	0.1	0.1	0.2	0.3	0.03	0.95	0.0009
Manure vs. Fertilizer	0.09	0.5	0.1	0.2	0.6	0.0009	0.0004	0.06

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate; F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

S4. Global Warming Potential as influenced by long-term manure and inorganic fertilizer management under corn-soybean rotation at Brookings locations of South Dakota.

Treatments	**----CH4----**		**----CO2----**		**----N2O----**		**-Cumulative-**		**--Total--**
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	
	---(GWP CO_2-C kg ha^{-1} d^{-1})-------------------------------------								
P	0.26[a†]	0.40[a]	290[b]	172[bc]	8.96[a]	7.9[b]	299[b]	180[bc]	479[bc]
N	0.71[a]	0.35[a]	366[b]	205[ba]	58.41[a]	26.7[b]	425[b]	232[ba]	657[b]
2N	0.98[a]	0.15[a]	707[a]	266[a]	90.62[a]	22.4[b]	799[a]	288[ba]	1087[a]
F	0.32[a]	0.01[a]	151[b]	164[bc]	2.30[a]	23.9[b]	154[b]	188[bc]	341[bc]
HF	0.36[a]	0.002[a]	243[b]	157[bc]	34.87[a]	175.9[a]	278[b]	333[a]	611 [b]
CK	0.005[a]	0.45[a]	119[b]	99[c]	4.91[a]	0.4[b]	124[b]	99[c]	223[c]
						Analysis of variance			
Treatment	0.3	0.4	0.006	0.01	0.2	0.0003	0.007	0.005	0.002
P vs. 2N	0.1	0.4	0.007	0.03	0.04	0.6	0.006	0.053	0.003
Manure vs. Fertilizer	0.2	0.2	0.0004	0.1	0.09	0.006	0.0003	0.5	0.007

[†]Mean values followed by different lower letters between each treatment within each depth represent significant differences due to manure and inorganic fertilizer application at $P<0.05$.
[††]P, phosphorus based recommended manure; N, nitrogen based recommended manure; 2N, nitrogen based double of recommended manure application rate;F, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

APPENDIX 1

A1.1. Soil pH for 0-10 and 10-20 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

0-10 cm					10-20 cm				
Plot	**Location**	**REP**	**pH**	**TRT**	**Plot**	**Location**	**REP**	**pH**	**TRT**
101	BRK	1	7.33	CNT	101	BRK	1	7.39	CNT
201	BRK	2	6.89	CNT	201	BRK	2	7.14	CNT
301	BRK	3	6.81	CNT	301	BRK	3	6.96	CNT
401	BRK	4	6.39	CNT	401	BRK	4	6.92	CNT
102	BRK	1	7.24	F	102	BRK	1	7.17	F
202	BRK	2	6.63	F	202	BRK	2	6.73	F
302	BRK	3	6.73	F	302	BRK	3	7.21	F
402	BRK	4	6.05	F	402	BRK	4	6.47	F
103	BRK	1	7.14	P	103	BRK	1	7.13	P
203	BRK	2	6.9	P	203	BRK	2	6.83	P
303	BRK	3	7	P	303	BRK	3	7.13	P
403	BRK	4	6.6	P	403	BRK	4	6.79	P
104	BRK	1	7.1	N	104	BRK	1	7.2	N
204	BRK	2	6.97	N	204	BRK	2	6.91	N
304	BRK	3	6.8	N	304	BRK	3	6.99	N
404	BRK	4	6.71	N	404	BRK	4	6.75	N
105	BRK	1	7.16	2N	105	BRK	1	7.35	2N
205	BRK	2	7.07	2N	205	BRK	2	7.03	2N
305	BRK	3	7	2N	305	BRK	3	6.92	2N
405	BRK	4	6.96	2N	405	BRK	4	6.85	2N
106	BRK	1	6.96	HF	106	BRK	1	7.25	HF
206	BRK	2	6.49	HF	206	BRK	2	7.14	HF
306	BRK	3	6.23	HF	306	BRK	3	6.72	HF
406	BRK	4	5.84	HF	406	BRK	4	6.75	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.2. Soil pH for 20-30 and 30-40 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

20-30 cm					30-40 cm				
Plot	**Location**	**REP**	**pH**	**TRT**	**Plot**	**Location**	**REP**	**pH**	**TRT**
101	BRK	1	7.61	CNT	101	BRK	1	7.6	CNT
201	BRK	2	7.3	CNT	201	BRK	2	7.5	CNT
301	BRK	3	7.16	CNT	301	BRK	3	7.53	CNT
401	BRK	4	7.11	CNT	401	BRK	4	7.44	CNT
102	BRK	1	7.24	F	102	BRK	1	7.47	F
202	BRK	2	7.27	F	202	BRK	2	7.61	F
302	BRK	3	7.34	F	302	BRK	3	7.71	F
402	BRK	4	7.2	F	402	BRK	4	7.66	F
103	BRK	1	7.29	P	103	BRK	1	7.66	P
203	BRK	2	7.19	P	203	BRK	2	7.47	P
303	BRK	3	7.37	P	303	BRK	3	7.68	P
403	BRK	4	7.15	P	403	BRK	4	7.48	P
104	BRK	1	7.26	N	104	BRK	1	7.45	N
204	BRK	2	7.43	N	204	BRK	2	7.3	N
304	BRK	3	7.1	N	304	BRK	3	7.54	N
404	BRK	4	7.22	N	404	BRK	4	7.47	N
105	BRK	1	7.61	2N	105	BRK	1	7.72	2N
205	BRK	2	7.25	2N	205	BRK	2	7.51	2N
305	BRK	3	7.15	2N	305	BRK	3	7.54	2N
405	BRK	4	7.16	2N	405	BRK	4	7.39	2N
106	BRK	1	7.5	HF	106	BRK	1	7.66	HF
206	BRK	2	7.47	HF	206	BRK	2	7.62	HF
306	BRK	3	7.06	HF	306	BRK	3	7.41	HF
406	BRK	4	7.24	HF	406	BRK	4	7.56	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.3. Soil pH for 0-10 and 10-20 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

0-10 cm					10-20 cm				
Plot	**Location**	**REP**	**pH**	**TRT**	**Plot**	**Location**	**REP**	**pH**	**TRT**
101	SE	1	5.93	CNT	101	SE	1	5.24	CNT
201	SE	2	5.61	CNT	201	SE	2	5.35	CNT
301	SE	3	6.1	CNT	301	SE	3	5.54	CNT
401	SE	4	7.43	CNT	401	SE	4	7.31	CNT
102	SE	1	5.36	F	102	SE	1	5.52	F
202	SE	2	5.16	F	202	SE	2	5.36	F
302	SE	3	6.02	F	302	SE	3	5.62	F
402	SE	4	6.51	F	402	SE	4	5.84	F
103	SE	1	6.55	P	103	SE	1	5.13	P
203	SE	2	6.73	P	203	SE	2	5.83	P
303	SE	3	7.27	P	303	SE	3	7.19	P
403	SE	4	6.94	P	403	SE	4	5.8	P
104	SE	1	6.66	N	104	SE	1	5.46	N
204	SE	2	6.95	N	204	SE	2	5.93	N
304	SE	3	7.05	N	304	SE	3	6.78	N
404	SE	4	7.12	N	404	SE	4	6.78	N
105	SE	1	6.96	2N	105	SE	1	6.24	2N
205	SE	2	6.99	2N	205	SE	2	6.91	2N
305	SE	3	7.06	2N	305	SE	3	6.84	2N
405	SE	4	7.05	2N	405	SE	4	6.99	2N
106	SE	1	4.79	HF	106	SE	1	5.32	HF
206	SE	2	5.09	HF	206	SE	2	5.46	HF
306	SE	3	6.08	HF	306	SE	3	6.88	HF
406	SE	4	6.07	HF	406	SE	4	5.96	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.4. Soil pH for 20-30 and 30-40 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

20-30 cm					30-40 cm				
Plot	**Location**	**REP**	**pH**	**TRT**	**Plot**	**Location**	**REP**	**pH**	**TRT**
101	SE	1	5.49	CNT	101	SE	1	5.82	CNT
201	SE	2	5.57	CNT	201	SE	2	5.83	CNT
301	SE	3	5.89	CNT	301	SE	3	6.25	CNT
401	SE	4	7.18	CNT	401	SE	4	7.32	CNT
102	SE	1	5.81	F	102	SE	1	6.08	F
202	SE	2	5.92	F	202	SE	2	6.24	F
302	SE	3	6.06	F	302	SE	3	6.46	F
402	SE	4	6.27	F	402	SE	4	6.48	F
103	SE	1	5.59	P	103	SE	1	5.97	P
203	SE	2	6.2	P	203	SE	2	6.48	P
303	SE	3	7.13	P	303	SE	3	7.11	P
403	SE	4	6.36	P	403	SE	4	7.12	P
104	SE	1	5.8	N	104	SE	1	6.1	N
204	SE	2	6.16	N	204	SE	2	6.4	N
304	SE	3	6.5	N	304	SE	3	6.77	N
404	SE	4	6.88	N	404	SE	4	7.02	N
105	SE	1	5.76	2N	105	SE	1	6.32	2N
205	SE	2	6.26	2N	205	SE	2	6.26	2N
305	SE	3	6.61	2N	305	SE	3	6.92	2N
405	SE	4	6.96	2N	405	SE	4	7.4	2N
106	SE	1	5.84	HF	106	SE	1	6.06	HF
206	SE	2	5.66	HF	206	SE	2	6.16	HF
306	SE	3	6.98	HF	306	SE	3	7.41	HF
406	SE	4	6.7	HF	406	SE	4	7.28	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.5. Soil Electrical Conductivity (µS/cm) for 0-10 and 10-20 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

0-10 cm					**10-20 cm**				
Plot	**Location**	**REP**	**EC**	**TRT**	**Plot**	**Location**	**REP**	**EC**	**TRT**
101	BRK	1	878.2	CNT	101	BRK	1	662.4	CNT
201	BRK	2	727.5	CNT	201	BRK	2	602.7	CNT
301	BRK	3	760.8	CNT	301	BRK	3	619.1	CNT
401	BRK	4	508.7	CNT	401	BRK	4	579	CNT
102	BRK	1	876	F	102	BRK	1	613.9	F
202	BRK	2	722.4	F	202	BRK	2	564.3	F
302	BRK	3	1011	F	302	BRK	3	690	F
402	BRK	4	405.4	F	402	BRK	4	432.8	F
103	BRK	1	1254	P	103	BRK	1	794.8	P
203	BRK	2	1110	P	203	BRK	2	691.9	P
303	BRK	3	1225	P	303	BRK	3	768	P
403	BRK	4	1007	P	403	BRK	4	683.2	P
104	BRK	1	2191	N	104	BRK	1	1179	N
204	BRK	2	1384	N	204	BRK	2	778.2	N
304	BRK	3	1430	N	304	BRK	3	795.6	N
404	BRK	4	1028	N	404	BRK	4	560.2	N
105	BRK	1	2314	2N	105	BRK	1	1237	2N
205	BRK	2	2400	2N	205	BRK	2	1244	2N
305	BRK	3	1772	2N	305	BRK	3	1151	2N
405	BRK	4	1552	2N	405	BRK	4	678.4	2N
106	BRK	1	955	HF	106	BRK	1	639.8	HF
206	BRK	2	670.1	HF	206	BRK	2	685.6	HF
306	BRK	3	602.1	HF	306	BRK	3	540.1	HF
406	BRK	4	418.9	HF	406	BRK	4	532.2	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.6. Soil Electrical Conductivity (µS/cm) for 20-30 and 30-40 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

20-30 cm					**30-40 cm**				
Plot	**Location**	**REP**	**EC**	**TRT**	**Plot**	**Location**	**REP**	**EC**	**TRT**
101	BRK	1	705.6	CNT	101	BRK	1	693.6	CNT
201	BRK	2	584.8	CNT	201	BRK	2	697.7	CNT
301	BRK	3	628.8	CNT	301	BRK	3	704.8	CNT
401	BRK	4	567.2	CNT	401	BRK	4	571.4	CNT
102	BRK	1	688	F	102	BRK	1	618.9	F
202	BRK	2	647.3	F	202	BRK	2	653.2	F
302	BRK	3	707	F	302	BRK	3	762.5	F
402	BRK	4	563.4	F	402	BRK	4	578.2	F
103	BRK	1	824	P	103	BRK	1	862.9	P
203	BRK	2	711.4	P	203	BRK	2	685	P
303	BRK	3	747.7	P	303	BRK	3	764.3	P
403	BRK	4	667.3	P	403	BRK	4	683.2	P
104	BRK	1	914	N	104	BRK	1	852.2	N
204	BRK	2	752.8	N	204	BRK	2	673.7	N
304	BRK	3	711.8	N	304	BRK	3	850.3	N
404	BRK	4	752.2	N	404	BRK	4	732.8	N
105	BRK	1	1022	2N	105	BRK	1	994.1	2N
205	BRK	2	1136	2N	205	BRK	2	854.8	2N
305	BRK	3	1087	2N	305	BRK	3	953.97	2N
405	BRK	4	1001	2N	405	BRK	4	1013	2N
106	BRK	1	668.5	HF	106	BRK	1	719.3	HF
206	BRK	2	762.2	HF	206	BRK	2	738.6	HF
306	BRK	3	571	HF	306	BRK	3	750.8	HF
406	BRK	4	523.5	HF	406	BRK	4	736.23	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.7. Soil Electrical Conductivity (µS/cm) for 0-10 and 10-20 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

0-10 cm					**10-20 cm**				
Plot	**Location**	**REP**	**EC**	**TRT**	**Plot**	**Location**	**REP**	**EC**	**TRT**
101	SE	1	396.8	CNT	101	SE	1	144.6	CNT
201	SE	2	252.8	CNT	201	SE	2	133.1	CNT
301	SE	3	344.2	CNT	301	SE	3	169.3	CNT
401	SE	4	753.9	CNT	401	SE	4	613.7	CNT
102	SE	1	246.2	F	102	SE	1	189.2	F
202	SE	2	178.1	F	202	SE	2	135.4	F
302	SE	3	362.2	F	302	SE	3	170.4	F
402	SE	4	498.1	F	402	SE	4	236	F
103	SE	1	729.8	P	103	SE	1	231.5	P
203	SE	2	810.4	P	203	SE	2	242.9	P
303	SE	3	770	P	303	SE	3	683.6	P
403	SE	4	761.3	P	403	SE	4	317.2	P
104	SE	1	774.2	N	104	SE	1	252.8	N
204	SE	2	888.5	N	204	SE	2	333.7	N
304	SE	3	1100	N	304	SE	3	728.8	N
404	SE	4	973.7	N	404	SE	4	596.3	N
105	SE	1	977.6	2N	105	SE	1	560.8	2N
205	SE	2	1103	2N	205	SE	2	839.2	2N
305	SE	3	1114	2N	305	SE	3	829.7	2N
405	SE	4	1136	2N	405	SE	4	767.9	2N
106	SE	1	281.7	HF	106	SE	1	210.7	HF
206	SE	2	268	HF	206	SE	2	215.3	HF
306	SE	3	403.5	HF	306	SE	3	536.7	HF
406	SE	4	483	HF	406	SE	4	265.5	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.8. Soil Electrical Conductivity (µS/cm) for 20-30 and 30-40 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

20-30 cm					30-40 cm				
Plot	**Location**	**REP**	**EC**	**TRT**	**Plot**	**Location**	**REP**	**EC**	**TRT**
101	SE	1	116	CNT	101	SE	1	144.7	CNT
201	SE	2	126.3	CNT	201	SE	2	153.7	CNT
301	SE	3	169.4	CNT	301	SE	3	227.9	CNT
401	SE	4	549.4	CNT	401	SE	4	662.4	CNT
102	SE	1	176.2	F	102	SE	1	159.9	F
202	SE	2	24.9	F	202	SE	2	236.6	F
302	SE	3	272.6	F	302	SE	3	283.1	F
402	SE	4	260.8	F	402	SE	4	294.7	F
103	SE	1	184.1	P	103	SE	1	236	P
203	SE	2	309.5	P	203	SE	2	331.6	P
303	SE	3	605.7	P	303	SE	3	518.7	P
403	SE	4	370.2	P	403	SE	4	718.7	P
104	SE	1	300.3	N	104	SE	1	278.6	N
204	SE	2	312.8	N	204	SE	2	366.2	N
304	SE	3	501.4	N	304	SE	3	498.1	N
404	SE	4	577.7	N	404	SE	4	492.4	N
105	SE	1	337.2	2N	105	SE	1	388.4	2N
205	SE	2	514	2N	205	SE	2	467.7	2N
305	SE	3	623.7	2N	305	SE	3	706.7	2N
405	SE	4	613.1	2N	405	SE	4	771.4	2N
106	SE	1	249.7	HF	106	SE	1	359.1	HF
206	SE	2	214.8	HF	206	SE	2	255.1	HF
306	SE	3	506.9	HF	306	SE	3	623.8	HF
406	SE	4	659.9	HF	406	SE	4	677.2	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.9. Soil Total Nitrogen (gr kg^{-1}) for 0-10 and 10-20 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

0-10 cm					10-20 cm				
Plot	**Location**	**REP**	**TN**	**TRT**	**Plot**	**Location**	**REP**	**TN**	**TRT**
101	BRK	1	2.1643	CNT	101	BRK	1	1.8344	CNT
201	BRK	2	2.3525	CNT	201	BRK	2	2.0397	CNT
301	BRK	3	2.2781	CNT	301	BRK	3	1.9508	CNT
401	BRK	4	2.1674	CNT	401	BRK	4	1.9028	CNT
102	BRK	1	2.2237	F	102	BRK	1	2.0179	F
202	BRK	2	2.3572	F	202	BRK	2	2.0982	F
302	BRK	3	2.4533	F	302	BRK	3	1.9676	F
402	BRK	4	2.1666	F	402	BRK	4	1.9011	F
103	BRK	1	2.5269	P	103	BRK	1	2.0706	P
203	BRK	2	2.5603	P	203	BRK	2	2.1337	P
303	BRK	3	2.5577	P	303	BRK	3	1.9864	P
403	BRK	4	2.4531	P	403	BRK	4	1.9609	P
104	BRK	1	3.3434	N	104	BRK	1	2.0864	N
204	BRK	2	2.5384	N	204	BRK	2	1.9747	N
304	BRK	3	2.7503	N	304	BRK	3	2.0197	N
404	BRK	4	2.5763	N	404	BRK	4	1.9619	N
105	BRK	1	3.7983	2N	105	BRK	1	2.2158	2N
205	BRK	2	3.7735	2N	205	BRK	2	1.6362	2N
305	BRK	3	3.2551	2N	305	BRK	3	2.2099	2N
405	BRK	4	2.9858	2N	405	BRK	4	2.0607	2N
106	BRK	1	2.4868	HF	106	BRK	1	1.9522	HF
206	BRK	2	3.5391	HF	206	BRK	2	1.9125	HF
306	BRK	3	2.3186	HF	306	BRK	3	2.0639	HF
406	BRK	4	2.2017	HF	406	BRK	4	1.9265	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.10 Soil Total Nitrogen (gr kg^{-1}) for 20-30 and 30-40 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

20-30 cm					30-40 cm				
Plot	**Location**	**REP**	**TN**	**TRT**	**Plot**	**Location**	**REP**	**TN**	**TRT**
101	BRK	1	1.2668	CNT	101	BRK	1	1.2571	CNT
201	BRK	2	1.6957	CNT	201	BRK	2	1.3464	CNT
301	BRK	3	1.7172	CNT	301	BRK	3	1.2678	CNT
401	BRK	4	1.5033	CNT	401	BRK	4	1.0958	CNT
102	BRK	1	1.756	F	102	BRK	1	1.0524	F
202	BRK	2	1.7434	F	202	BRK	2	1.223	F
302	BRK	3	1.787	F	302	BRK	3	1.2996	F
402	BRK	4	1.4293	F	402	BRK	4	1.1	F
103	BRK	1	1.5441	P	103	BRK	1	1.0782	P
203	BRK	2	1.7505	P	203	BRK	2	1.359	P
303	BRK	3	1.5792	P	303	BRK	3	1.1575	P
403	BRK	4	1.6473	P	403	BRK	4	1.0776	P
104	BRK	1	1.7295	N	104	BRK	1	1.2038	N
204	BRK	2	1.336	N	204	BRK	2	1.4133	N
304	BRK	3	1.7559	N	304	BRK	3	1.3806	N
404	BRK	4	1.6562	N	404	BRK	4	1.1964	N
105	BRK	1	1.5174	2N	105	BRK	1	1.1112	2N
205	BRK	2	1.166	2N	205	BRK	2	2.2642	2N
305	BRK	3	2.0399	2N	305	BRK	3		2N
405	BRK	4	1.9261	2N	405	BRK	4	1.4557	2N
106	BRK	1	1.6436	HF	106	BRK	1	1.1455	HF
206	BRK	2	1.5158	HF	206	BRK	2	1.1262	HF
306	BRK	3	1.9202	HF	306	BRK	3	1.3633	HF
406	BRK	4	1.4682	HF	406	BRK	4	1.1001	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.11. Soil Total Nitrogen (gr kg^{-1}) for 0-10 and 10-20 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

0-10 cm					10-20 cm				
Plot	**Location**	**REP**	**TN**	**TRT**	**Plot**	**Location**	**REP**	**TN**	**TRT**
101	SE	1	2.2008	CNT	101	SE	1	1.9938	CNT
201	SE	2	2.1974	CNT	201	SE	2	1.9097	CNT
301	SE	3	2.127	CNT	301	SE	3	1.8219	CNT
401	SE	4	1.946	CNT	401	SE	4	1.6608	CNT
102	SE	1	2.3903	F	102	SE	1	2.1507	F
202	SE	2	2.1052	F	202	SE	2	1.887	F
302	SE	3	2.2144	F	302	SE	3	1.7853	F
402	SE	4	2.2113	F	402	SE	4	1.8354	F
103	SE	1	2.7023	P	103	SE	1	2.126	P
203	SE	2	2.4753	P	203	SE	2	1.9374	P
303	SE	3	2.4666	P	303	SE	3	1.9558	P
403	SE	4	2.3514	P	403	SE	4	2.0046	P
104	SE	1	2.7315	N	104	SE	1	2.0681	N
204	SE	2	2.7697	N	204	SE	2	2.0207	N
304	SE	3	2.7898	N	304	SE	3	2.0754	N
404	SE	4	2.7633	N	404	SE	4	1.8416	N
105	SE	1	3.0016	2N	105	SE	1	2.3908	2N
205	SE	2	3.4838	2N	205	SE	2	2.4504	2N
305	SE	3	3.0108	2N	305	SE	3	1.8575	2N
405	SE	4	3.2015	2N	405	SE	4	1.9749	2N
106	SE	1	2.3522	HF	106	SE	1	2.0636	HF
206	SE	2	2.2439	HF	206	SE	2	1.984	HF
306	SE	3	2.0612	HF	306	SE	3	1.6315	HF
406	SE	4	2.2079	HF	406	SE	4	2.0025	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.12. Soil Total Nitrogen (gr kg^{-1}) for 20-30 and 30-40 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

20-30 cm					**30-40 cm**				
Plot	**Location**	**REP**	**TN**	**TRT**	**Plot**	**Location**	**REP**	**TN**	**TRT**
101	SE	1	1.9438	CNT	101	SE	1	1.7062	CNT
201	SE	2	1.7825	CNT	201	SE	2	1.2859	CNT
301	SE	3	1.5214	CNT	301	SE	3	1.0897	CNT
401	SE	4	1.6415	CNT	401	SE	4	1.3427	CNT
102	SE	1	1.9272	F	102	SE	1	1.6669	F
202	SE	2	1.7558	F	202	SE	2	1.3239	F
302	SE	3	1.3183	F	302	SE	3	1.0784	F
402	SE	4	1.5955	F	402	SE	4	1.076	F
103	SE	1	2.1201	P	103	SE	1	1.7644	P
203	SE	2	1.5651	P	203	SE	2	1.1703	P
303	SE	3	1.687	P	303	SE	3	1.1525	P
403	SE	4	1.4697	P	403	SE	4	1.1928	P
104	SE	1	2.0293	N	104	SE	1	1.8147	N
204	SE	2	1.5999	N	204	SE	2	1.2199	N
304	SE	3	1.7952	N	304	SE	3	1.2386	N
404	SE	4	1.4933	N	404	SE	4	1.1034	N
105	SE	1	2.053	2N	105	SE	1	1.584	2N
205	SE	2	2.0979	2N	205	SE	2	1.7509	2N
305	SE	3	1.3721	2N	305	SE	3	1.0374	2N
405	SE	4	1.2198	2N	405	SE	4	0.9941	2N
106	SE	1	1.8275	HF	106	SE	1	1.5301	HF
206	SE	2	1.7062	HF	206	SE	2	1.2418	HF
306	SE	3	1.3248	HF	306	SE	3	0.9492	HF
406	SE	4	1.7371	HF	406	SE	4	1.1792	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.13. Soil Wet Aggregate Stability (%) for 0-10 and 10-20 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

0-10 cm					**10-20 cm**				
Plot	**Location**	**REP**	**WAS**	**TRT**	**Plot**	**Location**	**REP**	**WAS**	**TRT**
101	BRK	1	89.97	CNT	101	BRK	1	82.95	CNT
201	BRK	2	89.62	CNT	201	BRK	2	92.48	CNT
301	BRK	3	91.01	CNT	301	BRK	3	92.75	CNT
401	BRK	4	89.82	CNT	401	BRK	4	93.45	CNT
102	BRK	1	92.37	F	102	BRK	1	85.13	F
202	BRK	2	82.13	F	202	BRK	2	95.27	F
302	BRK	3	92.03	F	302	BRK	3	91.01	F
402	BRK	4	90.34	F	402	BRK	4	85.02	F
103	BRK	1	97.52	P	103	BRK	1	98.97	P
203	BRK	2	95.27	P	203	BRK	2	97.86	P
303	BRK	3	88.96	P	303	BRK	3	86.24	P
403	BRK	4	85.86	P	403	BRK	4	77.41	P
104	BRK	1	94.12	N	104	BRK	1	95.41	N
204	BRK	2	98.85	N	204	BRK	2	98.52	N
304	BRK	3	88.93	N	304	BRK	3	86.14	N
404	BRK	4	92.16	N	404	BRK	4	89.04	N
105	BRK	1	97.40	2N	105	BRK	1	98.07	2N
205	BRK	2	99.64	2N	205	BRK	2	95.54	2N
305	BRK	3	99.61	2N	305	BRK	3	89.01	2N
405	BRK	4	97.70	2N	405	BRK	4	86.99	2N
106	BRK	1	85.81	HF	106	BRK	1	79.77	HF
206	BRK	2	85.71	HF	206	BRK	2	81.43	HF
306	BRK	3	88.15	HF	306	BRK	3	89.93	HF
406	BRK	4	89.87	HF	406	BRK	4	87.10	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.14. Soil Wet Aggregate Stability (%) for 0-10 and 10-20 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

0-10 cm					**10-20 cm**				
Plot	**Location**	**REP**	**WAS**	**TRT**	**Plot**	**Location**	**REP**	**WAS**	**TRT**
101	SE	1	92.98	CNT	101	SE	1	90.30	CNT
201	SE	2	92.33	CNT	201	SE	2	91.12	CNT
301	SE	3	91.59	CNT	301	SE	3	89.42	CNT
401	SE	4	92.76	CNT	401	SE	4	91.23	CNT
102	SE	1	93.10	F	102	SE	1	87.11	F
202	SE	2	89.33	F	202	SE	2	93.63	F
302	SE	3	88.70	F	302	SE	3	85.37	F
402	SE	4	86.31	F	402	SE	4	90.68	F
103	SE	1	94.16	P	103	SE	1	92.88	P
203	SE	2	87.95	P	203	SE	2	91.53	P
303	SE	3	95.05	P	303	SE	3	91.87	P
403	SE	4	94.30	P	403	SE	4	92.98	P
104	SE	1	93.43	N	104	SE	1	94.30	N
204	SE	2	95.72	N	204	SE	2	92.75	N
304	SE	3	95.90	N	304	SE	3	87.87	N
404	SE	4	88.14	N	404	SE	4	93.67	N
105	SE	1	94.53	2N	105	SE	1	93.95	2N
205	SE	2	97.18	2N	205	SE	2	93.12	2N
305	SE	3	96.59	2N	305	SE	3	92.98	2N
405	SE	4	98.64	2N	405	SE	4	91.35	2N
106	SE	1	89.07	HF	106	SE	1	85.62	HF
206	SE	2	91.28	HF	206	SE	2	88.71	HF
306	SE	3	89.97	HF	306	SE	3	90.00	HF
406	SE	4	86.25	HF	406	SE	4	91.37	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.15. Soil Organic carbon (g kg^{-1}) for 0-10 and 10-20 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

0-10 cm					10-20 cm				
Plot	**Location**	**REP**	**SOC**	**TRT**	**Plot**	**Location**	**REP**	**SOC**	**TRT**
101	BRK	1	22.86	CNT	101	BRK	1	20.00	CNT
201	BRK	2	24.34	CNT	201	BRK	2	21.45	CNT
301	BRK	3	22.74	CNT	301	BRK	3	21.54	CNT
401	BRK	4	23.42	CNT	401	BRK	4	21.78	CNT
102	BRK	1	22.93	F	102	BRK	1	21.28	F
202	BRK	2	24.76	F	202	BRK	2	21.89	F
302	BRK	3	27.85	F	302	BRK	3	21.95	F
402	BRK	4	24.39	F	402	BRK	4	21.35	F
103	BRK	1	27.18	P	103	BRK	1	21.27	P
203	BRK	2	27.29	P	203	BRK	2	21.43	P
303	BRK	3	29.00	P	303	BRK	3	21.79	P
403	BRK	4	26.82	P	403	BRK	4	21.61	P
104	BRK	1	34.74	N	104	BRK	1	21.49	N
204	BRK	2	28.69	N	204	BRK	2	22.28	N
304	BRK	3	31.06	N	304	BRK	3	22.03	N
404	BRK	4	29.06	N	404	BRK	4	21.86	N
105	BRK	1	40.84	2N	105	BRK	1	23.17	2N
205	BRK	2	41.79	2N	205	BRK	2	19.28	2N
305	BRK	3	36.25	2N	305	BRK	3	22.04	2N
405	BRK	4	34.29	2N	405	BRK	4	23.15	2N
106	BRK	1	26.48	HF	106	BRK	1	20.79	HF
206	BRK	2	40.79	HF	206	BRK	2	21.20	HF
306	BRK	3	25.94	HF	306	BRK	3	22.12	HF
406	BRK	4	24.93	HF	406	BRK	4	21.15	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.16. Soil Organic carbon (g kg^{-1}) for 20-30 and 30-40 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

20-30 cm					30-40 cm				
Plot	**Location**	**REP**	**SOC**	**TRT**	**Plot**	**Location**	**REP**	**SOC**	**TRT**
101	BRK	1	16.14	CNT	101	BRK	1	12.35	CNT
201	BRK	2	15.84	CNT	201	BRK	2	13.08	CNT
301	BRK	3	18.58	CNT	301	BRK	3	13.32	CNT
401	BRK	4	16.86	CNT	401	BRK	4	10.27	CNT
102	BRK	1	17.84	F	102	BRK	1	10.39	F
202	BRK	2	17.75	F	202	BRK	2	11.79	F
302	BRK	3	13.77	F	302	BRK	3	14.75	F
402	BRK	4	14.93	F	402	BRK	4	9.86	F
103	BRK	1	14.83	P	103	BRK	1	11.57	P
203	BRK	2	18.32	P	203	BRK	2	11.69	P
303	BRK	3	15.92	P	303	BRK	3	11.64	P
403	BRK	4	17.07	P	403	BRK	4	10.33	P
104	BRK	1	16.84	N	104	BRK	1	10.39	N
204	BRK	2	14.22	N	204	BRK	2	14.61	N
304	BRK	3	19.04	N	304	BRK	3	14.01	N
404	BRK	4	17.61	N	404	BRK	4	11.23	N
105	BRK	1	17.09	2N	105	BRK	1	16.67	2N
205	BRK	2	11.84	2N	205	BRK	2	25.25	2N
305	BRK	3	21.18	2N	305	BRK	3	0.00	2N
405	BRK	4	21.64	2N	405	BRK	4	14.82	2N
106	BRK	1	15.75	HF	106	BRK	1	11.94	HF
206	BRK	2	16.36	HF	206	BRK	2	14.83	HF
306	BRK	3	20.21	HF	306	BRK	3	9.54	HF
406	BRK	4	15.10	HF	406	BRK	4	10.53	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.17. Soil Organic carbon (g kg^{-1}) for 0-10 and 10-20 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

0-10 cm					**10-20 cm**				
Plot	**Location**	**REP**	**SOC**	**TRT**	**Plot**	**Location**	**REP**	**SOC**	**TRT**
101	SE	1	23.77	CNT	101	SE	1	21.69	CNT
201	SE	2	23.89	CNT	201	SE	2	19.62	CNT
301	SE	3	22.08	CNT	301	SE	3	18.06	CNT
401	SE	4	21.86	CNT	401	SE	4	18.65	CNT
102	SE	1	25.52	F	102	SE	1	22.67	F
202	SE	2	22.67	F	202	SE	2	14.59	F
302	SE	3	23.11	F	302	SE	3	17.47	F
402	SE	4	20.88	F	402	SE	4	16.54	F
103	SE	1	28.79	P	103	SE	1	22.36	P
203	SE	2	25.37	P	203	SE	2	19.40	P
303	SE	3	25.53	P	303	SE	3	20.62	P
403	SE	4	22.55	P	403	SE	4	18.74	P
104	SE	1	29.12	N	104	SE	1	21.61	N
204	SE	2	28.15	N	204	SE	2	20.01	N
304	SE	3	29.35	N	304	SE	3	20.94	N
404	SE	4	29.66	N	404	SE	4	15.79	N
105	SE	1	31.47	2N	105	SE	1	24.85	2N
205	SE	2	36.29	2N	205	SE	2	24.77	2N
305	SE	3	31.29	2N	305	SE	3	19.14	2N
405	SE	4	30.85	2N	405	SE	4	17.40	2N
106	SE	1	25.89	HF	106	SE	1	21.85	HF
206	SE	2	23.96	HF	206	SE	2	19.81	HF
306	SE	3	21.56	HF	306	SE	3	16.83	HF
406	SE	4	23.16	HF	406	SE	4	17.72	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A1.18. Soil Organic carbon (g kg^{-1}) for 20-30 and 30-40 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

20-30 cm					30-40 cm				
Plot	**Location**	**REP**	**SOC**	**TRT**	**Plot**	**Location**	**REP**	**SOC**	**TRT**
101	SE	1	17.96	CNT	101	SE	1	17.51	CNT
201	SE	2	17.29	CNT	201	SE	2	11.32	CNT
301	SE	3	13.60	CNT	301	SE	3	7.72	CNT
401	SE	4	15.07	CNT	401	SE	4	12.17	CNT
102	SE	1	19.74	F	102	SE	1	15.94	F
202	SE	2	16.84	F	202	SE	2	12.28	F
302	SE	3	11.62	F	302	SE	3	7.95	F
402	SE	4	12.77	F	402	SE	4	7.41	F
103	SE	1	22.44	P	103	SE	1	18.27	P
203	SE	2	14.34	P	203	SE	2	9.25	P
303	SE	3	17.11	P	303	SE	3	9.96	P
403	SE	4	12.68	P	403	SE	4	11.53	P
104	SE	1	21.22	N	104	SE	1	18.12	N
204	SE	2	14.44	N	204	SE	2	9.71	N
304	SE	3	17.80	N	304	SE	3	11.69	N
404	SE	4	11.96	N	404	SE	4	9.04	N
105	SE	1	20.53	2N	105	SE	1	14.27	2N
205	SE	2	21.23	2N	205	SE	2	16.96	2N
305	SE	3	12.26	2N	305	SE	3	8.13	2N
405	SE	4	8.36	2N	405	SE	4	7.91	2N
106	SE	1	20.43	HF	106	SE	1	16.81	HF
206	SE	2	17.05	HF	206	SE	2	10.97	HF
306	SE	3	12.05	HF	306	SE	3	8.08	HF
406	SE	4	14.85	HF	406	SE	4	10.78	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

APPENDIX 2

A2.1. Soil Bulk Density (gr cm^{-1}) for 0-10 and 10-20 cm depths in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

0-10 cm					10-20 cm				
Plot	**Location**	**REP**	**BD**	**TRT**	**Plot**	**Location**	**REP**	**BD**	**TRT**
101	BRK	1	1.37	CNT	101	BRK	1	1.40	CNT
201	BRK	2	1.24	CNT	201	BRK	2	1.33	CNT
301	BRK	3	1.29	CNT	301	BRK	3	1.41	CNT
401	BRK	4	1.25	CNT	401	BRK	4	1.37	CNT
102	BRK	1	1.21	F	102	BRK	1	1.38	F
202	BRK	2	1.36	F	202	BRK	2	1.32	F
302	BRK	3	1.27	F	302	BRK	3	1.38	F
402	BRK	4	1.23	F	402	BRK	4	1.36	F
103	BRK	1	1.10	P	103	BRK	1	1.30	P
203	BRK	2	1.14	P	203	BRK	2	1.33	P
303	BRK	3	1.13	P	303	BRK	3	1.37	P
403	BRK	4	1.15	P	403	BRK	4	1.33	P
104	BRK	1	0.88	N	104	BRK	1	1.32	N
204	BRK	2	1.14	N	204	BRK	2	1.26	N
304	BRK	3	1.11	N	304	BRK	3	1.31	N
404	BRK	4	1.14	N	404	BRK	4	1.29	N
105	BRK	1	0.82	2N	105	BRK	1	1.21	2N
205	BRK	2	0.84	2N	205	BRK	2	1.14	2N
305	BRK	3	0.90	2N	305	BRK	3	1.25	2N
405	BRK	4	0.91	2N	405	BRK	4	1.25	2N
106	BRK	1	1.21	HF	106	BRK	1	1.22	HF
206	BRK	2	1.33	HF	206	BRK	2	1.30	HF
306	BRK	3	1.20	HF	306	BRK	3	1.37	HF
406	BRK	4	1.35	HF	406	BRK	4	1.30	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.2. Soil Bulk Density (gr cm^{-1}) for 0-10 and 10-20 cm depths in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

0-10 cm					**10-20 cm**				
Plot	**Location**	**REP**	**BD**	**TRT**	**Plot**	**Location**	**REP**	**BD**	**TRT**
101	SE	1	1.21	CNT	101	SE	1	1.29	CNT
201	SE	2	1.20	CNT	201	SE	2	1.28	CNT
301	SE	3	1.18	CNT	301	SE	3	1.28	CNT
401	SE	4	1.28	CNT	401	SE	4	1.43	CNT
102	SE	1	1.20	F	102	SE	1	1.24	F
202	SE	2	1.23	F	202	SE	2	1.29	F
302	SE	3	1.23	F	302	SE	3	1.34	F
402	SE	4	1.23	F	402	SE	4	1.41	F
103	SE	1	0.85	P	103	SE	1	1.30	P
203	SE	2	1.18	P	203	SE	2	1.37	P
303	SE	3	1.20	P	303	SE	3	1.34	P
403	SE	4	1.19	P	403	SE	4	1.36	P
104	SE	1	0.98	N	104	SE	1	1.03	N
204	SE	2	1.11	N	204	SE	2	1.33	N
304	SE	3	1.10	N	304	SE	3	1.31	N
404	SE	4	1.11	N	404	SE	4	1.35	N
105	SE	1	1.01	2N	105	SE	1	1.23	2N
205	SE	2	1.04	2N	205	SE	2	1.18	2N
305	SE	3	1.10	2N	305	SE	3	1.28	2N
405	SE	4	1.09	2N	405	SE	4	1.27	2N
106	SE	1	1.18	HF	106	SE	1	1.38	HF
206	SE	2	1.18	HF	206	SE	2	1.30	HF
306	SE	3	1.28	HF	306	SE	3	1.34	HF
406	SE	4	1.16	HF	406	SE	4	1.39	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.3. Soil Water Retention (m^3 m^{-3}) for 0-10 cm depth in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	TRT	REP	0	-0.04	-0.1	-2.5	-5	-10	-30
101	BRK	CNT	1	0.53	0.53	0.51	0.49	0.48	0.47	0.44
201	BRK	CNT	2	0.55	0.52	0.49	0.48	0.46	0.45	0.45
301	BRK	CNT	3	0.62	0.58	0.56	0.53	0.51	0.48	0.46
401	BRK	CNT	4	0.59	0.54	0.52	0.49	0.46	0.45	0.43
102	BRK	F	1	0.59	0.55	0.54	0.52	0.50	0.49	0.48
202	BRK	F	2	0.58	0.52	0.49	0.44	0.42	0.40	0.38
302	BRK	F	3	0.59	0.55	0.54	0.52	0.50	0.49	0.48
402	BRK	F	4	0.58	0.52	0.49	0.44	0.42	0.40	0.38
103	BRK	P	1	0.67	0.65	0.63	0.60	0.57	0.56	0.54
203	BRK	P	2	0.61	0.60	0.58	0.55	0.53	0.51	0.50
303	BRK	P	3	0.62	0.60	0.59	0.56	0.54	0.52	0.51
403	BRK	P	4	0.55	0.54	0.51	0.49	0.47	0.46	0.44
104	BRK	N	1	0.62	0.61	0.60	0.58	0.56	0.54	0.52
204	BRK	N	2	0.62	0.62	0.61	0.58	0.56	0.54	0.51
304	BRK	N	3	0.63	0.63	0.62	0.60	0.58	0.56	0.53
404	BRK	N	4	0.66	0.65	0.64	0.62	0.61	0.58	0.56
105	BRK	2N	1	0.61	0.60	0.58	0.56	0.53	0.51	0.48
205	BRK	2N	2	0.64	0.60	0.58	0.54	0.52	0.51	0.49
305	BRK	2N	3	0.64	0.62	0.60	0.57	0.55	0.53	0.51
405	BRK	2N	4	0.67	0.65	0.63	0.61	0.59	0.57	0.55
106	BRK	HF	1	0.51	0.50	0.49	0.47	0.46	0.45	0.44
206	BRK	HF	2	0.54	0.50	0.46	0.44	0.42	0.41	0.40
306	BRK	HF	3	0.51	0.50	0.49	0.47	0.46	0.45	0.44
406	BRK	HF	4	0.54	0.50	0.46	0.44	0.42	0.41	0.40

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.4. Soil Water Retention (m^3 m^{-3}) for 10-20 cm depth in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	TRT	REP	0	-0.04	-0.1	-2.5	-5	-10	-30
101	BRK	CNT	1	0.56	0.56	0.55	0.54	0.53	0.52	0.51
201	BRK	CNT	2	0.54	0.54	0.50	0.45	0.43	0.41	0.39
301	BRK	CNT	3	0.54	0.55	0.54	0.52	0.52	0.51	0.49
401	BRK	CNT	4	0.52	0.52	0.51	0.49	0.47	0.45	0.44
102	BRK	F	1	0.55	0.56	0.55	0.53	0.52	0.51	0.48
202	BRK	F	2	0.51	0.52	0.50	0.49	0.48	0.47	0.46
302	BRK	F	3	0.60	0.61	0.60	0.58	0.57	0.54	0.53
402	BRK	F	4	0.51	0.51	0.49	0.46	0.44	0.43	0.41
103	BRK	P	1	0.66	0.66	0.65	0.62	0.60	0.58	0.56
203	BRK	P	2	0.53	0.53	0.52	0.50	0.49	0.47	0.46
303	BRK	P	3	0.52	0.52	0.51	0.50	0.49	0.49	0.48
403	BRK	P	4	0.56	0.57	0.56	0.54	0.53	0.51	0.50
104	BRK	N	1	0.55	0.69	0.67	0.64	0.63	0.61	0.59
204	BRK	N	2	0.59	0.59	0.57	0.55	0.53	0.52	0.49
304	BRK	N	3	0.59	0.60	0.59	0.58	0.57	0.54	0.54
404	BRK	N	4	0.59	0.59	0.58	0.57	0.57	0.55	0.54
105	BRK	2N	1	0.63	0.63	0.62	0.60	0.58	0.57	0.55
205	BRK	2N	2	0.64	0.64	0.62	0.60	0.58	0.57	0.55
305	BRK	2N	3	0.59	0.60	0.58	0.57	0.56	0.54	0.52
405	BRK	2N	4	0.61	0.61	0.60	0.59	0.58	0.57	0.56
106	BRK	HF	1	0.66	0.66	0.64	0.60	0.58	0.56	0.54
206	BRK	HF	2	0.70	0.70	0.69	0.67	0.64	0.62	0.60
306	BRK	HF	3	0.57	0.57	0.56	0.55	0.54	0.53	0.52
406	BRK	HF	4	0.59	0.59	0.58	0.55	0.53	0.50	0.47

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.5. Soil Water Retention (m^3 m^{-3}) for 0-10 cm depth in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

Plot	Location	TRT	REP	0	-0.04	-0.1	-2.5	-5	-10	-30
101	SE	CNT	1	0.61	0.60	0.59	0.58	0.54	0.51	0.49
201	SE	CNT	2	0.62	0.61	0.60	0.59	0.55	0.51	0.48
301	SE	CNT	3	0.61	0.61	0.57	0.58	0.54	0.51	0.48
401	SE	CNT	4	0.61	0.61	0.60	0.58	0.54	0.51	0.48
102	SE	F	1	0.59	0.58	0.57	0.55	0.54	0.52	0.47
202	SE	F	2	0.59	0.58	0.57	0.55	0.54	0.52	0.47
302	SE	F	3	0.59	0.59	0.57	0.55	0.51	0.48	0.45
402	SE	F	4	0.59	0.59	0.57	0.55	0.51	0.48	0.45
103	SE	P	1	0.66	0.64	0.59	0.58	0.55	0.54	0.52
203	SE	P	2	0.60	0.59	0.58	0.57	0.55	0.53	0.51
303	SE	P	3	0.60	0.59	0.59	0.58	0.55	0.54	0.50
403	SE	P	4	0.62	0.61	0.59	0.58	0.57	0.56	0.54
104	SE	N	1	0.64	0.63	0.63	0.54	0.48	0.47	0.42
204	SE	N	2	0.66	0.65	0.64	0.62	0.56	0.54	0.53
304	SE	N	3	0.64	0.63	0.60	0.59	0.56	0.53	0.50
404	SE	N	4	0.63	0.62	0.61	0.60	0.59	0.58	0.56
105	SE	2N	1	0.63	0.63	0.61	0.60	0.58	0.57	0.52
205	SE	2N	2	0.65	0.64	0.62	0.57	0.54	0.52	0.50
305	SE	2N	3	0.63	0.63	0.61	0.60	0.58	0.57	0.52
405	SE	2N	4	0.64	0.63	0.61	0.59	0.57	0.55	0.52
106	SE	HF	1	0.61	0.60	0.58	0.57	0.55	0.53	0.49
206	SE	HF	2	0.61	0.61	0.60	0.57	0.52	0.50	0.46
306	SE	HF	3	0.62	0.61	0.59	0.58	0.56	0.54	0.52
406	SE	HF	4	0.60	0.59	0.57	0.56	0.55	0.54	0.49

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.6. Soil Water Retention (m^3 m^{-3}) for 10-20 cm depth in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

Plot	Location	TRT	REP	0	-0.04	-0.1	-2.5	-5	-10	-30
101	SE	CNT	1	0.55	0.52	0.49	0.46	0.44	0.42	0.38
201	SE	CNT	2	0.58	0.57	0.56	0.55	0.54	0.52	0.47
301	SE	CNT	3	0.55	0.54	0.51	0.50	0.49	0.47	0.45
401	SE	CNT	4	0.56	0.56	0.54	0.54	0.53	0.52	0.47
102	SE	F	1	0.61	0.61	0.60	0.58	0.57	0.55	0.53
202	SE	F	2	0.60	0.59	0.59	0.57	0.56	0.55	0.53
302	SE	F	3	0.59	0.58	0.57	0.57	0.56	0.55	0.51
402	SE	F	4	0.55	0.55	0.53	0.52	0.52	0.51	0.49
103	SE	P	1	0.62	0.61	0.60	0.58	0.57	0.55	0.54
203	SE	P	2	0.57	0.56	0.56	0.55	0.54	0.53	0.51
303	SE	P	3	0.33	0.33	0.31	0.31	0.30	0.30	0.28
403	SE	P	4	0.62	0.61	0.59	0.58	0.57	0.56	0.54
104	SE	N	1	0.63	0.60	0.57	0.53	0.49	0.48	0.46
204	SE	N	2	0.62	0.61	0.61	0.60	0.59	0.59	0.57
304	SE	N	3	0.64	0.63	0.59	0.57	0.55	0.53	0.51
404	SE	N	4	0.56	0.55	0.53	0.51	0.50	0.49	0.47
105	SE	2N	1	0.62	0.61	0.61	0.59	0.58	0.56	0.55
205	SE	2N	2	0.63	0.62	0.61	0.57	0.55	0.54	0.51
305	SE	2N	3	0.66	0.65	0.63	0.63	0.62	0.62	0.61
405	SE	2N	4	0.59	0.58	0.56	0.55	0.54	0.53	0.52
106	SE	HF	1	0.56	0.55	0.55	0.54	0.53	0.53	0.51
206	SE	HF	2	0.63	0.63	0.62	0.61	0.58	0.56	0.54
306	SE	HF	3	0.67	0.67	0.66	0.65	0.64	0.63	0.61
406	SE	HF	4	0.56	0.56	0.54	0.54	0.53	0.53	0.50

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.7. Soil Pore Size Distribution (m^3 m^{-3}) for 0-10 cm depth in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**TRT**	**REP**	**Macropores (>1000 µm)**	**Coarse Mesopores (60-1000 µm)**	**Fine Mesopores (10-60 µm)**	**Micropores (<10 µm)**
101	BRK	CNT	1	0.005	0.049	0.030	0.440
201	BRK	CNT	2	0.034	0.060	0.510	0.000
301	BRK	CNT	3	0.039	0.072	0.050	0.460
401	BRK	CNT	4	0.046	0.076	0.030	0.430
102	BRK	F	1	0.017	0.052	0.020	0.480
202	BRK	F	2	0.007	0.099	0.040	0.380
302	BRK	F	3	0.033	0.052	0.020	0.480
402	BRK	F	4	0.061	0.099	0.040	0.380
103	BRK	P	1	0.020	0.084	0.030	0.540
203	BRK	P	2	0.027	0.070	0.030	0.500
303	BRK	P	3	0.022	0.058	0.030	0.510
403	BRK	P	4	0.009	0.068	0.040	0.440
104	BRK	N	1	0.020	0.047	0.040	0.520
204	BRK	N	2	0.007	0.053	0.050	0.510
304	BRK	N	3	0.018	0.047	0.050	0.530
404	BRK	N	4	0.006	0.041	0.050	0.560
105	BRK	2N	1	0.013	0.065	0.050	0.480
205	BRK	2N	2	0.040	0.082	0.030	0.490
305	BRK	2N	3	0.016	0.067	0.040	0.510
405	BRK	2N	4	0.026	0.054	0.040	0.550
106	BRK	HF	1	0.037	0.034	0.020	0.440
206	BRK	HF	2	0.062	0.080	0.020	0.400
306	BRK	HF	3	0.012	0.034	0.020	0.440
406	BRK	HF	4	0.040	0.080	0.020	0.400

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.8. Soil Pore Size Distribution (m^3 m^{-3}) for 10-20 cm depth in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**TRT**	**REP**	**Macropores (>1000 µm)**	**Coarse Mesopores (60-1000 µm)**	**Fine Mesopores (10-60 µm)**	**Micropores (<10 µm)**
101	BRK	CNT	1	0.007	0.029	0.024	0.507
201	BRK	CNT	2	0.054	0.116	0.036	0.392
301	BRK	CNT	3	0.006	0.030	0.026	0.491
401	BRK	CNT	4	0.024	0.057	0.029	0.439
102	BRK	F	1	0.007	0.042	0.037	0.479
202	BRK	F	2	0.009	0.039	0.016	0.461
302	BRK	F	3	0.013	0.035	0.038	0.534
402	BRK	F	4	0.042	0.065	0.037	0.407
103	BRK	P	1	0.014	0.062	0.042	0.559
203	BRK	P	2	0.026	0.045	0.026	0.461
303	BRK	P	3	0.011	0.030	0.017	0.477
403	BRK	P	4	0.018	0.033	0.034	0.500
104	BRK	N	1	0.026	0.064	0.041	0.585
204	BRK	N	2	0.011	0.055	0.042	0.492
304	BRK	N	3	0.008	0.027	0.032	0.538
404	BRK	N	4	0.006	0.023	0.024	0.542
105	BRK	2N	1	0.017	0.052	0.029	0.553
205	BRK	2N	2	0.017	0.055	0.034	0.550
305	BRK	2N	3	0.023	0.034	0.041	0.521
405	BRK	2N	4	0.014	0.035	0.019	0.560
106	BRK	HF	1	0.024	0.087	0.032	0.544
206	BRK	HF	2	0.009	0.058	0.038	0.603
306	BRK	HF	3	0.007	0.032	0.026	0.516
406	BRK	HF	4	0.015	0.062	0.056	0.474

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.9. Soil Pore Size Distribution ($m^3 m^{-3}$) for 0-10 cm depth in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

Plot	**Location**	**TRT**	**REP**	**Macropores (>1000 µm)**	**Coarse Mesopores (60-1000 µm)**	**Fine Mesopores (10-60 µm)**	**Micropores (<10 µm)**
101	SE	CNT	1	0.006	0.060	0.056	0.485
201	SE	CNT	2	0.008	0.065	0.069	0.478
301	SE	CNT	3	0.007	0.062	0.062	0.482
401	SE	CNT	4	0.007	0.062	0.062	0.482
102	SE	F	1	0.008	0.040	0.071	0.468
202	SE	F	2	0.008	0.040	0.071	0.468
302	SE	F	3	0.007	0.072	0.062	0.452
402	SE	F	4	0.007	0.072	0.062	0.452
103	SE	P	1	0.021	0.085	0.038	0.517
203	SE	P	2	0.008	0.043	0.044	0.507
303	SE	P	3	0.009	0.046	0.048	0.499
403	SE	P	4	0.010	0.048	0.023	0.543
104	SE	N	1	0.007	0.151	0.060	0.424
204	SE	N	2	0.008	0.089	0.037	0.526
304	SE	N	3	0.009	0.078	0.056	0.500
404	SE	N	4	0.008	0.035	0.031	0.559
105	SE	2N	1	0.007	0.041	0.061	0.524
205	SE	2N	2	0.013	0.104	0.039	0.499
305	SE	2N	3	0.007	0.041	0.061	0.524
405	SE	2N	4	0.009	0.062	0.054	0.515
106	SE	HF	1	0.008	0.056	0.054	0.491
206	SE	HF	2	0.007	0.082	0.063	0.462
306	SE	HF	3	0.010	0.048	0.042	0.517
406	SE	HF	4	0.008	0.038	0.058	0.495

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.10. Soil Pore Size Distribution (m^3 m^{-3}) for 10-20 cm depth in 2015 at Beresford (South East) site. SE, Beresford (South East) site; REP, replication; TRT, treatment.

Plot	**Location**	**TRT**	**REP**	**Macropores (>1000 µm)**	**Coarse Mesopores (60-1000 µm)**	**Fine Mesopores (10-60 µm)**	**Micropores (<10 µm)**
101	SE	CNT	1	0.033	0.075	0.057	0.383
201	SE	CNT	2	0.005	0.034	0.063	0.473
301	SE	CNT	3	0.016	0.051	0.035	0.451
401	SE	CNT	4	0.004	0.026	0.057	0.472
102	SE	F	1	0.004	0.034	0.037	0.534
202	SE	F	2	0.005	0.039	0.030	0.525
302	SE	F	3	0.005	0.025	0.048	0.510
402	SE	F	4	0.006	0.030	0.027	0.490
103	SE	P	1	0.008	0.039	0.028	0.541
203	SE	P	2	0.004	0.024	0.025	0.514
303	SE	P	3	0.006	0.026	0.018	0.283
403	SE	P	4	0.010	0.043	0.027	0.544
104	SE	N	1	0.030	0.109	0.032	0.463
204	SE	N	2	0.005	0.021	0.027	0.566
304	SE	N	3	0.014	0.076	0.037	0.512
404	SE	N	4	0.008	0.046	0.032	0.471
105	SE	2N	1	0.005	0.039	0.025	0.551
205	SE	2N	2	0.008	0.076	0.038	0.508
305	SE	2N	3	0.011	0.028	0.012	0.609
405	SE	2N	4	0.010	0.046	0.019	0.518
106	SE	HF	1	0.005	0.022	0.020	0.511
206	SE	HF	2	0.005	0.042	0.041	0.542
306	SE	HF	3	0.005	0.026	0.037	0.606
406	SE	HF	4	0.005	0.026	0.035	0.496

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A2.11. Water Infiltration (mm hr^{-1}) in 2015 at Brookings and Beresford (South East) sites. BRK, Brookings; SE, Beresford (South East) site; REP, replication; TRT, treatment.

Brookings					Beresford				
Plot	**Location**	**REP**	**WI**	**TRT**	**Plot**	**Location**	**REP**	**WI**	**TRT**
101	BRK	1	232	CNT	101	BRK	1	225	CNT
201	BRK	2	264	CNT	201	BRK	2	149	CNT
301	BRK	3	232	CNT	301	BRK	3	159	CNT
401	BRK	4	252	CNT	401	BRK	4	182	CNT
102	BRK	1	267	F	102	BRK	1	232	F
202	BRK	2	170	F	202	BRK	2	127	F
302	BRK	3	172	F	302	BRK	3	162	F
402	BRK	4	353	F	402	BRK	4	51	F
103	BRK	1	287	P	103	BRK	1	278	P
203	BRK	2	332	P	203	BRK	2	238	P
303	BRK	3	349	P	303	BRK	3	240	P
403	BRK	4	248	P	403	BRK	4	243	P
104	BRK	1	303	N	104	BRK	1	237	N
204	BRK	2	355	N	204	BRK	2	375	N
304	BRK	3	284	N	304	BRK	3	222	N
404	BRK	4	364	N	404	BRK	4	224	N
105	BRK	1	396	2N	105	BRK	1	274	2N
205	BRK	2	368	2N	205	BRK	2	361	2N
305	BRK	3	535	2N	305	BRK	3	317	2N
405	BRK	4	349	2N	405	BRK	4	363	2N
106	BRK	1	274	HF	106	BRK	1	187	HF
206	BRK	2	207	HF	206	BRK	2	172	HF
306	BRK	3	291	HF	306	BRK	3	162	HF
406	BRK	4	128	HF	406	BRK	4	190	HF

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

APPENDIX 3

A 3.1. Weather data for June and July 2015. PRCP, precipitation in mm; TMAX, maximum temperature in °C; TMIN, minimum temperature in °C.

DATE	PRCP	T-MAX	T-MIN	DATE	PRCP	T-MAX	T-MIN
6/5/2015	0.0	21.1	13.9	7/1/2015	3.8	26.7	16.7
6/6/2015	0.0	23.3	16.7	7/2/2015	0.0	22.2	13.3
6/7/2015	1.8	26.1	15.6	7/3/2015	0.0	22.2	10.0
6/8/2015	0.0	24.4	13.3	7/4/2015	0.0	25.6	13.9
6/9/2015	0.0	28.9	15.6	7/5/2015	13.5	27.2	17.8
6/10/2015	0.0	34.4	15.0	7/6/2015	15.7	30.0	18.3
6/11/2015	0.0	25.0	14.4	7/7/2015	0.5	21.7	8.3
6/12/2015	0.0	18.3	8.9	7/8/2015	0.0	20.0	10.0
6/13/2015	0.0	23.9	13.9	7/9/2015	0.0	22.2	12.2
6/14/2015	0.0	25.0	15.0	7/10/2015	0.0	27.2	15.6
6/15/2015	1.3	29.4	15.0	7/11/2015	0.0	27.2	18.3
6/16/2015	0.0	24.4	11.1	7/12/2015	1.3	29.4	19.4
6/17/2015	5.8	20.0	12.2	7/13/2015	0.8	32.8	18.3
6/18/2015	0.0	17.8	10.6	7/14/2015	0.0	31.1	17.8
6/19/2015	0.0	23.9	12.2	7/15/2015	0.0	29.4	17.8
6/20/2015	11.7	25.0	17.2	7/16/2015	0.0	28.3	17.8
6/21/2015	0.0	27.2	16.1	7/17/2015	0.0	27.2	16.7
6/22/2015	16.8	28.3	16.7	7/18/2015	0.0	32.2	18.9
6/23/2015	0.0	24.4	11.7	7/19/2015	0.0	28.3	13.3
6/24/2015	0.0	22.8	13.3	7/20/2015	3.6	27.8	18.3
6/25/2015	0.0	26.1	13.3	7/21/2015	0.0	25.0	10.0
6/26/2015	8.1	26.7	16.1	7/22/2015	0.0	25.6	14.4
6/27/2015	8.9	27.2	12.2	7/23/2015	0.0	27.2	16.1
6/28/2015	0.0	27.8	16.1	7/24/2015	1.3	29.4	18.3
6/29/2015	0.0	26.7	15.0	7/25/2015	0.0	29.4	16.7
6/30/2015	0.0	26.7	14.4	7/26/2015	38.9	28.9	16.7
				7/27/2015	0.0	27.2	19.4
				7/28/2015	21.3	30.6	18.9
				7/29/2015	0.0	25.0	14.4
				7/30/2015	0.0	27.2	12.2
				7/31/2015	0.0	29.4	13.3

A 3.2. Weather data for August and September 2015. PRCP, precipitation in mm; TMAX, maximum temperature in °C; TMIN, minimum temperature in °C.

DATE	PRCP	T-MAX	T-MIN	DATE	PRCP	T-MAX	T-MIN
8/1/2015	0.0	28.3	15.0	9/1/2015	0.0	28.3	17.8
8/2/2015	0.0	28.9	16.7	9/2/2015	2.3	25.6	17.2
8/3/2015	0.0	27.2	11.1	9/3/2015	0.0	30.0	18.9
8/4/2015	0.0	25.6	11.1	9/4/2015	0.0	31.1	20.0
8/5/2015	0.0	25.0	13.9	9/5/2015	0.0	27.2	20.6
8/6/2015	8.4	26.1	15.0	9/6/2015	0.0	28.9	21.1
8/7/2015	44.5	27.8	16.7	9/7/2015	0.0	28.3	10.6
8/8/2015	1.5	28.9	18.3	9/8/2015	0.5	22.8	12.8
8/9/2015	0.0	27.2	18.3	9/9/2015	0.0	23.3	10.0
8/10/2015	21.3	26.1	15.0	9/10/2015	1.5	25.0	11.7
8/11/2015	0.0	25.6	13.3	9/11/2015	0.0	20.6	4.4
8/12/2015	0.0	28.9	15.6	9/12/2015	0.0	17.2	2.8
8/13/2015	0.0	29.4	18.3	9/13/2015	0.0	20.6	4.4
8/14/2015	0.8	25.0	18.3	9/14/2015	0.0	25.0	8.9
8/15/2015	0.0	31.1	20.0	9/15/2015	0.0	28.9	15.0
8/16/2015	22.1	30.6	20.0	9/16/2015	0.0	26.7	17.8
8/17/2015	14.2	20.6	12.8	9/17/2015	0.0	28.9	19.4
8/18/2015	12.2	18.3	12.8	9/18/2015	0.0	23.3	8.9
8/19/2015	51.8	14.4	10.0	9/19/2015	1.3	15.6	2.8
8/20/2015	0.0	20.0	7.2	9/20/2015	0.0	18.9	7.2
8/21/2015	0.0	23.9	10.0	9/21/2015	0.0	24.4	11.1
8/22/2015	0.0	25.6	15.6	9/22/2015	0.0	27.8	12.8
8/23/2015	0.0	26.7	10.6	9/23/2015	0.0	25.0	13.3
8/24/2015	0.0	18.9	6.7	9/24/2015	24.9	22.8	16.7
8/25/2015	0.0	19.4	5.6	9/25/2015	13.2	17.2	14.4
8/26/2015	0.0	22.2	7.8	9/26/2015	0.0	25.6	11.1
8/27/2015	0.0	22.2	11.1	9/27/2015	0.0	25.0	12.2
8/28/2015	0.0	25.6	16.1	9/28/2015	0.0	28.3	14.4
8/29/2015	0.0	22.8	10.6	9/29/2015	0.0	21.7	9.4
8/30/2015	0.0	25.0	11.1	9/30/2015	0.0	19.4	6.7
8/31/2015	0.0	25.6	16.1				

A 3.3. Weather data for October 2015, May and June 2016. PRCP, precipitation in mm; TMAX, maximum temperature in °C; TMIN, minimum temperature in °C.

DATE	PRCP	T-MAX	T-MIN	DATE	PRCP	T-MAX	T-MIN
10/1/2015	0.0	19.4	7.2	6/1/2016	0.0	21.1	10.6
10/2/2015	0.0	16.7	5.0	6/2/2016	0.0	18.3	6.7
10/3/2015	0.0	15.6	3.9	6/3/2016	11.9	24.4	11.1
10/4/2015	0.0	13.9	4.4	6/4/2016	6.1	23.9	12.8
10/5/2015	0.0	13.9	6.1	6/5/2016	0.0	21.7	11.7
10/6/2015	0.0	16.1	10.6	6/6/2016	0.0	26.7	11.7
10/7/2015	0.0	20.6	4.4	6/7/2016	0.0	20.0	8.3
10/8/2015	0.0	20.6	5.6	6/8/2016	0.0	22.2	12.8
5/10/2016	3.3	18.9	11.7	6/9/2016	0.0	29.4	16.7
5/11/2016	9.7	20.6	11.1	6/10/2016	0.0	33.9	20.6
5/12/2016	0.0	17.2	7.8	6/11/2016	0.5	32.8	20.0
5/13/2016	2.5	15.0	2.8	6/12/2016	0.0	33.9	21.7
5/14/2016	0.5	6.7	-1.7	6/13/2016	0.0	33.9	18.9
5/15/2016	0.0	12.2	0.0	6/14/2016	1.0	26.7	18.3
5/16/2016	0.0	17.8	5.0	6/15/2016	1.8	25.6	13.9
5/17/2016	2.0	19.4	2.8	6/16/2016	0.0	26.7	13.3
5/18/2016	0.0	18.9	3.3	6/17/2016	0.0	30.0	17.2
5/19/2016	0.0	20.6	8.3	6/18/2016	70.1	33.9	17.8
5/20/2016	0.0	21.7	8.3	6/19/2016	0.0	27.8	19.4
5/21/2016	0.0	19.4	7.8	6/20/2016	0.5	31.7	15.0
5/22/2016	0.0	23.3	9.4	6/21/2016	0.0	25.6	11.7
5/23/2016	7.9	28.3	15.0	6/22/2016	2.8	27.8	16.7
5/24/2016	0.0	22.8	13.3	6/23/2016	0.0	27.8	13.9
5/25/2016	3.6	28.9	15.0	6/24/2016	0.0	24.4	15.6
5/26/2016	0.0	23.9	11.1	6/25/2016	0.0	29.4	17.2
5/27/2016	0.0	24.4	12.8	6/26/2016	0.5	29.4	13.3
5/28/2016	13.5	21.7	15.0	6/27/2016	0.0	28.9	13.3
5/29/2016	16.8	17.8	13.3	6/28/2016	0.0	25.0	10.6
5/30/2016	0.0	23.9	12.8	6/29/2016	0.0	25.0	15.0
5/31/2016	8.6	27.2	13.9	6/30/2016	0.0	27.2	16.7

A 3.4. Weather data for July and August 2016. PRCP, precipitation in mm; TMAX, maximum temperature in °C; TMIN, minimum temperature in °C.

DATE	PRCP	T-MAX	T-MIN	DATE	PRCP	T-MAX	T-MIN
7/1/2016	0.0	24.4	6.7	8/1/2016	0.0	28.3	19.4
7/2/2016	0.0	22.2	11.1	8/2/2016	1.8	26.1	19.4
7/3/2016	0.0	25.0	11.1	8/3/2016	0.0	30.0	20.0
7/4/2016	0.0	24.4	15.0	8/4/2016	15.7	28.9	18.9
7/5/2016	0.0	28.9	17.2	8/5/2016	0.0	25.6	12.8
7/6/2016	3.3	31.7	16.1	8/6/2016	0.0	25.0	11.7
7/7/2016	11.4	28.3	16.1	8/7/2016	0.0	25.6	13.9
7/8/2016	1.3	22.8	13.3	8/8/2016	0.0	25.6	14.4
7/9/2016	0.3	26.1	13.9	8/9/2016	0.0	25.6	16.7
7/10/2016	60.2	27.8	17.2	8/10/2016	0.0	31.7	20.6
7/11/2016	23.9	30.0	17.2	8/11/2016	20.3	32.8	18.9
7/12/2016	0.3	30.0	15.6	8/12/2016	42.7	28.9	16.7
7/13/2016	0.0	27.8	16.7	8/13/2016	1.3	26.1	13.9
7/14/2016	0.0	27.2	14.4	8/14/2016	1.8	25.6	13.3
7/15/2016	0.0	21.7	8.9	8/15/2016	0.0	26.7	16.1
7/16/2016	0.0	24.4	11.7	8/16/2016	0.0	26.1	17.8
7/17/2016	27.4	25.6	15.6	8/17/2016	2.3	28.9	13.3
7/18/2016	0.0	25.6	14.4	8/18/2016	0.0	28.3	17.2
7/19/2016	3.6	28.3	18.3	8/19/2016	26.2	27.8	17.2
7/20/2016	0.0	27.8	21.7	8/20/2016	4.8	22.2	13.3
7/21/2016	0.0	32.2	23.3	8/21/2016	1.3	20.0	8.9
7/22/2016	0.0	32.2	22.8	8/22/2016	0.0	24.4	12.8
7/23/2016	17.3	31.7	19.4	8/23/2016	0.0	28.9	16.7
7/24/2016	3.8	31.7	18.3	8/24/2016	0.0	25.0	13.3
7/25/2016	0.0	25.6	14.4				
7/26/2016	0.0	28.9	18.3				
7/27/2016	2.0	29.4	18.9				
7/28/2016	0.0	26.1	15.0				
7/29/2016	0.0	23.9	11.7				
7/30/2016	0.0	25.0	12.2				
7/31/2016	0.0	25.6	16.1				

A3.5 Daily CH_4 Fluxes (g CH_4-C ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**REP**	**TRT**	**06/05**	**06/13**	**06/21**	**06/23**	**06/27**	**07/07**	**07/17**	**07/29**
101	BRK	1	CK	0.033	-0.035	-0.019	-0.096	4.965	-26.032	1.036	-0.472
102	BRK	1	F	-0.055	0.112	-0.260	-4.071	0.108	0.052	0.431	0.051
103	BRK	1	P	0.276	0.040	0.100	0.040	0.184	-0.019	1.122	0.156
104	BRK	1	N	-0.052	0.224	0.345	-0.026	-0.102	4.636	1.054	0.246
105	BRK	1	2N	-0.168	0.089	0.006	-0.014	-0.020	-0.035	0.570	37.217
106	BRK	1	HF	0.131	-0.054	0.231	-0.083	-0.033	0.049	0.202	0.023
201	BRK	2	CK	0.060	0.096	0.118	0.037	-0.093	0.019	0.951	0.057
202	BRK	2	F	0.196	-0.094	-0.002	-0.044	-0.062	0.154	0.248	-0.010
203	BRK	2	P	0.128	0.043	0.055	-0.077	0.217	0.007	-0.165	0.062
204	BRK	2	N	0.037	0.101	0.165	0.105	0.394	0.046	0.043	0.791
205	BRK	2	2N	0.020	0.165	0.184	0.672	64.022	0.448	0.529	-0.082
206	BRK	2	HF	0.065	7.270	-0.011	-0.045	-0.057	-0.005	0.075	0.177
301	BRK	3	CK	-0.050	10.799	-8.704	0.076	-0.022	0.064	1.118	0.073
302	BRK	3	F	0.005	0.119	-0.042	0.191	0.040	0.289	-0.009	0.138
303	BRK	3	P	-0.076	-0.080	-0.088	-0.041	0.355	0.149	0.241	0.446
304	BRK	3	N	-0.010	0.081	0.016	0.166	0.016	-11.485	1.124	-0.067
305	BRK	3	2N	0.288	0.068	38.688	0.578	18.349	0.064	0.163	0.047
306	BRK	3	HF	0.047	-0.010	0.178	0.167	0.041	0.015	0.239	0.051
401	BRK	4	CK	0.100	0.075	-0.156	-0.034	0.104	0.162	1.039	-9.269
402	BRK	4	F	0.017	0.141	-0.024	-0.068	0.007	-0.008	0.111	-0.126
403	BRK	4	P	-0.021	0.062	0.173	-0.021	8.902	0.198	0.194	15.216
404	BRK	4	N	-0.029	7.517	0.175	0.082	52.571	10.977	3.577	-0.011
405	BRK	4	2N	-0.030	0.089	-0.093	0.053	0.055	0.094	0.111	0.251
406	BRK	4	HF	0.073	0.195	0.088	0.243	0.446	0.062	0.711	0.079

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.6. Daily CH_4 Fluxes (g CH_4-C ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	08/02	08/16	08/22	08/25	08/31	09/15	09/20	09/22	10/08
101	BRK	1	CK	0.184	-0.081	0.330	0.014	-0.040	0.332	-0.161	0.605	1.223
102	BRK	1	F	-0.128	0.134	0.168	-0.176	-0.077	-0.056	-0.027	-0.160	0.178
103	BRK	1	P	-0.056	0.221	13.517	-0.108	0.201	-0.003	0.093	0.296	0.132
104	BRK	1	N	0.111	0.041	0.139	0.325	0.191	-0.006	40.002	0.443	1.104
105	BRK	1	2N	0.650	0.137	0.500	0.254	0.213	0.262	30.329	0.718	-0.024
106	BRK	1	HF	-6.952	0.011	0.364	0.084	-0.213	0.015	0.117	-0.322	-0.507
201	BRK	2	CK	0.431	0.051	0.094	-0.327	-0.690	-0.029	-0.139	0.049	0.115
202	BRK	2	F	-0.004	0.189	0.080	0.151	-0.021	-0.057	-0.285	-0.215	0.113
203	BRK	2	P	-0.041	-0.147	0.186	-0.043	0.097	0.224	0.102	0.365	1.036
204	BRK	2	N	-0.221	-0.053	0.179	0.065	0.470	0.046	-28.311	-22.790	21.639
205	BRK	2	2N	0.180	0.297	-0.527	0.089	-0.138	-0.035	0.414	-0.076	-26.871
206	BRK	2	HF	0.546	0.198	0.147	0.228	0.132	0.077	0.294	0.210	0.057
301	BRK	3	CK	-0.142	-0.081	-0.062	0.301	-0.007	-11.725	-119.517	0.154	0.284
302	BRK	3	F	-10.627	0.134	-0.758	0.436	-0.032	0.116	-0.173	62.667	2.114
303	BRK	3	P	0.091	0.221	-0.025	-0.127	-0.069	1.090	0.472	-0.132	0.224
304	BRK	3	N	-0.026	0.041	-0.069	9.875	2.415	0.069	0.259	-28.259	-103.152
305	BRK	3	2N	0.020	0.137	-0.109	0.119	0.153	0.435	-0.587	-0.052	0.021
306	BRK	3	HF	-13.598	0.011	0.490	0.044	-0.506	0.081	0.536	0.113	0.263
401	BRK	4	CK	0.044	0.051	0.161	0.092	0.295	-0.107	0.547	0.181	0.067
402	BRK	4	F	0.438	0.189	0.030	0.010	-0.809	-0.111	-0.907	0.304	0.654
403	BRK	4	P	-0.022	-0.147	0.119	0.029	0.535	-0.408	0.084	-0.339	-0.153
404	BRK	4	N	0.001	-0.053	0.450	-0.031	-0.201	-0.082	0.054	-0.061	-0.018
405	BRK	4	2N	0.377	0.297	-0.184	0.093	0.250	-0.017	-0.012	0.514	0.079
406	BRK	4	HF	0.240	0.198	32.525	27.401	0.722	-9.192	-0.162	-0.043	-0.150

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.7. Daily CH_4 Fluxes (g CH_4-C ha^{-1} d^{-1}) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	05/10	05/15	05/20	05/26	06/02	06/16	06/28	06/30	07/15	07/29	08/24
101	BRK	1	CK	0.182	0.187	0.417	-0.194	-0.389	-0.292	0.046	-0.188	-0.060	11.948	-0.280
102	BRK	1	F	0.107	0.870	0.146	0.287	-0.074	-0.199	0.013	0.029	-0.313	0.119	0.116
103	BRK	1	P	-0.025	0.080	48.993	-0.041	0.142	0.514	0.318	0.098	0.664	0.165	-0.028
104	BRK	1	N	0.009	-0.335	24.981	0.358	0.026	0.212	0.016	-0.081	-0.167	0.275	0.001
105	BRK	1	2N	0.113	-0.216	0.596	0.046	-0.011	0.489	-8.265	-0.076	-0.221	0.054	-0.109
106	BRK	1	HF	-0.010	-0.098	0.355	0.039	-39.734	0.031	-0.025	0.033	0.130	0.172	0.387
201	BRK	2	CK	0.126	-0.375	0.238	-0.030	0.209	0.000	0.179	-0.113	0.508	0.592	0.016
202	BRK	2	F	0.261	0.193	0.128	-0.028	0.003	0.237	-0.035	0.002	-6.576	0.605	-0.039
203	BRK	2	P	0.269	-0.072	0.122	0.574	-0.096	0.487	-0.299	-0.136	0.633	0.259	12.397
204	BRK	2	N	-20.306	-0.184	36.901	0.096	-0.303	0.109	0.063	0.288	0.662	-0.003	0.040
205	BRK	2	2N	0.202	-0.134	-0.112	0.193	-0.011	-0.183	0.071	-0.075	0.467	-0.079	0.558
206	BRK	2	HF	0.010	-0.051	0.012	0.220	-0.195	0.018	0.050	0.020	0.049	0.070	0.118
301	BRK	3	CK	-0.032	-0.042	0.499	-0.107	-0.250	-0.303	-0.044	-0.521	0.112	0.142	-0.499
302	BRK	3	F	0.067	0.006	-0.081	0.256	-0.313	-0.340	0.128	0.088	-0.024	0.062	-0.165
303	BRK	3	P	-0.050	0.078	0.051	-0.120	0.206	4.297	-0.023	-0.063	0.612	0.038	-0.057
304	BRK	3	N	0.018	0.279	0.317	-0.075	0.059	-0.181	-0.112	-0.024	-0.294	0.006	0.059
305	BRK	3	2N	-0.104	0.034	0.033	0.191	0.014	0.116	0.032	0.059	-0.102	0.053	0.016
306	BRK	3	HF	0.243	-0.810	0.063	0.017	-0.125	-0.050	0.126	0.305	-0.112	0.227	-0.021
401	BRK	4	CK	14.559	-0.136	0.078	-0.076	0.048	-0.233	0.004	-0.147	50.230	0.409	-0.018
402	BRK	4	F	0.043	0.739	-0.103	-0.061	0.224	0.084	0.128	0.183	-0.172	0.182	-0.175
403	BRK	4	P	0.205	0.043	-0.098	0.037	0.000	0.048	-0.139	-8.668	0.701	0.047	0.215
404	BRK	4	N	0.560	0.189	15.986	0.065	-0.232	0.072	-0.008	0.242	0.502	0.264	0.512
405	BRK	4	2N	23.936	0.134	0.095	0.102	0.205	-0.281	0.213	-0.109	-0.124	0.156	0.599
406	BRK	4	HF	0.031	-0.211	-0.033	0.081	0.032	-0.139	-0.016	0.035	-0.072	0.104	0.139

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.8. Daily CO_2 Fluxes (kg CO_2-C ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**REP**	**TRT**	**06/05**	**06/13**	**06/21**	**06/23**	**06/27**	**07/07**	**07/17**	**07/29**
101	BRK	1	CK	0.211	15.068	5.561	12.188	0.618	0.116	0.493	0.410
102	BRK	1	F	0.172	20.437	0.572	0.306	100.903	31.528	23.371	0.568
103	BRK	1	P	56.113	31.194	41.920	0.937	132.647	37.016	59.622	0.964
104	BRK	1	N	0.812	0.624	0.846	0.751	87.797	38.769	0.781	0.673
105	BRK	1	2N	157.251	22.173	144.616	1.218	223.473	90.728	66.116	0.933
106	BRK	1	HF	0.305	0.045	0.631	42.121	0.691	25.933	25.278	1.159
201	BRK	2	CK	24.634	9.463	0.107	27.166	34.894	0.138	0.422	0.589
202	BRK	2	F	19.878	0.168	0.239	19.368	0.229	0.138	0.251	33.594
203	BRK	2	P	0.565	14.990	0.566	43.823	80.100	27.358	24.014	0.624
204	BRK	2	N	0.403	0.466	63.300	84.218	1.959	66.596	0.627	83.413
205	BRK	2	2N	1.191	35.732	26.300	2.200	250.261	1.451	62.412	1.532
206	BRK	2	HF	0.136	0.274	0.213	20.491	25.011	0.161	0.267	0.302
301	BRK	3	CK	0.307	0.180	0.291	0.287	30.628	15.600	0.500	0.560
302	BRK	3	F	20.223	0.160	0.301	14.129	35.834	0.163	30.317	0.410
303	BRK	3	P	22.959	16.266	0.275	0.268	39.987	0.171	48.063	26.200
304	BRK	3	N	79.981	0.141	0.654	98.061	1.787	0.739	0.604	1.054
305	BRK	3	2N	53.468	125.200	121.453	141.345	1.614	59.296	144.822	79.655
306	BRK	3	HF	29.473	0.307	23.170	16.496	31.982	4.426	37.465	0.138
401	BRK	4	CK	0.236	9.848	0.338	5.642	0.055	0.167	0.557	0.628
402	BRK	4	F	0.076	11.899	0.395	0.325	0.149	0.250	0.401	0.649
403	BRK	4	P	1.025	25.468	0.543	0.405	0.461	0.365	0.412	0.666
404	BRK	4	N	60.467	2.487	1.469	1.702	2.005	93.543	2.290	89.560
405	BRK	4	2N	105.403	0.453	0.852	0.750	86.951	40.707	0.945	0.750
406	BRK	4	HF	21.563	18.083	0.412	0.516	40.825	19.501	0.641	41.477

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.9. Daily CO_2 Fluxes (kg CO_2-C ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**REP**	**TRT**	**08/02**	**08/16**	**08/22**	**08/25**	**08/31**	**09/15**	**09/20**	**09/22**	**10/08**
101	BRK	1	CK	22.477	0.427	0.149	0.084	0.305	4.590	8.811	0.213	0.147
102	BRK	1	F	0.566	0.469	0.442	23.022	26.276	18.700	12.317	21.487	13.188
103	BRK	1	P	83.327	1.382	0.638	36.621	0.455	0.295	0.290	37.993	16.103
104	BRK	1	N	0.747	0.458	0.542	0.309	0.671	0.251	15.751	0.286	0.358
105	BRK	1	2N	1.223	0.008	0.883	38.611	61.394	45.654	37.835	0.489	23.258
106	BRK	1	HF	35.125	95.024	0.557	29.226	0.362	0.153	7.751	0.110	-0.058
201	BRK	2	CK	18.991	23.855	0.412	0.200	0.139	9.940	3.854	10.111	0.103
202	BRK	2	F	33.694	0.391	0.293	0.248	0.322	0.325	18.361	14.840	0.115
203	BRK	2	P	31.739	0.346	0.462	0.255	24.731	9.543	5.562	0.281	0.276
204	BRK	2	N	25.725	0.497	44.446	33.561	39.604	0.128	0.115	0.132	0.231
205	BRK	2	2N	2.518	0.388	0.979	0.409	35.087	25.667	13.775	20.460	0.148
206	BRK	2	HF	1.024	0.316	0.293	0.115	14.359	9.893	0.243	14.222	0.057
301	BRK	3	CK	0.528	0.427	28.748	14.953	25.617	11.601	10.007	0.061	2.044
302	BRK	3	F	0.387	0.469	0.218	14.101	0.210	0.235	0.065	0.137	0.304
303	BRK	3	P	0.500	1.382	32.489	23.486	29.936	0.288	0.152	0.050	0.074
304	BRK	3	N	67.391	0.458	0.091	33.187	0.925	0.168	0.244	0.172	0.067
305	BRK	3	2N	79.315	0.008	86.071	43.796	78.462	0.324	34.836	0.368	10.716
306	BRK	3	HF	22.181	95.024	24.636	17.934	0.101	0.258	15.270	9.760	0.105
401	BRK	4	CK	0.668	23.855	0.365	21.508	20.282	0.167	2.283	8.611	0.058
402	BRK	4	F	34.725	0.391	0.370	0.211	0.106	0.224	-0.056	0.088	0.206
403	BRK	4	P	45.602	0.346	0.456	21.422	16.317	0.204	0.138	0.180	0.014
404	BRK	4	N	140.432	0.497	92.840	44.873	1.012	48.763	0.194	0.258	0.183
405	BRK	4	2N	0.765	0.388	0.662	45.573	44.426	28.429	14.189	0.228	0.054
406	BRK	4	HF	61.199	0.316	32.292	23.045	0.437	22.659	0.167	0.083	6.935

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.10. Daily CO_2 Fluxes (kg CO_2-C ha^{-1} d^{-1}) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	05/10	05/15	05/20	05/26	06/02	06/16	06/28	06/30	07/15	07/29	08/24
101	BRK	1	CK	8.079	6.672	0.028	0.040	21.716	0.210	35.130	0.131	21.631	0.240	0.144
102	BRK	1	F	0.832	0.071	1.634	-0.002	0.108	31.526	48.918	33.783	0.569	42.540	36.738
103	BRK	1	P	14.682	3.810	0.059	0.046	23.960	25.338	32.951	32.868	32.652	0.431	40.122
104	BRK	1	N	32.185	33.105	29.496	52.114	0.475	90.798	0.532	0.663	0.514	0.520	0.482
105	BRK	1	2N	22.590	-0.006	0.087	45.610	0.231	85.757	73.967	48.218	41.851	0.714	42.958
106	BRK	1	HF	0.094	-0.003	0.088	0.053	0.329	44.210	0.413	55.811	0.849	39.657	0.408
201	BRK	2	CK	0.069	8.014	9.519	33.926	0.079	0.307	36.504	0.505	48.766	0.407	0.425
202	BRK	2	F	-0.003	-1.145	2.276	25.088	0.238	0.239	41.777	28.687	0.391	0.442	0.363
203	BRK	2	P	23.087	0.173	0.148	35.167	0.525	0.552	0.456	0.492	0.374	0.673	0.412
204	BRK	2	N	18.682	0.161	0.032	0.159	0.162	0.411	0.519	65.692	0.562	0.535	39.620
205	BRK	2	2N	0.104	26.676	0.290	76.348	0.391	0.426	0.906	1.574	105.769	0.864	0.633
206	BRK	2	HF	0.082	0.009	0.099	0.212	0.190	0.108	0.430	64.785	52.503	0.389	30.905
301	BRK	3	CK	0.007	-0.020	0.003	0.095	0.134	17.710	21.842	0.141	31.081	0.223	0.138
302	BRK	3	F	0.189	20.047	0.068	36.058	33.116	36.653	0.587	58.276	64.842	0.431	0.429
303	BRK	3	P	13.581	17.974	0.016	25.548	0.018	62.313	67.506	56.484	53.688	0.533	0.444
304	BRK	3	N	29.940	0.036	17.455	59.705	60.963	70.605	0.578	0.516	0.471	0.426	0.394
305	BRK	3	2N	48.017	0.099	43.701	0.101	0.090	61.423	42.295	40.791	28.841	32.066	33.207
306	BRK	3	HF	16.220	-0.123	0.243	38.100	0.272	39.839	38.650	40.577	55.249	0.495	0.363
401	BRK	4	CK	0.129	0.023	0.147	0.033	0.358	0.402	47.044	0.466	41.230	0.433	0.282
402	BRK	4	F	0.018	0.379	0.088	0.200	0.406	0.212	41.539	19.213	45.997	0.383	0.413
403	BRK	4	P	0.127	2.023	0.030	18.942	42.060	0.544	55.910	0.401	0.585	0.456	0.452
404	BRK	4	N	0.486	0.019	0.224	52.868	0.729	0.811	68.515	84.014	0.819	0.524	0.532
405	BRK	4	2N	0.171	0.037	15.556	0.029	0.193	0.516	61.099	76.359	0.639	0.537	0.573
406	BRK	4	HF	0.053	0.017	8.258	0.122	0.405	0.190	51.657	45.480	0.619	0.523	0.480

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.11. Daily N_2O Fluxes (g N_2O ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	06/05	06/13	06/21	06/23	06/27	07/07	07/17	07/29
101	BRK	1	CK	0.077	0.036	0.000	0.008	8.822	0.031	0.193	0.000
102	BRK	1	F	0.021	0.042	0.201	0.000	3.117	0.016	0.064	2.574
103	BRK	1	P	0.109	0.117	17.635	0.379	40.218	0.031	0.065	14.670
104	BRK	1	N	0.204	0.220	46.052	10.961	0.845	0.158	0.242	8.033
105	BRK	1	2N	159.78	0.195	515.498	1.094	0.874	65.911	44.618	1.010
106	BRK	1	HF	0.001	0.008	0.000	0.048	0.049	0.128	0.000	0.062
201	BRK	2	CK	0.002	1.096	9.600	0.029	7.901	0.000	0.207	0.090
202	BRK	2	F	0.055	0.042	0.000	0.060	0.177	0.023	0.045	0.010
203	BRK	2	P	0.152	0.089	0.091	3.805	0.154	0.041	0.051	0.108
204	BRK	2	N	0.205	0.207	36.711	36.185	1.189	17.291	0.100	0.129
205	BRK	2	2N	0.170	3.480	0.195	0.621	0.576	0.591	73.367	1.050
206	BRK	2	HF	0.010	4.400	0.070	0.029	0.168	0.030	0.633	0.063
301	BRK	3	CK	0.027	0.000	0.030	0.000	0.017	0.004	0.187	0.000
302	BRK	3	F	0.000	0.011	3.041	0.000	0.136	0.000	0.000	0.023
303	BRK	3	P	0.017	0.046	0.041	0.030	0.051	0.031	0.078	0.039
304	BRK	3	N	26.177	0.079	0.726	56.716	0.714	16.437	0.279	0.189
305	BRK	3	2N	22.070	0.615	0.849	59.723	0.928	0.208	40.904	0.332
306	BRK	3	HF	38.969	18.813	48.625	0.227	79.813	0.022	0.138	0.040
401	BRK	4	CK	0.000	0.057	3.014	0.036	0.000	0.010	0.185	0.037
402	BRK	4	F	0.000	2.922	0.024	2.602	0.000	0.000	0.001	0.050
403	BRK	4	P	0.163	6.489	0.151	0.109	0.199	0.051	0.031	0.079
404	BRK	4	N	21.611	1.759	2.169	1.552	0.631	104.926	1.974	37.353
405	BRK	4	2N	61.126	0.270	0.595	0.551	24.015	9.197	19.913	5.680
406	BRK	4	HF	12.188	0.061	0.070	7.767	0.839	5.576	0.038	0.167

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.12. Daily N_2O Fluxes (g N_2O ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	08/02	08/16	08/22	08/25	08/31	09/15	09/20	09/22	10/08
101	BRK	1	CK	0.011	0.047	0.000	0.000	0.035	0.108	0.000	0.096	0.104
102	BRK	1	F	0.002	0.043	0.044	0.019	0.000	0.037	0.000	5.057	9.551
103	BRK	1	P	3.408	0.280	0.055	0.044	0.080	0.082	0.012	0.047	23.681
104	BRK	1	N	0.088	0.000	0.070	13.341	0.111	0.034	0.059	11.440	0.201
105	BRK	1	2N	0.510	0.000	0.359	0.069	18.524	0.103	0.062	0.138	0.012
106	BRK	1	HF	0.015	119.972	0.022	0.039	0.154	0.059	0.032	0.000	0.000
201	BRK	2	CK	0.013	0.142	0.021	0.004	0.000	0.040	0.039	0.072	0.155
202	BRK	2	F	0.052	0.035	0.036	0.000	0.000	0.021	0.034	0.018	0.090
203	BRK	2	P	0.057	0.031	0.028	0.033	0.057	0.036	0.002	0.145	0.220
204	BRK	2	N	1.201	0.347	0.127	0.035	0.058	0.000	0.072	0.134	0.244
205	BRK	2	2N	0.987	0.055	0.708	0.209	14.652	0.173	5.450	0.151	5.815
206	BRK	2	HF	0.121	0.057	0.069	0.000	0.000	0.008	0.111	0.000	0.000
301	BRK	3	CK	0.053	0.047	0.043	0.000	11.644	11.458	0.097	0.000	0.000
302	BRK	3	F	0.040	0.043	0.000	0.027	0.012	0.073	0.000	0.008	0.327
303	BRK	3	P	0.059	0.280	0.014	0.067	0.035	0.392	0.095	0.045	0.149
304	BRK	3	N	0.082	0.000	0.038	0.024	0.527	0.142	7.634	0.039	0.000
305	BRK	3	2N	22.916	0.000	22.773	0.052	0.165	0.019	0.026	0.094	0.000
306	BRK	3	HF	0.031	119.972	0.038	0.033	0.000	0.060	0.030	0.000	10.766
401	BRK	4	CK	0.026	0.142	0.068	0.013	3.318	0.042	0.028	0.049	6.784
402	BRK	4	F	0.029	0.035	0.042	0.017	0.000	0.034	0.000	0.008	0.111
403	BRK	4	P	0.015	0.031	0.057	0.076	0.084	0.000	5.968	0.044	0.000
404	BRK	4	N	216.344	0.347	0.414	37.347	0.653	46.032	7.267	12.557	0.226
405	BRK	4	2N	0.080	0.055	11.659	0.125	2.394	0.065	0.095	0.031	0.000
406	BRK	4	HF	0.030	0.057	0.057	0.051	0.191	0.071	0.111	0.000	0.042

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.13. Daily N_2O Fluxes (g N_2O ha^{-1} d^{-1}) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	05/10	05/15	05/20	05/26	06/02	06/16	06/28	06/30	07/15	07/29	08/24
101	BRK	1	CK	0.110	0.006	0.022	0.000	0.046	0.013	0.030	0.000	0.043	0.051	0.000
102	BRK	1	F	0.008	0.012	0.000	0.002	0.108	11.098	0.095	0.114	0.083	0.064	0.020
103	BRK	1	P	0.170	0.000	0.000	0.035	0.127	0.094	0.249	0.155	0.105	0.057	0.057
104	BRK	1	N	0.385	0.388	27.584	0.220	0.265	0.257	0.128	0.064	0.044	0.051	13.957
105	BRK	1	2N	10.056	0.000	7.640	0.249	0.154	0.098	0.294	0.140	0.118	0.020	0.196
106	BRK	1	HF	0.050	0.000	0.083	0.000	0.292	212.524	98.259	170.239	1.442	0.356	0.025
201	BRK	2	CK	0.000	0.000	0.111	0.092	0.062	0.110	0.026	0.087	0.029	0.013	0.106
202	BRK	2	F	0.023	0.000	0.038	0.000	8.592	0.420	74.668	0.274	85.319	0.142	0.094
203	BRK	2	P	0.343	8.853	0.239	0.146	0.210	0.220	17.083	0.120	0.080	0.464	0.000
204	BRK	2	N	0.179	0.078	0.000	0.178	0.083	0.115	0.038	0.094	0.077	0.000	0.000
205	BRK	2	2N	0.168	22.161	0.582	72.909	0.832	0.542	0.879	1.143	0.367	0.133	15.989
206	BRK	2	HF	0.000	0.024	0.035	0.077	0.107	1.711	25.393	444.550	408.425	1.343	0.107
301	BRK	3	CK	0.020	0.005	0.000	0.000	0.029	0.096	0.063	0.000	0.005	0.039	0.000
302	BRK	3	F	0.052	0.143	0.035	7.302	0.070	16.487	0.049	0.161	0.292	0.041	0.000
303	BRK	3	P	9.035	11.889	0.000	0.047	0.033	22.522	0.116	0.058	0.050	1.858	0.032
304	BRK	3	N	33.610	0.000	0.054	67.662	98.141	24.402	0.294	0.117	0.066	0.148	0.283
305	BRK	3	2N	34.071	0.025	30.718	0.000	0.067	0.069	0.206	0.128	0.009	0.009	0.016
306	BRK	3	HF	0.000	0.000	0.105	14.319	0.129	342.713	20.110	85.206	377.606	2.417	0.093
401	BRK	4	CK	0.096	0.000	0.052	0.038	0.117	0.012	0.000	0.000	0.050	4.006	0.094
402	BRK	4	F	0.017	0.333	0.026	0.000	0.126	1.050	113.986	0.574	0.954	0.050	0.083
403	BRK	4	P	0.106	0.015	0.049	0.061	17.738	0.000	11.014	0.132	0.066	2.566	0.000
404	BRK	4	N	0.876	0.097	0.133	50.304	40.344	0.212	0.102	0.148	0.157	0.000	0.069
405	BRK	4	2N	0.238	0.015	0.310	0.086	0.419	0.643	99.205	0.686	0.511	0.086	0.500
406	BRK	4	HF	0.000	0.000	0.004	3.786	0.112	0.254	97.683	67.369	0.048	0.089	0.022

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.14. Water Filled Pore Space (WFPS; m^3 m^{-3}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	06/05	06/13	06/21	06/23	06/27	07/07	07/17	07/29	08/02
101	BRK	1	CK	69.55	62.93	52.16	66.65	71.21	70.17	65.52	71.83	61.38
102	BRK	1	F	54.07	49.52	58.16	61.79	65.52	60.52	59.88	64.61	57.79
103	BRK	1	P	49.28	38.05	51.51	47.40	52.97	52.79	49.97	54.68	35.40
104	BRK	1	N	46.75	41.89	46.00	52.42	51.23	51.60	51.68	48.84	42.42
105	BRK	1	2N	53.34	47.27	49.80	50.45	54.50	52.62	50.38	46.40	39.54
106	BRK	1	HF	48.02	44.96	55.39	55.14	55.47	56.22	39.66	50.17	41.23
201	BRK	2	CK	52.88	51.41	50.19	54.87	53.14	48.37	59.21	58.25	56.09
202	BRK	2	F	66.11	52.87	55.84	61.70	61.90	63.95	54.72	71.76	52.66
203	BRK	2	P	58.08	47.20	60.63	61.33	66.77	64.31	57.65	64.14	54.49
204	BRK	2	N	56.82	50.84	61.66	59.81	72.04	65.44	57.96	53.65	43.54
205	BRK	2	2N	57.10	45.42	48.56	55.49	58.12	57.68	53.08	51.92	44.54
206	BRK	2	HF	50.54	45.60	49.42	51.82	55.24	47.11	46.55	59.95	44.72
301	BRK	3	CK	58.26	60.91	64.85	62.38	64.76	57.89	57.53	63.94	45.16
302	BRK	3	F	56.08	50.01	57.82	59.29	62.51	63.55	58.43	58.69	43.84
303	BRK	3	P	58.35	59.05	56.87	61.32	60.53	55.91	54.60	59.75	41.95
304	BRK	3	N	57.27	56.58	58.56	61.76	65.29	62.27	50.20	57.87	47.78
305	BRK	3	2N	44.53	37.64	44.23	57.63	57.78	57.33	49.15	56.65	44.53
306	BRK	3	HF	60.95	61.59	62.42	64.52	66.26	62.51	48.41	62.51	48.14
401	BRK	4	CK	49.16	41.72	47.00	53.23	51.33	52.37	48.30	60.16	39.04
402	BRK	4	F	49.93	49.74	53.00	50.86	58.02	54.21	59.88	57.37	48.07
403	BRK	4	P	54.46	39.49	53.75	51.98	53.93	60.30	49.94	60.30	37.10
404	BRK	4	N	49.07	46.79	63.18	63.27	68.26	67.47	67.39	64.76	46.00
405	BRK	4	2N	51.27	46.16	47.23	50.20	57.74	55.99	53.78	52.56	34.51
406	BRK	4	HF	42.92	46.74	47.46	51.52	54.31	50.49	52.87	49.37	40.85

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.15. Water Filled Pore Space (WFPS; $m^3\ m^{-3}$) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	08/16	08/22	08/25	08/31	09/15	09/20	09/22	10/08
101	BRK	1	CK	78.97	70.48	62.10	55.99	45.95	44.09	48.33	55.68
102	BRK	1	F	75.51	64.61	51.71	36.17	49.89	50.80	45.44	48.80
103	BRK	1	P	72.68	58.45	42.77	43.80	43.20	33.08	35.65	41.05
104	BRK	1	N	63.18	54.89	44.06	34.87	41.59	35.62	38.38	39.21
105	BRK	1	2N	53.13	50.96	45.46	38.74	37.37	39.18	25.37	40.40
106	BRK	1	HF	53.40	56.13	46.61	41.65	38.42	32.70	28.98	33.20
201	BRK	2	CK	66.23	53.23	39.53	30.08	33.55	34.33	34.94	49.33
202	BRK	2	F	80.48	63.03	53.69	35.83	50.51	51.33	42.91	54.30
203	BRK	2	P	68.17	61.42	48.87	50.01	45.36	43.69	38.69	52.29
204	BRK	2	N	66.58	63.15	50.66	46.35	37.21	42.13	25.33	38.61
205	BRK	2	2N	56.44	48.19	45.49	39.43	43.45	39.50	27.24	39.87
206	BRK	2	HF	57.63	55.88	48.47	45.28	42.57	42.33	28.14	52.69
301	BRK	3	CK	69.89	63.94	39.94	36.27	39.76	42.23	44.15	53.59
302	BRK	3	F	72.14	59.47	44.10	38.02	41.41	38.81	42.10	50.44
303	BRK	3	P	73.96	60.27	49.10	45.18	49.54	52.16	44.31	47.62
304	BRK	3	N	72.97	64.00	57.87	49.77	56.67	52.01	37.86	53.30
305	BRK	3	2N	55.66	57.93	49.22	37.18	48.47	44.53	33.55	34.61
306	BRK	3	HF	59.03	66.08	49.97	48.14	57.84	45.03	27.91	46.13
401	BRK	4	CK	66.13	58.51	45.53	32.03	43.62	44.40	35.75	43.45
402	BRK	4	F	72.90	52.81	53.84	37.29	41.93	40.07	49.93	48.81
403	BRK	4	P	68.81	63.67	44.81	33.65	40.73	35.07	27.01	30.37
404	BRK	4	N	66.33	65.98	48.02	42.94	43.46	38.56	32.51	46.97
405	BRK	4	2N	58.88	57.59	46.09	42.43	34.20	37.10	21.63	31.99
406	BRK	4	HF	57.57	51.60	40.61	29.78	36.31	30.18	25.16	29.38

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.16. Water Filled Pore Space (WFPS; m^3 m^{-3}) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	05/10	05/15	05/20	05/26	06/02	06/16	06/28	06/30	07/15	07/29	08/24
101	BRK	1	CK	49.163	57.754	57.236	49.163	55.373	58.271	53.820	46.575	63.964	60.031	76.694
102	BRK	1	F	48.071	39.710	36.712	36.530	48.343	40.983	46.526	29.624	59.793	54.159	67.880
103	BRK	1	P	47.995	44.395	36.510	35.653	50.309	47.395	40.110	31.882	57.680	51.080	66.850
104	BRK	1	N	40.101	46.822	41.371	34.351	44.955	39.728	50.108	47.867	44.432	43.312	58.621
105	BRK	1	2N	30.863	45.102	41.054	36.139	42.645	47.632	39.609	35.489	46.837	43.078	53.848
106	BRK	1	HF	49.179	47.689	48.020	39.741	50.752	49.510	43.798	42.887	52.491	63.420	66.069
201	BRK	2	CK	41.264	31.555	37.709	31.381	41.350	39.183	33.115	34.762	51.840	50.279	68.310
202	BRK	2	F	43.013	56.563	61.080	31.926	45.579	50.917	61.285	47.016	61.183	61.183	76.684
203	BRK	2	P	53.346	45.098	50.714	39.220	46.853	47.467	45.098	52.205	61.506	50.889	69.490
204	BRK	2	N	42.044	46.618	41.604	42.132	58.228	45.210	50.048	43.099	55.765	52.423	70.806
205	BRK	2	2N	48.776	31.616	38.991	34.464	43.810	38.188	33.515	41.912	49.068	55.931	59.947
206	BRK	2	HF	38.583	35.793	34.198	26.147	40.815	41.452	34.836	33.640	45.040	61.063	63.614
301	BRK	3	CK	50.106	61.648	49.190	39.572	55.877	51.938	55.236	48.091	54.045	53.129	68.426
302	BRK	3	F	30.472	39.674	37.764	45.491	47.661	42.973	30.732	35.854	46.098	51.741	66.326
303	BRK	3	P	33.231	37.243	46.837	32.708	44.569	42.738	38.639	38.028	53.640	50.588	70.125
304	BRK	3	N	39.158	41.573	40.193	47.524	43.643	51.923	41.573	46.231	55.201	51.406	62.705
305	BRK	3	2N	46.649	45.589	44.831	35.441	44.453	44.301	33.926	33.396	53.010	58.008	55.131
306	BRK	3	HF	46.950	52.441	60.586	34.228	51.617	56.925	43.106	40.635	55.918	70.104	68.731
401	BRK	4	CK	33.151	31.247	42.932	43.797	42.932	40.768	33.930	30.554	53.751	50.202	56.521
402	BRK	4	F	39.517	43.329	42.027	44.445	46.025	45.003	45.839	40.447	59.787	55.416	71.037
403	BRK	4	P	49.147	47.642	42.417	40.912	46.225	46.933	46.579	33.650	51.804	51.361	71.197
404	BRK	4	N	50.649	40.747	40.572	41.273	41.624	56.696	46.093	36.103	54.768	52.227	66.072
405	BRK	4	2N	43.954	35.651	39.231	42.430	36.412	36.717	27.881	27.347	44.487	58.351	58.275
406	BRK	4	HF	43.876	34.719	40.293	44.115	40.770	35.913	33.126	29.861	49.370	60.996	60.439

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.17. Soil Temperature (^{0}C) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**REP**	**TRT**	**06/05**	**06/13**	**06/21**	**06/23**	**06/27**	**07/07**	**07/17**	**07/29**	**08/02**
101	BRK	1	CK	23.7	23.85	21.6	23	27.55	17.55	25	20.45	22.25
102	BRK	1	F	25.15	22.25	22.3	22.95	26.4	16.45	24.35	18.75	25
103	BRK	1	P	21.7	22.25	21.4	23.2	26.05	16.55	23.2	18.7	21.6
104	BRK	1	N	23.1	21.95	21.65	23.2	26.55	16.5	22.35	19.1	21.7
105	BRK	1	2N	22.55	21.55	19.95	23.05	27.05	18.15	24.3	21.15	23.25
106	BRK	1	HF	23.9	22.2	22.8	22.8	28.4	16.85	24	19.7	26.05
201	BRK	2	CK	22.2	21.5	21.9	21.55	27.45	16.65	23.45	20.1	22.1
202	BRK	2	F	23.95	22.85	23.15	22.5	28.4	19	24.95	19.9	21.35
203	BRK	2	P	23.85	21.2	20.6	23.05	28.15	16.6	23.55	19.8	25.6
204	BRK	2	N	22.8	20.3	20.75	21.75	25.55	16.5	21.75	19.25	22.8
205	BRK	2	2N	19.6	19.5	19.75	21.7	27.2	17.9	24.75	21.1	22.7
206	BRK	2	HF	23.9	22.1	23.45	23.95	28.9	17.1	23.8	19.5	21.2
301	BRK	3	CK	24.45	22.65	23.1	23.3	27.2	18.65	27.2	21	24.4
302	BRK	3	F	24.2	22.55	23.75	22.45	26.3	18.45	26.2	19.4	23.15
303	BRK	3	P	21.3	21.05	23.35	23.15	26.9	17.9	27.35	19.45	20.6
304	BRK	3	N	22.95	21.7	22.4	21.5	25.85	17.55	25.3	21.4	25.8
305	BRK	3	2N	21.3	20.75	22.35	22	25.4	17.15	23.85	19.6	20.8
306	BRK	3	HF	23	23.55	23	21.4	26.95	17.25	23.4	19.2	20.65
401	BRK	4	CK	23.6	22.55	23.6	23.3	26.55	18.35	26.2	20.5	22.8
402	BRK	4	F	20.75	22.3	21.25	21.7	25.85	18.15	25.8	19.4	20.95
403	BRK	4	P	22.85	22.6	23.4	23.7	26.65	18.55	26.55	19.75	21.2
404	BRK	4	N	22.85	22.3	23.3	21.7	25	17.6	25.4	20.9	24.5
405	BRK	4	2N	21.4	19.05	20.25	20.1	24.9	17.9	30.05	19.55	23.2
406	BRK	4	HF	23.1	23.15	23.75	22.6	26	17.7	26.65	19.65	21.8

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.18. Soil Temperature (^{0}C) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**REP**	**TRT**	**08/16**	**08/22**	**08/25**	**08/31**	**09/15**	**09/20**	**09/22**	**10/08**
101	BRK	1	CK	20.55	19.15	16.95	20.2	25	18.2	23.25	15.45
102	BRK	1	F	20.25	19	14.15	19	20.3	14.75	25.4	14.35
103	BRK	1	P	20.6	19.1	19.3	19.6	21.2	15.7	18.85	14.65
104	BRK	1	N	20.35	18.95	18.2	21.45	25.05	16.9	26.45	14.3
105	BRK	1	2N	20.6	19.35	14.8	17.3	22.4	14.9	25.8	14.35
106	BRK	1	HF	20.65	19.2	15.55	22.35	24.3	16.4	24.25	14.55
201	BRK	2	CK	20.35	19.3	16.2	21.55	23	16.1	22.75	13.95
202	BRK	2	F	20.6	19.35	16.4	21.6	21.45	15.65	25.45	15.25
203	BRK	2	P	20.5	21.15	17.65	21.8	23.15	17.7	18.9	13.9
204	BRK	2	N	20.75	19.2	16.35	21.65	21.9	16.7	22.95	14.9
205	BRK	2	2N	20.55	19.3	15.25	20.65	21.5	15.3	23	14.8
206	BRK	2	HF	20.65	19.25	14.8	19.4	21.85	16.35	19.55	14.75
301	BRK	3	CK	20.55	18.7	20.45	22.15	23	16.6	17.75	13.55
302	BRK	3	F	20.25	18.7	16.5	19.5	20.4	17.25	17.6	13.8
303	BRK	3	P	20.6	18.5	13.75	19.8	19.35	14.7	16.4	13.7
304	BRK	3	N	20.35	19	15.9	22.1	20.5	15.45	17.35	7.805
305	BRK	3	2N	20.6	18.45	14.15	19.5	20.4	14.85	22.8	14.45
306	BRK	3	HF	20.65	18.4	15.8	19.05	20.4	15.3	21.4	14.65
401	BRK	4	CK	20.35	18.95	13.95	20.55	20.5	15.55	21.4	14.35
402	BRK	4	F	20.6	26.6	14.05	18.9	21.25	15.95	18.9	13.65
403	BRK	4	P	20.5	18.9	14.2	20.1	22.75	15.85	17.2	14
404	BRK	4	N	20.75	19.15	13.95	22.3	21.6	15.1	20.4	14.1
405	BRK	4	2N	20.55	18.3	14.7	20	21.2	16.8	22.35	13.8
406	BRK	4	HF	20.65	19.45	13.9	19.9	20.55	15.1	24	14.7

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.19. Soil Temperature (^{0}C) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	05/10	05/15	05/20	05/26	06/02	06/16	06/28	06/30	07/15	07/29	08/24
101	BRK	1	CK	13.4	15.7	14.85	17.7	29.6	24.5	21.8	21.85	17	19.25	18.2
102	BRK	1	F	13.15	11.55	13.25	18.6	28.75	27.15	23.15	23.7	17.9	19.4	18.75
103	BRK	1	P	13.6	14.65	15.5	20.6	28.65	28.55	22.75	23.65	19.4	20.4	19.45
104	BRK	1	N	13.45	12.95	14.85	19.3	29.3	26.7	23.5	24.7	18.95	20.5	20.4
105	BRK	1	2N	13.15	17.1	14.55	17.35	31.5	25.3	21.5	22.65	17.9	19.5	18.6
106	BRK	1	HF	13.05	15.05	14.2	17.5	29.85	28.35	24.75	22.9	18.8	20.05	18.6
201	BRK	2	CK	13.55	15.85	15.55	21.35	30.75	26.25	23.05	23.8	19.3	20.45	18.95
202	BRK	2	F	13.1	15.95	14.7	19.2	27.5	28.25	23.35	23.8	18.5	21.75	18.95
203	BRK	2	P	13.15	13.4	13.8	17.95	28.95	23.2	20.5	21.1	17.4	18.9	18.65
204	BRK	2	N	12.85	10.3	13	16.75	25.35	26.95	21.4	21.15	17.45	19.35	18.6
205	BRK	2	2N	12.9	13.05	14.7	21.35	29.4	26.15	21.45	21.45	17.85	19.7	19.05
206	BRK	2	HF	13.55	14.1	15.4	19.15	28.35	25.95	23.85	23.9	18.15	20.75	19.05
301	BRK	3	CK	13.05	14.5	13.2	16.85	25.1	22.8	19.8	20.45	17.3	18.8	18.3
302	BRK	3	F	12.85	10.8	13.9	18.4	23.25	24.25	19.8	20.5	16.65	19	18.35
303	BRK	3	P	12.9	11.9	13.8	19.9	29.15	26.15	20.95	22.35	17.8	20.1	19.2
304	BRK	3	N	13.35	12.55	14.35	18.3	28.4	27.15	21.1	22.25	18.75	20.25	19.05
305	BRK	3	2N	12.55	13.1	13.45	18.1	24.05	23.2	20	20.75	17.75	19.35	18.4
306	BRK	3	HF	12.3	9.4	12.05	16.25	26.65	24.25	19.8	22.1	18.75	19.5	19.1
401	BRK	4	CK	13.3	15.45	14.4	18.15	28.1	26.8	21.5	22.1	17.7	20.35	19
402	BRK	4	F	12.55	12.05	12.7	17.7	25.4	26.55	22.9	22.65	17.95	19.7	18.6
403	BRK	4	P	13	13.8	14.4	17.5	27.05	25.05	20.6	21.2	17.1	19.25	18.25
404	BRK	4	N	13.15	15.9	13.55	18.45	27.95	27.8	23.25	22.35	18.25	19.7	18.25
405	BRK	4	2N	13.25	15.25	14.35	20.35	29.3	26.25	22.2	22.75	17.75	20.2	18.85
406	BRK	4	HF	13.25	13.5	14.4	19.5	31.1	27.7	23.9	23.2	19.65	20.75	19.85

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.20 Soil Moisture (m^3 m^{-3}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	06/05	06/13	06/21	06/23	06/27	07/07	07/17	07/29	08/02
101	BRK	1	CK	33.6	30.4	25.2	32.2	34.4	33.9	31.65	34.7	29.65
102	BRK	1	F	29.75	27.25	32	34	36.05	33.3	32.95	35.55	31.8
103	BRK	1	P	28.75	22.2	30.05	27.65	30.9	30.8	29.15	31.9	20.65
104	BRK	1	N	31.3	28.05	30.8	35.1	34.3	34.55	34.6	32.7	28.4
105	BRK	1	2N	36.9	32.7	34.45	34.9	37.7	36.4	34.85	32.1	27.35
106	BRK	1	HF	29	27.15	33.45	33.3	33.5	33.95	23.95	30.3	24.9
201	BRK	2	CK	30.5	29.65	28.95	31.65	30.65	27.9	34.15	33.6	32.35
202	BRK	2	F	32.2	25.75	27.2	30.05	30.15	31.15	26.65	34.95	25.65
203	BRK	2	P	33.1	26.9	34.55	34.95	38.05	36.65	32.85	36.55	31.05
204	BRK	2	N	32.3	28.9	35.05	34	40.95	37.2	32.95	30.5	24.75
205	BRK	2	2N	39.1	31.1	33.25	38	39.8	39.5	36.35	35.55	30.5
206	BRK	2	HF	31.7	28.6	31	32.5	34.65	29.55	29.2	37.6	28.05
301	BRK	3	CK	31.8	33.25	35.4	34.05	35.35	31.6	31.4	34.9	24.65
302	BRK	3	F	32.3	28.8	33.3	34.15	36	36.6	33.65	33.8	25.25
303	BRK	3	P	33.45	33.85	32.6	35.15	34.7	32.05	31.3	34.25	24.05
304	BRK	3	N	33.2	32.8	33.95	35.8	37.85	36.1	29.1	33.55	27.7
305	BRK	3	2N	29.4	24.85	29.2	38.05	38.15	37.85	32.45	37.4	29.4
306	BRK	3	HF	33.3	33.65	34.1	35.25	36.2	34.15	26.45	34.15	26.3
401	BRK	4	CK	28.4	24.1	27.15	30.75	29.65	30.25	27.9	34.75	22.55
402	BRK	4	F	26.85	26.75	28.5	27.35	31.2	29.15	32.2	30.85	25.85
403	BRK	4	P	30.75	22.3	30.35	29.35	30.45	34.05	28.2	34.05	20.95
404	BRK	4	N	28	26.7	36.05	36.1	38.95	38.5	38.45	36.95	26.25
405	BRK	4	2N	33.65	30.3	31	32.95	37.9	36.75	35.3	34.5	22.65
406	BRK	4	HF	26.95	29.35	29.8	32.35	34.1	31.7	33.2	31	25.65

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.21. Soil Moisture (m^3 m^{-3}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	08/16	08/22	08/25	08/31	09/15	09/20	09/22	10/08
101	BRK	1	CK	38.15	34.05	30	27.05	22.2	21.3	23.35	26.9
102	BRK	1	F	41.55	35.55	28.45	19.9	27.45	27.95	25	26.85
103	BRK	1	P	42.4	34.1	24.95	25.55	25.2	19.3	20.8	23.95
104	BRK	1	N	42.3	36.75	29.5	23.35	27.85	23.85	25.7	26.25
105	BRK	1	2N	36.75	35.25	31.45	26.8	25.85	27.1	17.55	27.95
106	BRK	1	HF	32.25	33.9	28.15	25.15	23.2	19.75	17.5	20.05
201	BRK	2	CK	38.2	30.7	22.8	17.35	19.35	19.8	20.15	28.45
202	BRK	2	F	39.2	30.7	26.15	17.45	24.6	25	20.9	26.45
203	BRK	2	P	38.85	35	27.85	28.5	25.85	24.9	22.05	29.8
204	BRK	2	N	37.85	35.9	28.8	26.35	21.15	23.95	14.4	21.95
205	BRK	2	2N	38.65	33	31.15	27	29.75	27.05	18.65	27.3
206	BRK	2	HF	36.15	35.05	30.4	28.4	26.7	26.55	17.65	33.05
301	BRK	3	CK	38.15	34.9	21.8	19.8	21.7	23.05	24.1	29.25
302	BRK	3	F	41.55	34.25	25.4	21.9	23.85	22.35	24.25	29.05
303	BRK	3	P	42.4	34.55	28.15	25.9	28.4	29.9	25.4	27.3
304	BRK	3	N	42.3	37.1	33.55	28.85	32.85	30.15	21.95	30.9
305	BRK	3	2N	36.75	38.25	32.5	24.55	32	29.4	22.15	22.85
306	BRK	3	HF	32.25	36.1	27.3	26.3	31.6	24.6	15.25	25.2
401	BRK	4	CK	38.2	33.8	26.3	18.5	25.2	25.65	20.65	25.1
402	BRK	4	F	39.2	28.4	28.95	20.05	22.55	21.55	26.85	26.25
403	BRK	4	P	38.85	35.95	25.3	19	23	19.8	15.25	17.15
404	BRK	4	N	37.85	37.65	27.4	24.5	24.8	22	18.55	26.8
405	BRK	4	2N	38.65	37.8	30.25	27.85	22.45	24.35	14.2	21
406	BRK	4	HF	36.15	32.4	25.5	18.7	22.8	18.95	15.8	18.45

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.22. Soil Moisture (m^3 m^{-3}) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	05/10	05/15	05/20	05/26	06/02	06/16	06/28	06/30	07/15	07/29	08/24
101	BRK	1	CK	23.75	27.9	27.65	23.75	26.75	28.15	26	22.5	30.9	29	37.05
102	BRK	1	F	26.45	21.85	20.2	20.1	26.6	22.55	25.6	16.3	32.9	29.8	37.35
103	BRK	1	P	28	25.9	21.3	20.8	29.35	27.65	23.4	18.6	33.65	29.8	39
104	BRK	1	N	26.85	31.35	27.7	23	30.1	26.6	33.55	32.05	29.75	29	39.25
105	BRK	1	2N	21.35	31.2	28.4	25	29.5	32.95	27.4	24.55	32.4	29.8	37.25
106	BRK	1	HF	29.7	28.8	29	24	30.65	29.9	26.45	25.9	31.7	38.3	39.9
201	BRK	2	CK	23.8	18.2	21.75	18.1	23.85	22.6	19.1	20.05	29.9	29	39.4
202	BRK	2	F	20.95	27.55	29.75	15.55	22.2	24.8	29.85	22.9	29.8	29.8	37.35
203	BRK	2	P	30.4	25.7	28.9	22.35	26.7	27.05	25.7	29.75	35.05	29	39.6
204	BRK	2	N	23.9	26.5	23.65	23.95	33.1	25.7	28.45	24.5	31.7	29.8	40.25
205	BRK	2	2N	33.4	21.65	26.7	23.6	30	26.15	22.95	28.7	33.6	38.3	41.05
206	BRK	2	HF	24.2	22.45	21.45	16.4	25.6	26	21.85	21.1	28.25	38.3	39.9
301	BRK	3	CK	27.35	33.65	26.85	21.6	30.5	28.35	30.15	26.25	29.5	29	37.35
302	BRK	3	F	17.55	22.85	21.75	26.2	27.45	24.75	17.7	20.65	26.55	29.8	38.2
303	BRK	3	P	19.05	21.35	26.85	18.75	25.55	24.5	22.15	21.8	30.75	29	40.2
304	BRK	3	N	22.7	24.1	23.3	27.55	25.3	30.1	24.1	26.8	32	29.8	36.35
305	BRK	3	2N	30.8	30.1	29.6	23.4	29.35	29.25	22.4	22.05	35	38.3	36.4
306	BRK	3	HF	25.65	28.65	33.1	18.7	28.2	31.1	23.55	22.2	30.55	38.3	37.55
401	BRK	4	CK	19.15	18.05	24.8	25.3	24.8	23.55	19.6	17.65	31.05	29	32.65
402	BRK	4	F	21.25	23.3	22.6	23.9	24.75	24.2	24.65	21.75	32.15	29.8	38.2
403	BRK	4	P	27.75	26.9	23.95	23.1	26.1	26.5	26.3	19	29.25	29	40.2
404	BRK	4	N	28.9	23.25	23.15	23.55	23.75	32.35	26.3	20.6	31.25	29.8	37.7
405	BRK	4	2N	28.85	23.4	25.75	27.85	23.9	24.1	18.3	17.95	29.2	38.3	38.25
406	BRK	4	HF	27.55	21.8	25.3	27.7	25.6	22.55	20.8	18.75	31	38.3	37.95

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.23. Monthly N_2O Fluxes (g N_2O ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	June	July	August	September	October
101	BRK	1	CK	8.943	0.224	0.094	0.204	0.104
102	BRK	1	F	3.381	2.654	0.109	5.095	9.551
103	BRK	1	P	58.458	14.766	3.867	0.141	23.681
104	BRK	1	N	58.282	8.433	13.611	11.533	0.201
105	BRK	1	2N	677.441	111.540	19.462	0.303	0.012
106	BRK	1	HF	0.107	0.190	120.202	0.092	0.000
201	BRK	2	CK	18.628	0.297	0.179	0.150	0.155
202	BRK	2	F	0.333	0.078	0.123	0.073	0.090
203	BRK	2	P	4.291	0.201	0.207	0.182	0.220
204	BRK	2	N	74.496	17.520	1.767	0.206	0.244
205	BRK	2	2N	5.041	75.009	16.611	5.774	5.815
206	BRK	2	HF	4.677	0.727	0.246	0.120	0.000
301	BRK	3	CK	0.074	0.191	11.787	11.555	0.000
302	BRK	3	F	3.189	0.023	0.123	0.081	0.327
303	BRK	3	P	0.185	0.148	0.456	0.531	0.149
304	BRK	3	N	84.413	16.905	0.670	7.816	0.000
305	BRK	3	2N	84.185	41.445	45.905	0.139	0.000
306	BRK	3	HF	186.446	0.201	120.073	0.090	10.766
401	BRK	4	CK	3.106	0.231	3.566	0.118	6.784
402	BRK	4	F	5.548	0.050	0.123	0.043	0.111
403	BRK	4	P	7.111	0.161	0.264	6.012	0.000
404	BRK	4	N	27.723	144.253	255.105	65.856	0.226
405	BRK	4	2N	86.556	34.790	14.315	0.191	0.000
406	BRK	4	HF	20.925	5.782	0.386	0.183	0.042

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.24. Monthly N_2O Fluxes (g N_2O ha^{-1} d^{-1}) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**REP**	**TRT**	**May**	**June**	**July**	**August**
101	BRK	1	CK	0.138	0.089	0.094	0.000
102	BRK	1	F	0.022	11.416	0.147	0.020
103	BRK	1	P	0.204	0.625	0.162	0.057
104	BRK	1	N	28.577	0.713	0.095	13.957
105	BRK	1	2N	17.945	0.685	0.138	0.196
106	BRK	1	HF	0.133	481.314	1.797	0.025
201	BRK	2	CK	0.203	0.285	0.042	0.106
202	BRK	2	F	0.061	83.953	85.461	0.094
203	BRK	2	P	9.581	17.633	0.544	0.000
204	BRK	2	N	0.435	0.329	0.077	0.000
205	BRK	2	2N	95.819	3.396	0.501	15.989
206	BRK	2	HF	0.137	471.761	409.768	0.107
301	BRK	3	CK	0.025	0.189	0.044	0.000
302	BRK	3	F	7.531	16.767	0.333	0.000
303	BRK	3	P	20.971	22.729	1.907	0.032
304	BRK	3	N	101.326	122.954	0.214	0.283
305	BRK	3	2N	64.814	0.470	0.018	0.016
306	BRK	3	HF	14.424	448.158	380.023	0.093
401	BRK	4	CK	0.187	0.129	4.056	0.094
402	BRK	4	F	0.375	115.736	1.004	0.083
403	BRK	4	P	0.231	28.884	2.632	0.000
404	BRK	4	N	51.411	40.807	0.157	0.069
405	BRK	4	2N	0.650	100.954	0.597	0.500
406	BRK	4	HF	3.791	165.418	0.137	0.022

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.25. Monthly CO_2 Fluxes (kg CO_2-C ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**REP**	**TRT**	**June**	**July**	**August**	**September**	**October**
101	BRK	1	CK	33.646	1.019	23.443	13.614	0.147
102	BRK	1	F	122.391	55.468	50.776	52.504	13.188
103	BRK	1	P	262.812	97.602	122.423	38.578	16.103
104	BRK	1	N	90.830	40.222	2.727	16.288	0.358
105	BRK	1	2N	548.731	157.778	102.120	83.978	23.258
106	BRK	1	HF	43.793	52.370	160.293	8.014	-0.058
201	BRK	2	CK	96.264	1.148	43.596	23.905	0.103
202	BRK	2	F	39.883	33.983	34.947	33.527	0.115
203	BRK	2	P	140.043	51.996	57.532	15.385	0.276
204	BRK	2	N	150.346	150.637	143.834	0.375	0.231
205	BRK	2	2N	315.685	65.394	39.381	59.901	0.148
206	BRK	2	HF	46.124	0.730	16.107	24.357	0.057
301	BRK	3	CK	31.693	16.660	70.273	21.668	2.044
302	BRK	3	F	70.648	30.889	15.387	0.437	0.304
303	BRK	3	P	79.755	74.434	87.793	0.490	0.074
304	BRK	3	N	180.624	2.397	102.053	0.584	0.067
305	BRK	3	2N	443.079	283.773	287.652	35.527	10.716
306	BRK	3	HF	101.429	42.029	159.875	25.288	0.105
401	BRK	4	CK	16.118	1.352	66.678	11.060	0.058
402	BRK	4	F	12.844	1.300	35.803	0.256	0.206
403	BRK	4	P	27.902	1.443	84.142	0.522	0.014
404	BRK	4	N	68.131	185.392	279.654	49.215	0.183
405	BRK	4	2N	194.409	42.402	91.815	42.846	0.054
406	BRK	4	HF	81.399	61.619	117.290	22.908	6.935

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.26. Monthly CO_2 Fluxes (kg CO_2-C ha^{-1} d^{-1}) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	May	June	July	August
101	BRK	1	CK	14.819	57.187	21.871	0.144
102	BRK	1	F	2.535	114.336	43.109	36.738
103	BRK	1	P	18.598	115.117	33.083	40.122
104	BRK	1	N	146.900	92.468	1.033	0.482
105	BRK	1	2N	68.281	208.172	42.565	42.958
106	BRK	1	HF	0.232	100.763	40.506	0.408
201	BRK	2	CK	51.528	37.394	49.173	0.425
202	BRK	2	F	26.216	70.941	0.833	0.363
203	BRK	2	P	58.575	2.026	1.046	0.412
204	BRK	2	N	19.034	66.785	1.097	39.620
205	BRK	2	2N	103.418	3.297	106.633	0.633
206	BRK	2	HF	0.403	65.513	52.892	30.905
301	BRK	3	CK	0.085	39.827	31.305	0.138
302	BRK	3	F	56.362	128.632	65.273	0.429
303	BRK	3	P	57.119	186.319	54.221	0.444
304	BRK	3	N	107.136	132.662	0.896	0.394
305	BRK	3	2N	91.917	144.600	60.908	33.207
306	BRK	3	HF	54.440	119.339	55.744	0.363
401	BRK	4	CK	0.332	48.270	41.664	0.282
402	BRK	4	F	0.685	61.370	46.380	0.413
403	BRK	4	P	21.122	98.915	1.041	0.452
404	BRK	4	N	53.598	154.069	1.344	0.532
405	BRK	4	2N	15.792	138.168	1.175	0.573
406	BRK	4	HF	8.450	97.733	1.142	0.480

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.27. Monthly CH_4 Fluxes (g CH_4-C ha^{-1} d^{-1}) in 2015 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	June	July	August	September	October
101	BRK	1	CK	4.847	-25.468	0.407	0.776	1.223
102	BRK	1	F	-4.166	0.534	-0.078	-0.243	0.178
103	BRK	1	P	0.641	1.259	13.776	0.386	0.132
104	BRK	1	N	0.389	5.936	0.806	40.440	1.104
105	BRK	1	2N	-0.106	37.752	1.754	31.309	-0.024
106	BRK	1	HF	0.192	0.274	-6.706	-0.190	-0.507
201	BRK	2	CK	0.218	1.028	-0.442	-0.119	0.115
202	BRK	2	F	-0.005	0.392	0.394	-0.556	0.113
203	BRK	2	P	0.366	-0.096	0.052	0.692	1.036
204	BRK	2	N	0.803	0.880	0.440	-51.054	21.639
205	BRK	2	2N	65.062	0.894	-0.100	0.304	-26.871
206	BRK	2	HF	7.222	0.247	1.252	0.581	0.057
301	BRK	3	CK	2.099	1.255	0.008	-131.088	0.284
302	BRK	3	F	0.313	0.418	-10.848	62.610	2.114
303	BRK	3	P	0.069	0.837	0.091	1.431	0.224
304	BRK	3	N	0.269	-10.427	12.236	-27.931	-103.152
305	BRK	3	2N	57.972	0.274	0.319	-0.204	0.021
306	BRK	3	HF	0.423	0.304	-13.559	0.730	0.263
401	BRK	4	CK	0.089	-8.068	0.643	0.621	0.067
402	BRK	4	F	0.072	-0.022	-0.141	-0.714	0.654
403	BRK	4	P	9.095	15.608	0.515	-0.662	-0.153
404	BRK	4	N	60.316	14.543	0.164	-0.089	-0.018
405	BRK	4	2N	0.075	0.456	0.833	0.485	0.079
406	BRK	4	HF	1.044	0.852	61.086	-9.396	-0.150

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.28. Monthly CH_4 Fluxes (g CH_4-C ha^{-1} d^{-1}) in 2016 at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	Location	REP	TRT	May	June	July	August
101	BRK	1	CK	0.592	-0.823	11.888	-0.280
102	BRK	1	F	1.409	-0.231	-0.195	0.116
103	BRK	1	P	49.006	1.072	0.829	-0.028
104	BRK	1	N	25.013	0.173	0.107	0.001
105	BRK	1	2N	0.539	-7.863	-0.167	-0.109
106	BRK	1	HF	0.287	-39.695	0.302	0.387
201	BRK	2	CK	-0.042	0.275	1.100	0.016
202	BRK	2	F	0.555	0.207	-5.971	-0.039
203	BRK	2	P	0.893	-0.044	0.892	12.397
204	BRK	2	N	16.507	0.157	0.658	0.040
205	BRK	2	2N	0.148	-0.200	0.388	0.558
206	BRK	2	HF	0.191	-0.107	0.118	0.118
301	BRK	3	CK	0.319	-1.119	0.254	-0.499
302	BRK	3	F	0.247	-0.436	0.038	-0.165
303	BRK	3	P	-0.041	4.417	0.650	-0.057
304	BRK	3	N	0.538	-0.258	-0.289	0.059
305	BRK	3	2N	0.154	0.220	-0.049	0.016
306	BRK	3	HF	-0.486	0.256	0.115	-0.021
401	BRK	4	CK	14.424	-0.328	50.639	-0.018
402	BRK	4	F	0.618	0.618	0.010	-0.175
403	BRK	4	P	0.187	-8.759	0.748	0.215
404	BRK	4	N	16.800	0.075	0.767	0.512
405	BRK	4	2N	24.268	0.028	0.032	0.599
406	BRK	4	HF	-0.133	-0.089	0.032	0.139

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

A3.29. Annual GHG Emissions at Brookings site. BRK, Brookings site; REP, replication; TRT, treatment.

Plot	**Location**	**REP**	**TRT**	**g CH_4-C ha^{-1} d^{-1}**		**kg CO_2-C ha^{-1} d^{-1}**		**g N_2O ha^{-1} d^{-1}**	
				2015	**2016**	**2015**	**2016**	**2015**	**2016**
101	BRK	1	CK	-18.215	11.377	71.868	94.021	9.568	0.321
102	BRK	1	F	-3.775	1.100	294.327	196.718	20.790	11.605
103	BRK	1	P	16.193	50.879	537.518	206.920	100.913	1.047
104	BRK	1	N	48.674	25.295	150.425	240.883	92.059	43.342
105	BRK	1	2N	70.684	-7.600	915.865	361.977	808.757	18.965
106	BRK	1	HF	-6.936	-38.719	264.412	141.910	120.591	483.270
201	BRK	2	CK	0.800	1.350	165.016	138.520	19.410	0.636
202	BRK	2	F	0.338	-5.248	142.455	98.353	0.698	169.569
203	BRK	2	P	2.050	14.139	265.232	62.060	5.101	27.758
204	BRK	2	N	-27.293	17.362	445.422	126.536	94.233	0.841
205	BRK	2	2N	39.289	0.894	480.509	213.981	108.250	115.705
206	BRK	2	HF	9.359	0.321	87.375	149.713	5.770	881.773
301	BRK	3	CK	-127.442	-1.045	142.338	71.354	23.607	0.258
302	BRK	3	F	54.608	-0.316	117.665	250.697	3.743	24.632
303	BRK	3	P	2.653	4.968	242.546	298.104	1.470	45.640
304	BRK	3	N	-129.005	0.051	285.724	241.088	109.803	224.776
305	BRK	3	2N	58.381	0.341	1060.747	330.632	171.675	65.318
306	BRK	3	HF	-11.839	-0.136	328.726	229.886	317.577	842.698
401	BRK	4	CK	-6.648	64.717	95.267	90.547	13.806	4.466
402	BRK	4	F	-0.151	1.072	50.408	108.848	5.874	117.198
403	BRK	4	P	24.402	-7.608	114.024	121.530	13.548	31.746
404	BRK	4	N	74.917	18.153	582.576	209.543	493.163	92.443
405	BRK	4	2N	1.928	24.926	371.526	155.708	135.852	102.701
406	BRK	4	HF	53.436	-0.051	290.151	107.804	27.317	169.368

CNT, control; P, Phosphorus based manure application rate; N, Nitrogen based recommended manure application rate; 2N, Double rate of nitrogen based manure application rate; F, Recommended rate of inorganic fertilizer; HF, High rate of inorganic fertilizer.

APPENDIX 4

Figure A4.1. Taking weight of manure for application to field.

Figure A4.2. An example of inorganic fertilizer application.

Figure A4.3. An example for the soybean planted filed.

Figure A4.4. An example for the corn planted filed.

Figure A4.5. Reduced-tillage in 1to 3 days after manure application.

Figure A4.6. Taking soil samples from field to analyze soil properties such as SOC, TN, pH, EC and WAS.

Figure A4.7. Taking core samples from field to analyze bulk density, soil water retention and pore size distribution of soil.

Figure A4.8. Examination of water infiltration rate in the field by using double rings method.

Figure A4.9 Analyzing of soil water retention and pore size distribution.

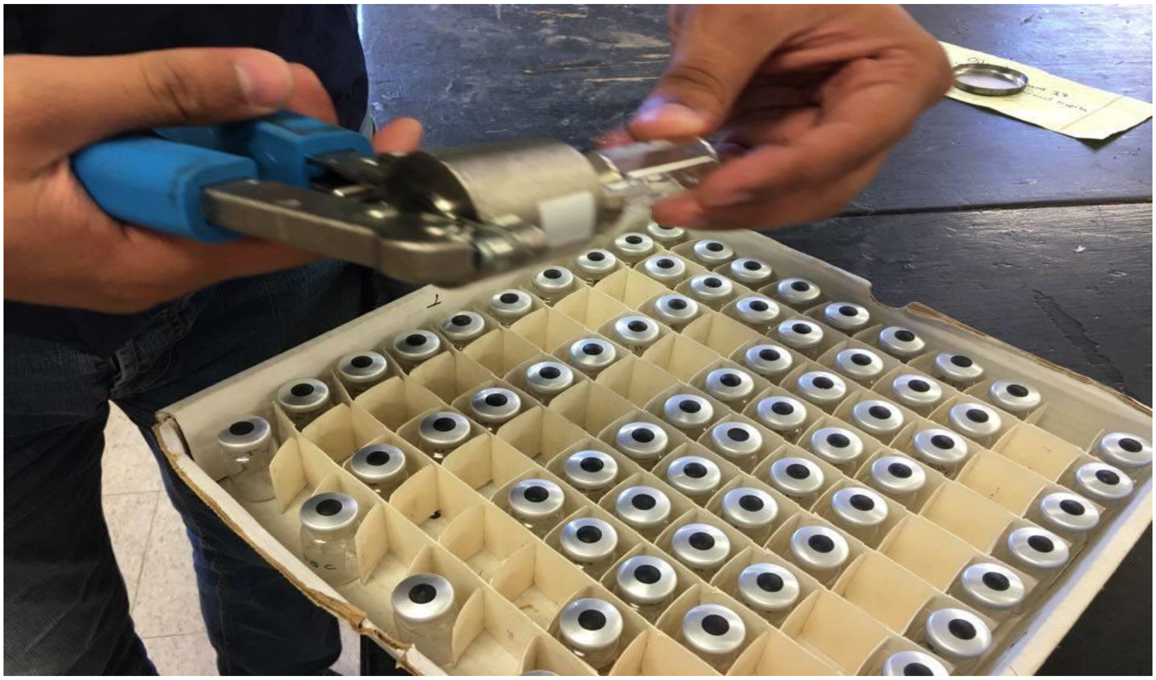

Figure 1.1.10 Preparing vials for GHGs sampling.

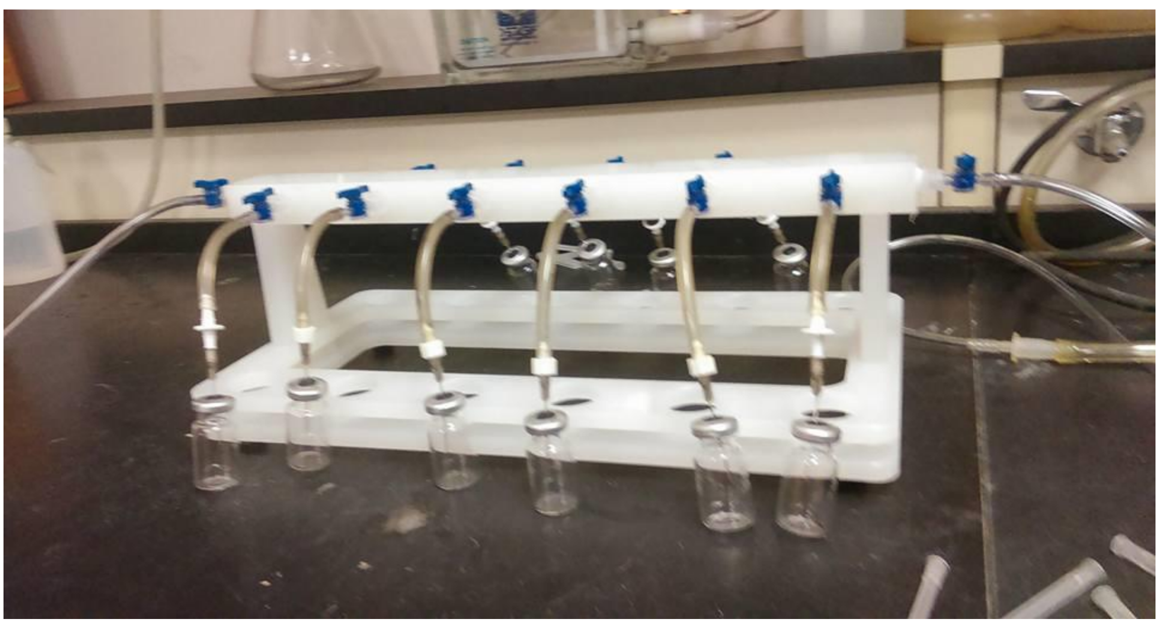

Figure A4.10. Vacuuming vials before gas sampling.

Figure A4.11. Taking gas samples from field to analyze CH_4, N_2O and CO_2 emissions.

Figure A4.12. Taking volumetric soil moisture readings from field.

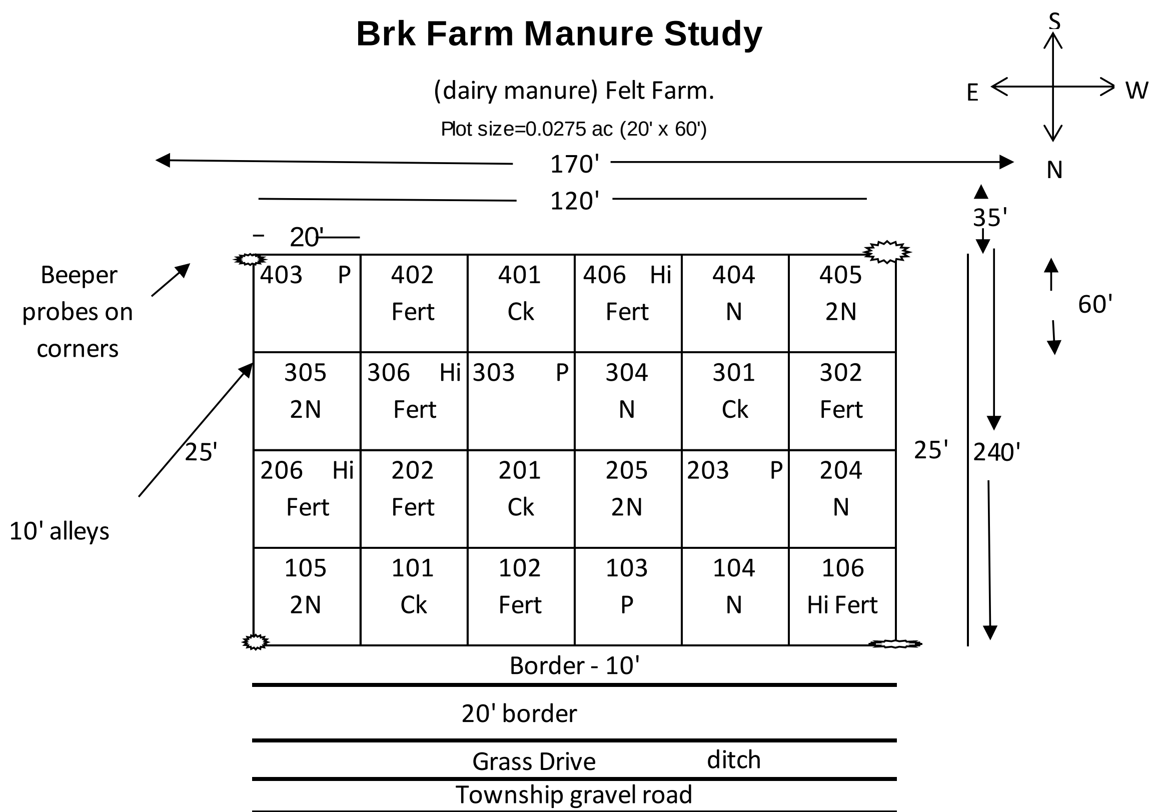

Figure A4.13. Plot layout at the Brookings Felt Farm site.

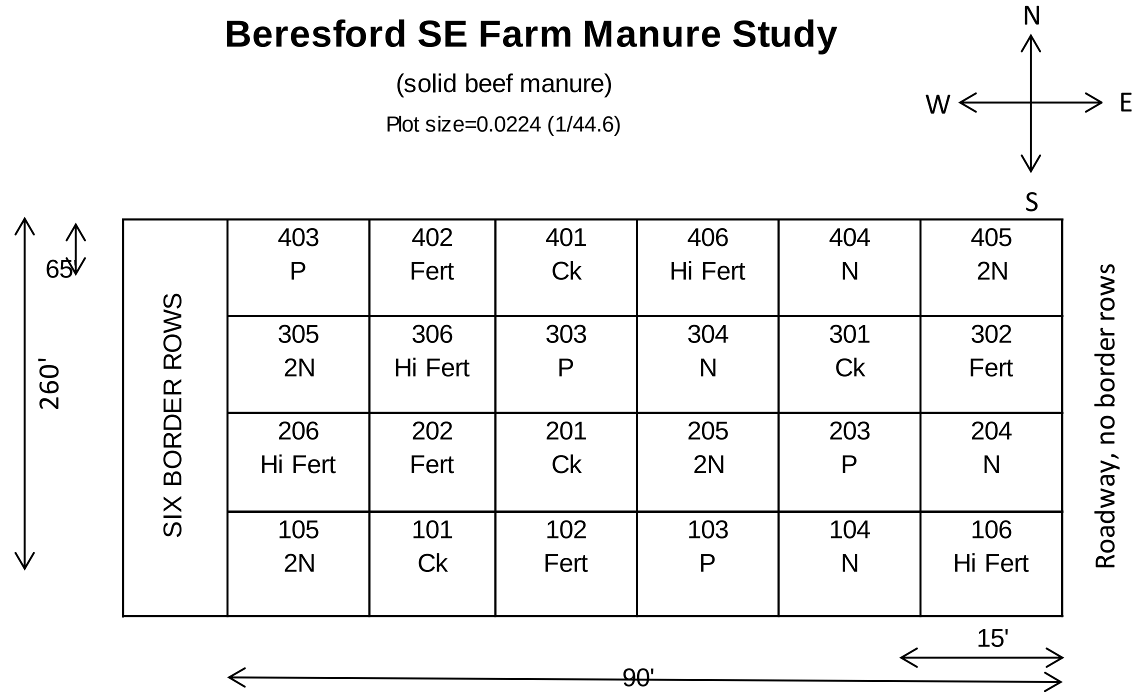

Figure A4.14. Plot layout at the Beresford SE Farm site.

APPENDIX 5

A5.1. SAS codes used to run all the statistics.

```
Data BD;
Input TRT REP BD trt2;
Cards;

;
run;

Proc glm;
Class Rep Trt2;
Model BD =Trt2 Rep Rep*Trt2;
Run;
;

test h = trt2 e = rep*trt2;
lsmeans trt2/Stderr e = rep*trt2;
Means trt2 Rep*Trt2/Duncan alpha = 0.05;
run;

Contrast '1 vs 2' trt2 1 -1 0 / e = rep*trt2;
Contrast '1 vs 3' trt2 1 0 -1 / e = rep*trt2;
Contrast '2 vs 3' trt2 0 1 -1 / e = rep*trt2;

run;
run;

Proc glm;
Class Rep Trt;
Model BD =Trt Rep Rep*Trt;
Run;
;

test h = trt e = rep*trt;
lsmeans trt/Stderr e = rep*trt;
Means trt Rep*Trt/Duncan alpha = 0.05;
run;

Contrast '2 vs 6' trt 0 1 0 0 0 -1 / e = rep*trt;
Contrast '3 vs 4' trt 0 0 1 -1 0 0 / e = rep*trt;
Contrast '3 vs 5' trt 0 0 1 0 -1 0 / e = rep*trt;
Contrast '4 vs 5' trt 0 0 0 1 -1 0 / e = rep*trt;

run;
```

VITA

Ekrem OZLU was born in Yunlukuyu Koyu, Cihanbeyli, Konya, Turkey to Guler and Halil Ibrahim Ozlu. He received his B.S. (Department of Soil Science and Plant Nutrition) in 2011 from Ataturk University, Erzurum, Turkey. For his M.S., he joined South Dakota State University and received an M.S. degree in Plant Science, emphasizing in Soil Science in 2016 under the supervision of Dr. Sandeep Kumar.