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thesis entitled

Dairy Forage Cropping Best Management Practices: A Comparison

of Yield, Forage Quality, Soil Carbon Sequestration, and

Greenhouse Gas Emissions

presented by

James Donald DeYoung

has been accepted towards fulfillment
of the requirements for the

Master of Science	degree in	Department of Crop and Soil Science

Richard R. Harwood
Major Professor's Signature

7/15/06

Date

MSU is an Affirmative Action/Equal Opportunity Institution

DAIRY FORAGE CROPPING BEST MANAGEMENT PRACTICES: A COMPARISON OF YIELD, FORAGE QUALITY, SOIL CARBON SEQUESTRATION, AND GREENHOUSE GAS EMISSIONS.

By

James Donald De Young

A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

MASTER OF SCIENCE

Department of Crop and Soil Science

2006

ABSTRACT

DAIRY FORAGE CROPPING BEST MANAGEMENT PRACTICES: A COMPARISON OF YIELD, FORAGE QUALITY, SOIL CARBON SEQUESTRATION, AND GREENHOUSE GAS EMISSIONS.
By

James Donald De Young

Increases in greenhouse gas (GHG) emissions have been found to contribute toward global warming. Better management practices in agriculture have been proposed as a partial solution to this problem. This study evaluated forage cropping systems and additions of manure or compost for their ability to sequester carbon (C) and reduce GHG emissions from the soil. Cropping systems and C additions were compared at a southern Michigan (KBS) and northern Michigan (UP) location. Compost was applied at KBS and manure slurry was applied at UP at rates to supply 3000 kg C ha^{-1}. Results indicated forage quality differences ($P<0.0001$) between forage species within each location. There were also significant ($P<0.0001$) yield differences between crops. The addition of compost at the KBS location had a significant ($P<0.0459$) impact on yield. The addition of manure at the UP location resulted in significant interactions on yield between crop x year ($P<0.0001$) and crop x manure ($P<0.0442$). GHG fluxes at the KBS location were not significantly different due to crop or compost additions, however N_2O fluxes were significantly greater ($P<0.040$) with manure additions at the UP location. Total soil C measured at KBS was greater with compost additions than without (0.943 kg C cm^{-2} and 0.798 kg C cm^{-2} respectively). POM differences at KBS were also significant ($P<0.0037$) (0.211 kg POM C cm^{-2} with compost additions and 0.202 kg POM C cm^{-2} without compost). The UP location TSC and POM did not respond in a measurable way to manure additions or cropping treatments.

Dedicated to Lisa Ann, and Asher James

ACKNOWLEDGMENTS

I wish to thank the many people who have helped me along the way through this project. To my committee, Drs. Richard H. Leep, Doo-Hong Min, Kurt D. Thelen, and Tim M. Harrigan; thank you for this great opportunity to study, learn, grow, and travel. I have appreciated your candor, wisdom, and guidance through this process. To my fellow lab mates, Tim Dietz, Tim Boring, Debbie Warnock, Nasser Al-Gumaiz, and Dan Hudson; thank you for the endless help with sample collection, ideas, data processing, and statistical analysis. To the KBS post docs and grads who helped me out with this project, Claire McSwiney, Sven Bohm, Drew Corbin, Terry Locke, Stuart Grandy; thank you for all the ideas, problem solving, borrowed equipment, brains picked, and expertise. To the staff at KBS including Nina, Sally, Alice, Jim, Greg, and various others who helped with office and field work through my stay at KBS; thank you for all that you do with very little thanks, you definitely made KBS home for me. To Todd Martin, Dave DeYoung, Brian Demming, Chris Kapp, Simon, thank you for all the soil cores, sieves, hand separations, numbers entered and overall good attitude. To my family; thanks Mom, Dad, Tim, Pam, and David for your encouragement, love, and understanding through all of this. And finally, to my beautiful wife Lisa and amazing son Asher; thank you for understanding the late nights, long trips to Chatham, frustrations, joys, and everything in between. I love you and am truly blessed by your companionship. This thesis is dedicated to you, since it took up so much of our time together.

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INTRODUCTION

Best management practices (BMPs) have been used to describe best-case scenarios for management decisions based on desired outcomes which reduce negative environmental impacts. BMPs have been used for reducing runoff during construction, reducing soil erosion and improving pest control for cropping systems. BMPs in cropping systems dictate the best times of year to harvest, fertility regimes, tillage practices and can include improved rotations of perennial forages, cover crops, reduced tillage, and manure additions which increase soil organic matter. Soil residues have been shown to minimize water and wind erosion, increase soil fertility, and improve ground and surface water quality (Halvorson et al., 2002a). The goal of most cropping BMPs is to reduce erosion and improve crop yields. BMPs have not been evaluated for dairy forage production. This study evaluated how forage cropping systems using best management practices, of reduced tillage, manure or compost addition, and crop rotations affect crop yields, forage quality, soil greenhouse gas production, and soil carbon (C) sequestration.

Increases in three major GHGs, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have been proposed as the main cause of the radiative forcing of the atmosphere leading to global climate change (Prather et al., 1995; Shine and Forster, 1999). Increases in atmospheric CO_2 since the 1700's have been documented through Antarctic ice core data (Siegenthaler and Sarmiento, 1993). Atmospheric data collected since the 1950's in Hawaii also support this trend (Etheridge et al., 1996; Keeling and Whorf, 2000; Siegenthaler and Sarmiento, 1993). These documented increases in global CO_2 levels are largely attributed to increased burning of fossil fuels and the conversion of land toward more intensive agricultural uses (IPCC, 1990; IPCC, 1992; Marland and Boden, 1991). Increases in CH_4 and N_2O gases also follow the growth of human population and activity(Liebig et al., 2005). CO_2 levels increased from 280 ppb to 360 ppb, CH_4 levels rose from 750 ppb to levels close to 1600 ppb in 2000 and N_2O increased from around 270 ppb to almost 300 ppb (IPCC, 2001). There has been a marked increase in each of the above greenhouse gasses, which can be tied directly to human activity. CO_2 release from soil results from the oxidation of soil organic matter due to increased tillage and fossil fuel use. N_2O results from increased fertilizer usage but is also from fossil fuel consumption. CH_4 comes from garbage landfills, stored animal wastes, rice production, and domesticated animals (mainly sheep and cattle)(Cole et al., 1997; Hutsch, 1998; Seneviratne and van Holm, 1998).

Plants use energy from the sun in combination with water and CO_2 to produce both structural and energy storing carbohydrates through the process of photosynthesis. By removing CO_2 from the atmosphere and converting it to organic matter, plants can play an important role in C sequestration. Cropping rotations can influence the production of greenhouse gases through their nitrogen (N) requirements. For example, corn is fertilized with N while a legume grown for forage fixes its own N. Soil conditions can also be affected by cropping practices including, but not limited to tillage and harvest practices (Prior et al., 2000). Irrigation of crops has been shown to temporarily increased soil CH_4 production (Liebig et al., 2005). Best management practices (BMPs) have been developed for different crops which dictate planting, fertilizing, and harvest practices. These BMPs can have an impact on the role that agriculture plays in GHG emissions and potentially, global warming.

Tillage is involved in increasing atmospheric CO_2 (Dyer and Desjardins, 2003; Halvorson et al., 2002b; Lal, 1997; West and Post, 2002). Tillage has long been used to prepare the soil for planting. Tillage prepares the seedbed for the crop to be planted by providing good seed to soil contact, weed control, and by helping to aerate the soil. However, with the advent of mechanized farm equipment, it is possible to till much more soil in a shorter amount of time than ever before In the process of tilling the soil for planting, nutrients are mineralized through the microbial breakdown of organic matter in the soil (Wander and Bidart, 2000). Microbes consume the organic matter in the soil and use it for energy. Through the different levels of animals, bacteria, and fungi in the soil, organic matter is broken into smaller and smaller pieces, with each trophic level releasing some waste products (Paustian et al., 2000). This helps recycle nutrients into forms that can be taken up and used by plants, but it also releases some of the CO_2 that has been immobilized in the form of structural carbohydrates in plant organic matter. If the conditions for the breakdown cause the material to accumulate faster than animals, bacteria, and fungi living in the soil can break it down, organic matter levels will increase. This scenario has occurred in the past and is the source of our reserves of fossil fuels and deep organic soils of the prairies. This stored (or sequestered) C remains in place until conditions arise when it can be released back to the atmosphere. This happens when fossil fuels are burned for energy. It also happens when the organic matter in soil is exposed to air, moisture, and other conditions that favor microbial degradation. Many of these conditions are present after the soil is tilled in preparation for planting crops.

In the United States, it is estimated that 30-70% of the original C in soils (in the form of organic matter) has been lost to the atmosphere due to tillage (Haas et al., 1957).

Jackson et al. (2003) found that the breakdown of soil organic matter from tillage events resulted in high rates of soil N mineralization for several days following tillage as well as a large flux of CO_2 from the soil.

Tillage is primarily used to prepare the seedbed for crop seeds to be planted into, thus ensuring good seed to soil contact and subsequent germination. Nutrients are released from tillage through the breakdown of soil organic matter. These nutrients play a critical role in the early development of seedlings. These nutrients include, but are not limited to organic forms of N, phosphorus, and potassium. However, this practice of tillage results in a breakdown of soil organic matter with a subsequent loss of soil C. The recovery of this lost organic matter from tillage can take many years (Burke et al., 1995) because the C contents of many agricultural soils are linearly related to C inputs from organic matter (Paul et al., 1999; Paustian et al., 1995; Rasmussen and Collins, 1991). Tillage reduces the total C input to the soil by increasing the level of oxygen in the soil and encouraging the microbial degradation of those inputs. Labile C is a form of C that is generally very quick to be degraded by soil microbes. Often, labile C and organic matter that was not readily available to microbes due to its placement in the soil (i.e. within soil aggregates and other anaerobic portions of the soil) is made available by disrupting soil aggregates and/or moving organic matter around in the soil profile to more aerobic portions of the soil (Min et al., 2003; Six et al., 2000; Wander and Yang, 2000; Wander and Bidart, 2000).

Tillage also affects the recovery of soil organic matter by reducing the mean residence time (MRT) of soil organic matter twice as much as no-till (NT) (Balesdent et al., 1990; Six et al., 1998). Specifically at the Kellogg Biological Station, Hickory

Corners, Michigan (where a portion of this study took place), the MRT for soil C was 30-66 days for the active pool and 9-13 years for the slow pool (Paul et al., 1999). This means that by tilling a previously untilled ground, it is possible to reduce the MRT for soil C to as little as 15-33 days.

Robertson et al. (2000) stated that conventional cropping systems have the highest overall global warming potential (GWP), but by adopting no-till and including perennial forage crops, they suggested it was possible to offset that potential. Globally, this potential for C sequestration by agriculture has been estimated to be on the order of 75-200 million MT C y^{-1} (Bruce et al., 1999; Eve et al., 2002a; Lal R. et al., 1998). With 166 million hectares of cropland in the contiguous United States (USDA_NRCS, 2000), and global cropland containing close to twice as much C as is present in the atmosphere (Prentice, 2001), it is easy to understand why agriculture has been touted as an important means to mitigate the effects of GHG through C sequestration (Lal, 2003b; Paustian et al., 1996; Sperow et al., 2003).

In many agricultural cropping systems, A few changes can bring about significant results. In the case of agriculture and soil C, turning losses into gains can be as simple as reducing tillage (Lal and Kimble, 1997; Post and Mann, 1990) and including manure or perennial crops in the cropping rotation (Lal et al., 1978). Robertson et al. (2000) found that this reduction in GWP from conversion to reduced tillage came from reduced fuel uses, lower soil greenhouse gas fluxes, and improved cropping efficiency. Paustch et al. (1999) argues that if all crop producers in the United States switched to conservation tillage, an additional 14 million metric tons of C could be sequestered in the soil. In the

Great Lakes region, conversion from conventional tillage to no-till has been suggested to have the potential to accumulate 0.36 MT C ha^{-1} y^{-1} (Eve et al., 2002b).

Other cropping practices which encourage C sequestration include increasing yields, using perennial crops, and using legumes to fix elemental N and reduce fossil fuel consumption associated with N-fertilizer production as well as N applications (Fortuna et al., 2003; Jastrow et al., 2005; Lal, 2002; Lal, 2003a). The potential to offset the GWP of certain crops by making small changes to management practices is substantial and can be done in a cost effective manner. Antle et al. (2001) estimated that in Montana, conversion from crop-fallow to continuous cropping of wheat could sequester 12 million tons of C. In the Midwest, Eve et al. (2002b) estimated that by adding hay, a winter cover crop, or manure applications to an annual cropping rotation, an additional 0.75 C ha^{-1} y^{-1} could be accumulated. Additionally, agriculture has the mitigation potential to reduce fossil C consumption through the production of biofuels which are renewable resources and provide an alternative to the finite resources of fossil fuels (Paustian et al., 1998).

TILLAGE

The adoption of no-till has had a positive effect on soil C sequestration (Campbell et al., 2001; Liebig et al., 2005; West and Post, 2002). No-till encourages soil aggregation and the development of improved soil structure. No-tillage (NT) is a practice which involves tilling only a small strip of soil, usually just wide and deep enough for the seed to be placed into the soil ensuring good seed to soil contact. Weeds are controlled with synthetic herbicides and crop rotations instead of intensive conventional tillage. This practice reduces the disruption of soil structures such as aggregates, root channels, and earthworm tunnels which all help to increase soil aeration, reduce soil compaction, and increase water infiltration. The practice of no-till leaves more crop residues on the soil surface where they are not broken down as quickly which leads to reduced C losses from crop residue, especially root material placed underground. Traditional soil tillage methods require massive amounts of energy to turn acres of soil over; however NT requires much less fuel to prepare fields for planting since fields do not need to be tilled before each crop. This results in lower fossil fuel derived CO_2 emissions produced by the NT planting operation.

Rochette et al. (1999) found that using no-till resulted in less corn residue C lost compared to moldboard plowing. Increased crop residues result in less wind and water erosion losses of soil (Hussain et al., 1998; Hussain et al., 1999; Ortega et al., 2002). It is estimated that no-till in the Great Lakes region has the potential to sequester up to 0.36 MT C ha^{-1} yr^{-1} (Eve et al., 2002b). However, it has been suggested that by just stopping tillage by taking by taking land out of crop production as in CRP (Conservation Reserve Program) conversion will yield little in the way of C sequestration (Robles and Burke, 1998).

Concerns about no-till contributing to soil compaction have led to some of the questions regarding the effects of compaction in the lower soil horizons and reduction in yields (Bakhsh et al., 2000; Hussain et al., 1998; Logsdon and Cambardella, 2000). On the other hand, one study showed increased yields and improved soil surface properties in no-till cotton fields which also had been deep tilled to break up the plow pan (Franzluebbers et al., 1999a). Water can have the same effect as compaction on soil aeration by filling soil pores leading to anaerobic soil conditions. Tillage also affects the availability of soil water through short term increased evaporation and by disrupting soil structure such as worm burrows and old root channels which may help with water diffusion deeper into the soil profile. Tillage disrupts those structures and replaces them with a less stable soil structure which is more susceptible to degradation and more anaerobic conditions.

The increased soil C in no-till cropping systems has been shown to be mainly the result of accumulations of root material that are not degraded by microbial activity (Bolinder et al., 1999; Cambardella and Elliott, 1993). This root material has been shown to play a key role in the development of C-rich soil macroaggregates and microaggregates, both of which are important factors in building good soil structure. Intensive tillage operations disrupt soil structure by breaking up macroaggregates and increasing the number of C poor microaggregates and can lead to a reduction in soil porosity, soil water holding capacity, and air diffusion through the soil.

CROPS

One way of reducing effects of intensive tillage is to adopt perennial cropping systems. Forage crops such as alfalfa (*Medicago sativa*), various clovers (*Trifolium spp.*), timothy (*Phleum pratense L.*), orchardgrass (*Dactylis glomerata L.*) and many others are different in that they are grown as perennial crops with most of their above ground biomass harvested while their crowns and roots stay in the soil. Perennial crops encourage the building of soil organic matter through a reduction of tillage (once every 3-6 years or longer in the case of pastures, versus annual tillage events). For this reason, forage crops have been found to have a strong GWP mitigation potential (Robertson et al., 2000). One of these perennial forage crops used extensively in the United States is Alfalfa (*Medicago sativa* L.).

Alfalfa is a perennial legume native to the Middle East, but grown extensively throughout the world as a forage crop. It is highly productive, fixes its own N, and provides high quality fodder for many classes of livestock animals. Alfalfa is used extensively in the United States as dry hay, silage, and grazing stocks for beef and dairy production. Paul et al. (1999) applauded the use of alfalfa due to its high productivity and the added benefit of underground C storage in long taproots. This potential for storing carbohydrates underground was also noted by Paul and Clark (1996) who found that the symbiotic relationship between alfalfa and its associated Rhizobium increase the transport of carbohydrates derived from photosynthesis to the underground portions of the plant.

Complex cropping rotations which include perennial forage crops such as alfalfa and orchardgrass have the added benefit of increased cropping intensity which in turn yields higher levels of surface soil organic C (Ortega et al., 2002). As noted by several researchers, residue quality as affected by legumes plays a key role in retention of soil C. Drinkwater et al. (1998) found legume-based systems have reduced C and N losses, while Gregorich et al. (2001) noted that soils under legume-based rotations were "more preservative of residue C" inputs (roots) than soils under monoculture. However, these benefits do not have to be limited to arable land. Robles and Burke (1997) found that by including legumes in CRP land they were able to increase the labile C and N fractions in the soils. Increases in soil N result in more Particulate Organic Matter (POM), more organic C, and more organic N (Liebig et al., 2002).

Forage cropping systems are not all based on legumes. Many producers feed corn grain and silage and use pastures for grazing. These crops can also play a significant role in soil C sequestration. Buyanovsky and Wagner (1986) estimated that corn grain residues have the potential for 9.2 ton ha^{-1} annual input, with approximately 50% of the input from root material. In contrast, corn silage cropping systems have the majority of the above ground biomass removed which results in much lower amounts of crop residue inputs for building soil organic matter levels.

Pasture systems, which are often perennial and include legumes, are also good ways to increase C sequestration. Pastures with tall fescue and common bermudagrass have been shown to increase C sequestration more than conservation tillage (Franzluebbers et al., 2000). Additionally, soils in which endophyte infected tall-fescue is grown had higher concentrations of soil organic C and N than soils with non-infected fescue (Franzluebbers et al., 1999b). This addition of organic C and N was most likely due to the increased underground fungal biomass.

While it is generally understood that by increasing crop yields one can expect more soil C production through increased biomass production both above and below ground, Puget and Drinkwater (2001) found that the origin of plant litter also plays a role in the fate of these inputs. They found that when legumes are used as green manures, up to 87% of the shoot material decomposed while close to 50% of root derived material was still present in the soil at the end of the growing season. Honneycutt et al. (1993) also found that the quality (ratio of C:N) of inputs affected C mineralization more than the loading rate, and Gale et al. (2000a; Gale et al., 2000b) showed that root derived C was more important in stabilizing macroaggregates than shoot derived C. A crop with larger amounts of fine roots stabilizes macroaggregates better than one with non-fibrous roots. This was also demonstrated by Davenport et al. (1988) who found that soil aggregates under bromegrass were more persistent than under corn due to the large additions of fine roots, shallow depth, and larger inputs of biomass C below ground.

MANURE AND SOIL ORGANIC MATTER

Manure has been tied to agriculture for as long as humans have grown crops and owned livestock and it is still used today on livestock farms as an important source of organic nutrients such as N, phosphorus, and potassium (Eghball, 2000; Paul and Beauchamp, 1993; Paul and Beauchamp, 1995; Sommerfeldt et al., 1988; Whalen and Chang, 2001). Manure is beneficial to cropping systems in that it supplies large amounts of partially decomposed C which translates into increased soil organic matter, improved soil water holding capacity, and higher soil fertility (Ginting et al., 2003; Min et al., 2003). Manure also influences soil microbial activity by providing an easily digestible food source for microbes. For example, Rochette et al. (2000a) describes how soil amended with pig manure resulted in a rapid increase of microbial biomass coinciding with peaks in concentrations of extractable C and CO_2 fluxes. In addition, Rochette and Gregorich (1998) found that soils with manure applied had large amounts of soluble C with a slower turnover rate than soluble C in unamended soil. However, it should also be noted that as much as half of C and N applied in manure can be lost to the atmosphere as CO_2 and NH_4 (Kulling et al., 2003; Rochette and Gregorich, 1998). This amount can increase when manure is not incorporated as in the case of no-till or winter applications of manure on frozen ground.

MEASURING SOIL ORGANIC MATTER

Tillage, crops, and manure inputs affect soil organic matter decomposition or accumulation at different rates and to differing degrees. However, measuring soil organic matter changes in soils and the subsequent effects of different treatments is difficult due to high levels of background C in the soil and lack of soil C homogeneity (Schuman et al., 2000). In order to measure small changes in large volumes of soil C, it is usually the case that long periods of time are needed to accurately assess changes. In one example of this problem, Conen et al. (2003) calculated that it would take 26 and 43 years to accurately measure significant soil organic C changes at two sites in Mongolia based on the local soil C variability and background levels. The difficulty in measuring changes in soil C arises from the minimum detectable difference (MDD), which is defined as the smallest difference that can be detected (at $\alpha = 0.05$) between two means with 95% confidence. MDD is influenced by sample variation and by the number of replications.

Because of difficulties of measuring changes in soil C, researchers have studied different methods for accuracy in detecting changes in soil C. One method developed for detecting changes in soil C is accomplished by dividing the total soil C into several pools, which are defined by their lifespan. Generally these divisions lead to three pools of soil C, a slow pool (10-40 years MRT), a resistant pool (500-1000 years MRT), and a fast pool (20-60 days MRT) (Fortuna et al., 2003; Paul et al., 2001). Because the time span for turnover in the slow and resistant pools is much longer than most research projects can allow, there has been emphasis on analyzing the fast pool C to detect changes in C in soils.

One proposed component of the fast pool C is a portion called particulate organic matter (POM). POM is a major component of soil organic matter lost very quickly following soil cultivation. POM plays a key role in soil quality in its relationship to structural stability, aggregate formation, water holding capacity, and soil N (Cambardella and Elliott, 1992; Denef et al., 2001; Schwenke et al., 2002; Wander and Bollero, 1999; Wander and Yang, 2000).

Cambardella and Elliott (1992) noted that POM is often the fraction of soil C that changes most rapidly following tillage events. Using electron microscopy they saw that POM was comprised mostly of fine root materials. POM is involved in the formation of structural material for aggregate formation as many soil organisms feed on the easily digestible forms of C and their wastes help to cement the organic matter together (Jongmans et al., 2001). This process continues until small aggregates are formed around the small pieces of organic material resulting in the organic matter being precluded from further degradation within the aggregate. We focused on POM in this short term study based on the fact that it changes rapidly after tillage and with supplemental organic matter applications such as manure or compost.

GREENHOUSE GASSES AND AGRICULTURE

Greenhouse gases such as carbon dioxide, methane, and nitrous oxide result from agricultural practices. CO_2 is the GHG produced in the greatest volume by agricultural practices which include tillage and manure handling activities. Land use changes have since resulted in CO_2 levels increasing as much as 136+/-55 Pg C (Lal, 2003a) however, other GHGs including CH_4 and N_2O are also produced from agricultural practices such as fertilization, irrigation, and manure handling (Ginting et al., 2003; Hao et al., 2001b;

Hutsch, 2001). Equal amounts of CH_4 and N_2O are more harmful than CO_2 as they have the potential to influence global warming through the absorption of more IR light which would otherwise be reflected back into space. CH_4 absorbs 30 times more thermal energy while N_2O absorbs 150 times more than CO_2. It should be noted however that CO_2 is produced by agriculture at quantities which far outweigh the stronger effects of CH_4 and N_2O. The production of these gases has increased steadily over the past 50 years due to greater consumption of fossil fuels and increased intensive agriculture production. However, agriculture may still provide an answer to these increases in GHGs. For example in Canada it has been proposed that a conversion of 10.5 million hectares of cropped land to grassland has the potential to meet GHG reduction goals (Mummey et al., 1998).

Plants fix CO_2 from the atmosphere through photosynthesis and convert the CO_2 into structural carbohydrates, proteins, amino acids, and sugars. These products of photosynthesis can be harvested in crops or they become food for soil fauna when plants die. Plant residues which are decomposed by the soil fauna result in soil evolved CO_2 as a direct product of respiration by the soil fauna as they consume these plant residues for energy. Examples of this organic matter include crop residues and tree leaves, stems branches, and roots. Perennial plants such as grasses and legumes store up energy and can transfer up to 50% of the photosynthates to their roots (Paul and Clark, 1996). The decomposition of fine roots in perennial systems plays a very important role in C cycling in these systems.

Soil respiration of organic matter by soil fauna generally requires water and O_2 to take place. Diffusion of O_2 through soil pores is influenced by soil structure and saturation with water. A heavily compacted soil will slow O_2 diffusion, where the O_2 is quickly depleted leading to anoxic soil conditions. N_2O can be produced under these anoxic conditions. Tillage quickly increases available O_2 by creating many passageways for air to enter the soil and by mixing the soil which often provides fresh organic matter for decomposition. This influx of O_2 and mixing of the soil quickly leads to increases of soil respiration of organic matter (Reicosky et al., 1997). Applications of manure also increase soil CO_2 production by providing an easily degradable source of C for soil fauna. Even under cold soil temperatures CO_2 production has been shown to continue for up to 29-d after manure applications under simulated snow (Chantigny et al., 2002).

Nitrous Oxide (N_2O) is another greenhouse gas of interest arising from agriculture. N_2O generally arises from the reduction of synthetic fertilizers and from the reduction of organic forms of N found in soil organic matter under O_2-limited conditions. Denitrification is the term given to the transformation of different forms of organic N into forms that can leave the biological system through leaching, volitization and/or diffusion. Denitrification of soil N as N_2O contributes little to global warming by itself. However it plays a key role in the production and destruction of ozone. In the lower atmosphere increased ozone can lead to smog, while in the upper atmosphere, through the process of photolysis, N_2O is transformed into NO which in turn reacts with both O_3 and CH_4.

Fertilizer bands, crop root residues, and small scale topographic features affect soil N dynamics since they contribute to determining local N and O_2 supplies. N availability in the soil directly affect the various forms of gaseous nitrogen oxide (NO_x) exchange, while O_2 availability affects the total amount of N gasses produced by the soil. One example of denitrification is shown by Rochette et al. (2000b) who saw a large flux of N_2O for 30d after applying pig manure to soil. They postulated the flux of N_2O was probably related to the NO_3 in the manure which became available for denitrification. These results agree with Paul et al. (1993) who saw that additions of cattle manure raise denitrification rates and soil N_2O production in the laboratory. Fan et al. (1997) found that denitrification rates due to gaseous N_2O emissions were linear with N-fertilizer application rates. However, Hao et al. (2001a) found that by incorporating straw (a high C source), it was possible to reduce soil N_2O emissions after applying manure. Six and Feller et al. (2002b) saw that no-till had higher CH_4 uptake and greater N_2O production but still lea to reduced global warming potential due to reduced fuel use. Marland et al. (2003) argue that conversion to no-till can have positive effects on building soil C over approximately 40 years, however, reduction of the global warming potential by that agricultural practice will mostly depend on N fertilizer use.

Methane (CH_4) is the other GHG of importance to agriculture. Methane is usually produced through the anaerobic respiration of organic matter by methanogenic bacteria (archeobacteria) under conditions like those found in rice paddies, or even after cropland irrigation through the creation of small, temporary anaerobic microsites and thus contribute to methane production.

Methane is unique among these three agriculturally derived GHG's, in that the oxidation of methane by another group of bacteria called methanotrophs has the potential to offset a portion of the global warming potential of the other GHG's produced by agriculture. In early successional settings, that potential has been estimated to be as much as 211 g of carbon dioxide equivalents m^{-2} yr^{-1} (Robertson et al., 2000). This potential is reduced through N fertilization oxidation in arable soils (Mosier et al., 1991).

Methane oxidation requires NO_3^- and NO_2^- but is inhibited by NH_4^+ and very dry conditions (Hutsch, 1998). The reason for inhibition of methane oxidation by NH_4^+ is not very well understood, but is thought to arise from competition for the non-selective enzyme mono-oxygenase which is used by the methanotrophs to oxidize CH_4. Methane oxidation rates are greater in direct drilled (no-till) treatments than oxidation rates under other forms of tillage (Six et al., 2002b). Wang et al. (1999) observed Canadian prairies and woodlands to discover that much like no-till, these unbroken soils are an important sink for CH_4.

It soon becomes obvious why there has been so much interest in these three greenhouse gasses and their ties to agriculture. It is almost impossible to remove one from the other. Now that the increases of each of these greenhouse gases have been seen and their origins have been better understood, efforts are being made to reduce their production due to agriculture.

OBJECTIVES

This study evaluated the effect of four forage cropping systems (no-till alfalfa, corn, corn/alfalfa, and alfalfa/orchardgrass) with and without compost or manure on soil C sequestration, greenhouse gas emissions, forage quality and yield at two locations of different climate that contained large differences in background soil C.

HYPOTHESIS

1. Additions of compost and manure to the soil will increase soil C concentration within three years.
2. Emissions of greenhouse gases, CO_2, CH_4, and N_2O will be different between forage cropping systems.

3. The two locations in this study with different soil type (medium OM content vs. high OM content) will sequester C at different rates, and result in differing rates of greenhouse gas emissions.
4. Forage nutritive value of crude protein, NDF and ADF will not be affected by manure or compost treatments.
5. Forage dry matter yield will be higher with soil treated with both manure and compost.

MATERIALS AND METHODS

SITE DESCRIPTION AND EXPERIMENTAL DESIGN

This study was conducted at the Michigan State University W. K. Kellogg Biological Station (KBS, Hickory Corners, MI; 42.42 °N, 85.37 °W) and the Michigan Agricultural Upper Peninsula Experiment Station (UP, Chatham, MI; 46.34 °N, 86.92 °W). The soils at the KBS site are Kalamazoo sandy loam (fine-loamy, mixed, mesic Typic Hapludalfs) and Oshtemo sandy loam (coarse-loamy, mixed, mesic Typic Hapludalfs). At the UP site the soil is a Ternary sandy loam (mixed, frigid Alfic Haplorthodes). The experiment was a randomized complete block design with 4 replications with 8 treatments (four cropping systems with two organic matter treatments each). Plot size was 10.6 x 9.1 m at KBS and 12.2 x 12.2 m at the UP site based upon the available machinery at each location for planting, manure spreading, and harvesting. Both sites had grown corn in the year prior to the initiation of the experiment.

Fertility management was specific to each plot based upon soil samples taken from each plot in the spring of each year. Fertilizer recommendations for P, K, lime, and

N were made according to "Tri-State" (Vitosh, 1995) guidelines using a 58 Mg ha^{-1} (11 Mg ha^{-1} DM) yield goal for corn silage, and 11 Mg ha^{-1} (DM) yield goal for the establishment year of the alfalfa and alfalfa/orchardgrass mix and 16 Mg ha^{-1} (DM) yield goal for every year thereafter. Fertilizer applications to the compost and manure amended plots were corrected for nutrients available in the applied compost and manure treatments to ensure similar fertility levels. Soil pH at the KBS site was 6, while at the UP site, soil pH was 7.4. Soil bulk density and soil total N values are shown in the appendix (Table 35).

Four forage cropping systems with two organic matter treatments per system (for a total of 8 treatments) were selected based on their importance to Michigan dairy production: continuous silage corn with winter rye cover (corn), continuous alfalfa (alfalfa), corn with winter rye cover followed by continuous alfalfa rotation (corn/alfalfa), and continuous binary mixture of alfalfa and orchardgrass (13.5 kg ha^{-1} alfalfa seed mixed with 4.9 kg ha^{-1} orchardgrass) (alfalfa/orchardgrass) (Tables 1 and 2).

The seedbed at KBS was prepared for planting with a primary tillage operation using a chisel plow in the fall prior to spring planting followed by two passes of a field cultivator in the spring (once north-south, and once east-west). At KBS corn was planted using a JD 7300 (Deere & Company). The legumes were planted with a conventional tillage John Deere grain drill set up for planting small seeded legumes or grasses using band seeding with press wheels, (Deere & Company) and each legume plot was coultipacked to ensure good seed-soil contact (treatments alfalfa and alfalfa/orchardgrass). At the UP location, the soil was disked in the spring prior to planting and the legume plots (treatments alfalfa and alfalfa/orchardgrass) were coultipacked before the field was seeded.

Compost (at KBS) and manure slurry (at UP) treatments were applied in the spring before corn planting (A table comparing the two organic matter source treatments is given in the appendix, Table 33). A dairy manure and sawdust bedding compost (18.8% C, 3.6% N, C:N = 5.22) from the Michigan State University Dairy Cattle Teaching and Research Center in East Lansing was applied at KBS at a rate of 35,860 kg compost ha^{-1} using a Millcreek model 50 (Millcreek Manufacturing Co., Leola, Pennsylvania) small plot manure spreader. This provided approximately 3000 kg of C ha^{-1} yr^{-1}. At UP, manure slurry (3.83% C, 0.287% N, C:N = 13.34) from the dairy at the Upper Peninsula Experiment Station was spread using a Houle 3150 (J. Houle & Fils Inc., Drummondville, Quebec, Canada #527) liquid manure tanker/spreader at a rate of 84,200 L manure ha^{-1} to provide approximately 3000 kg of C ha^{-1} yr^{-1}. Each lot of compost and manure was tested for nutrients and C content prior to application (N, P, and K as well as C:N Ratio and % C). Summary tables of all field activities are shown in the appendix (Tables 27 through 32).

SOIL ANALYSIS

Three soil cores were collected from each replication using a 5-cm diameter corer (Geoprobe® Macro-Core®, (Geoprobe Systems)) prior to compost and manure applications each year (4/23/2002, 4/20/03, and 4/27/04 at KBS and on 5/14/2002, 5/5/03, and 4/3/04 at UP). The cores from each plot were divided into 0-5 cm and 5-25 cm portions, composited by depth, and analyzed for bulk density, available N, total N, total C, and POM. Air-dried sub samples from each of the composited soil cores from each replication were also analyzed for soil pH, phosphorus, and potassium by the Michigan State University Soil and Plant Nutrient Laboratory.

The procedures for soil analysis were as follows. Available soil N was determined using KCl extraction by shaking 20 g soil in a 1-M KCl solution for 45 min. The solution was allowed to settle for approximately 10 min and the resultant supernatant filtered using Whatman brand, size 1 filter paper (Whatman plc). The filtered liquid was frozen in plastic sample vials until it could be analyzed by the Michigan State University Soil and Plant Nutrient Laboratory for available soil N. For total soil N and C determination (TSN and TSC), a sub-sample of soil was passed through a sieve (2-mm mesh size), powder-ground using a ball mill grinder. Approximately 15-mg (+/- 3-mg) sub-samples were analyzed for total soil N and C using a Costech Instruments ECS 4010 combustion furnace (Costech Analytical Technologies, Valencia, CA). The protocol developed by the Michigan State University, Kellogg Biological Station, Long Term Ecological Research project (Protocol: KBS024-prot01 (1): Soil C and N) was used to analyze total C and N. For POM determination, a modified version of the POM by subtraction method was used (Cambardella and Elliott, 1992; Carter, 1993). Thirty mL of 0.50% (5 g L^{-1}) sodium hexametaphosphate was added to a 10 g sub-sample of sieved soil (2 mm) and shaken for 15 hr in a reciprocal shaker to disperse soil particles. The solution was poured through a 53 um sieve. The material remaining on the sieve was thoroughly washed with distilled water and the mineral solution containing silt and clay was collected as it passed through the sieve. The mineral solution was dried overnight at 70 C° and weighed. The dried material was powder-ground and a 15-mg sub-sample was analyzed for C and N of the mineral fraction using a combustion furnace as previously described for total C and N. Subtracting this value from the total soil C and N results in POM C and N.

FORAGE YIELD AND NUTRATIVE EVALUATION

Alfalfa and orchardgrass were harvested with a Carter research plot flail harvester (Carter Manufacturing Co. Inc., Brookston, IN) designed to harvest a 1.2-m wide swath down the center of the plot. Corn silage was harvested using a research two-row corn silage chopper (custom built 2-row chopper built using a John Deere 34 corn silage chopper and a Kincaid plot combine, Kincaid Company, Haven, Kansas). In the seeding year, two cuttings of the alfalfa and alfalfa/orchardgrass treatments were harvested when alfalfa reached 10% bloom. Each successive year, first cutting for alfalfa, corn/alfalfa, and alfalfa/orchardgrass treatments were harvested when the alfalfa reached 10% bloom, and every 30-35 days thereafter for a total of four cuttings at KBS, and three cuttings at UP each year. The orchardgrass in the alfalfa/orchardgrass treatments at UP matured earlier in 2004 and the alfalfa/orchardgrass plots were subsequently harvested 10 days earlier than the alfalfa or corn/alfalfa treatments for the remainder of the season. Total forage wet-weight from each harvested strip was recorded for each plot and a sub-sample from each plot was used for dry matter determination and was retained for forage nutritive analysis.

Forage nutritive analysis was done by the Michigan State University Forage Research Laboratory. A sub-sample of approximately 20-g was retained for nutritive analysis, ground to pass a 1-mm screen using A Norris 8" lab mill (Ipswich UK), and was scanned with a 6500 near-infrared spectrophotometer for forage quality determination (FOSS NIRSystems Inc., Silver Spring, Maryland). Reflected wavelengths (between 800 and 2500 nm) were recorded. A subset of these scanned samples was selected using the "Select" program from WinISI software (Infrasoft International LLC., Port Matilda, Pennsylvania) to create equations for the prediction of crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF). Total N was determined for the subset by the Hach modified Kjeldahl procedure (Watkins, 1987), and CP was estimated by multiplying total N by 6.25. The Goering and Van Soest (1970) method was used for NDF and ADF determination with the addition of 1 ml of alpha-amylase to the neutral detergent solution to break down starch. Dry matter (DM) content was determined by drying 0.5-g of sample in ceramic crucibles at 100°C for 12 hrs. The samples were then ignited in a muffle furnace at 500 °C for 6 hrs to determine ash content.

GAS ANALYSIS

CO_2, CH_4, and N_2O fluxes were estimated monthly using in-situ closed-cover flux chambers. Bases of the chambers (25.4-cm circular PVC drainage pipe, 10-cm high) were installed in all plots (removed only for farming activities and in the winter). A PVC end-cap was placed over the exposed portion of the chamber and latex sheeting (approximately 94 x 7.5-cm) was wrapped around the edge of the cap to provide a gas-tight seal between the cap and the base. Soil temperature and a soil sample (analyzed for moisture content) were taken each time gas fluxes were sampled.

Gas flux sampling was done at four 45-min sampling intervals by drawing 40-mL of gas from each chamber. Sealed 10-mL Labco Exetainer glass vials were flushed with 30-mL of the collected gas. The vial was over-pressurized with 10-mL of gas from the chamber. In the laboratory, CO_2 was analyzed using an infrared gas analyzer (SB 100, Analytical Development Co. Ltd., Hoddeson, England). CH_4 and N_2O were analyzed by gas chromatography using a Hewlet Packard 5890 Series II Gas Chromatograph; Poropak Q column (1.8-m, 80/100 mesh) at 80 °C. N_2O was detected by electron capture at 350 °C (ECD), CH_4 by flame ionization at 300 °C (FID).

STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was performed on yield, forage quality, greenhouse gas flux, soil POM, and soil TOC data using Proc Mixed (SAS Institute, 2000). The crop and organic matter treatments were considered fixed effects, while replication was considered a random effect. Greenhouse gas flux data was log transformed when necessary to meet ANOVA assumptions of normal distribution. Unless otherwise stated, differences were considered significant at an alpha level of 0.05.

RESULTS AND DISCUSSION

UP FORAGE YIELDS

At the UP location, statistical analysis revealed the strongest effect on forage dry matter (DM) yields (Table 3) was from the crop x year interaction ($P<0.0001$). There was also a significant effect of crop x manure interaction ($P<0.05$). Due to the significant interaction effects for crop x year as well as for crop x manure; it is not possible to compare individual cropping treatment or manure treatment effects on DM.

There were no significant differences between the cropping treatments with and without manure with the exception of the Corn treatment. Although not statistically significant, in 2002, the treatments which received manure additions had higher yields than the cropping treatments which did not receive manure (Table 4). The perennial cropping systems were only harvested once in the seeding year and this resulted in these treatments yielding approximately one third less than the corn and corn/alfalfa treatments.

In the second year of the study (2003) at UP, the perennial crops (alfalfa, and alfalfa/orchardgrass) were harvested three times and resulted in higher dry matter yields than the corn treatment. The alfalfa treatment with manure resulted in the highest recorded DM yield (16.62 Mg ha^{-1}). The alfalfa treatment without manure resulted in a DM yield of 13.38 Mg ha^{-1}. The alfalfa/orchardgrass treatments were not significantly different (10.84 Mg DM ha^{-1} with manure and 11.27 Mg DM ha^{-1} without manure). The corn without manure treatment (8.37 Mg ha^{-1}) tended to yield more than corn with manure (6.91 Mg ha^{-1}). The alfalfa in the corn/alfalfa treatment was not harvested this year because the alfalfa was not well established at harvest time.

In 2004, the third year of the study, the alfalfa with manure resulted in the highest yield with 11.37 Mg ha^{-1} per hectare. The corn with manure (6.54 Mg ha^{-1}) and non-manured corn (6.64 Mg ha^{-1}) treatments were not significantly different from each other or the non-manured alfalfa (8.12 Mg ha^{-1}) and both corn treatments (7.61 Mg ha^{-1} with manure and 7.01 Mg ha^{-1} without manure). While not statistically significant, the corn/alfalfa treatment DM yields were slightly higher with manure added, while both corn/alfalfa with and without manure tended to out yield both of the alfalfa/orchardgrass treatments. This may have been due to increased competition from two species compared to the monoculture cropping systems in the corn/alfalfa treatment.

For each of the cropping treatments there were no significant differences in three-year accumulated yields from the manure treatments; however, manured treatments did yield slightly more than the non-manured treatments.

KBS FORAGE YIELD

At the KBS location, statistical analysis (Table 5) revealed the strongest effect on forage yield was from year ($P<0.0001$). However, there was also a significant ($P<0.0001$) crop x year interaction; therefore it is not possible to compare differences between cropping treatment yields. Cropping treatment means by year at KBS are presented in Table 6. There was a significant increase in DM yield with the addition of compost at the KBS location ($P<0.0459$). On average, treatments amended with compost yielded of 7.78 Mg ha^{-1} compared with 7.09 Mg ha^{-1} for the non-amended plots. However the corn with compost treatment in 2004 averaged 3.36 Mg ha-1 more than the corn without compost added, while the alfalfa and alfalfa/orchardgrass treatments with compost only averaged 0.63 and 0.62 Mg ha-1 more than their respective non-composted treatments.

At KBS, corn yields in 2002 (Table 6 and 7) were much lower than those at the UP due to poor stand establishment at the KBS site which was caused by seed predation by birds and ground squirrels (*Spermophilus tridecemlineatus, Mitchill*). However, both the corn and corn/alfalfa (corn/alfalfa treatment was planted to corn in 2002) treatments tended to yield more than other cropping treatments. The corn treatment yielded 7.37 Mg ha^{-1} and the corn/alfalfa treatment yielded 8.24 Mg ha^{-1}. The alfalfa and alfalfa/orchardgrass treatments were only harvested once during this the seeding year. The alfalfa treatment yielded 2.31 Mg ha^{-1}. The alfalfa/orchardgrass treatment yielded 1.78 Mg ha^{-1} in the first year.

In the second year (2003) the alfalfa and alfalfa/orchardgrass treatments were each harvested 4 times at KBS. There were no significant differences between crop treatment yields. The corn treatment yielded 4.89 Mg ha^{-1}, the alfalfa treatment yielded 10.26 Mg ha^{-1}, the corn/alfalfa treatment (planted to alfalfa) yielded 2.68 Mg ha^{-1}, and the alfalfa/orchardgrass treatment yielded 10.67 Mg ha^{-1}. For the second year, ground squirrels were a problem for the corn treatments. It was decided that planting another crop as similar to corn as possible (C-4 grass, harvested as forage, similar growth cycle, and nutrient requirements) would be the best remedy for this situation. Sorghum was planted that year since ground squirrels, contributed to a loss of approximately 50% of the corn stand for the second year. These research plots had a history of problems with ground squirrels in no-till situations which were not explained to us when we started the experiment. While damage to larger stands of corn may have been negligible, in this small plot setting, seed predation by ground squirrels was a serious issue. Sorghum was planted into the corn treatment on June 17, 2003 after it became evident that there would not be enough corn to harvest due to excessive stand loss.

In the third year of the study (2004), ground squirrels were more effectively controlled at KBS by trapping, poisoning, and by planting earlier resulting in the corn yields being closer to expected yields (12.48 Mg ha^{-1}), the alfalfa treatment yielded 12.78 Mg ha^{-1}, and the corn/alfalfa yielded a more typical 12.78 Mg ha^{-1}. The alfalfa/orchardgrass treatment yielded 11.57 Mg ha^{-1}.

After three years, the average yield for the corn treatment was 8.24 Mg ha^{-1} and the alfalfa treatment yielded an average of 8.45 Mg ha^{-1}. The three year average for the corn/alfalfa treatment was 6.98 Mg ha^{-1}, and the alfalfa/orchardgrass treatment yielded an average of 8.01 Mg ha^{-1}. The difference seen between the corn/alfalfa treatment and the other treatments was due to this treatment having to catch up one year later than the other perennial crops. While yields for this treatment tended to be lower than the other treatment planted to alfalfa, it yielded similarly to the alfalfa treatment in the prior year.

FORAGE NUTRITIVE ANALYSIS

Statistical analysis of forage nutritive analysis at both locations showed no significant differences between manure or compost treatments. This was probably due to the additions of synthetic fertilizers to compensate the plots not receiving manure or compost at both locations. There were however significant Crop x Manure x Year interactions at the UP location (Table 8), and significant Crop x Year interactions at the KBS location (Table 10). Treatment means for both locations are given in Tables 9 and 11. Significant differences between crops and years were expected since the differences in forage quality between different species of plant are what make some more desirable as fodder than others (Hofmann and Isselstein, 2005). The differences between years has also been shown by since growing conditions (rainfall and daily temperature) (Kim et al., 2005) as well as the timing of harvests significantly impact forage quality (Crasta et al., 1997). These impacts far outweigh the slight improvements or declines in forage quality with and without additional organic matter amendments in the forms of manure and compost. Additionally since the legumes fix their own nitrogen from the atmosphere and consume available nitrogen in the soil when it is present, the additions of N in the compost and manure do not be play a role in differences between the organic matter treatments.

The corn treatments which did not receive compost or manure were fertilized with inorganic fertilizer at a comparable rate as the treatments amended with compost and manure. At the UP location, manure was applied one month before the corn planting in

2004, 2 weeks before corn planting in 2003, and 1 week before corn planting in 2002. The inorganic N fertilizer was applied approximately one month after the corn was planted as anhydrous ammonia (28%).

At the KBS location, compost was applied the day before corn planting in 2004, 5 days before corn planted in 2003, and one month before corn planting in 2002. Anhydrous ammonia was applied to the corn treatments in 2004, approximately 6 weeks after corn was planted, and approximately one month after corn was planted in 2002. In 2003, the sorghum received ammonium sulfate (34%) after each harvest.

The different timing of N fertilization through the manure and compost compared with inorganic fertilizers was not significant for any of the forage quality factors studied here. There did appear to be a slight trend for CP to be higher at the UP location without manure. This may have been due to the timing of N applications. Manure derived N was surface applied almost 2 moths before the crop would need it for growth. It is likely that the majority of the nitrogen applied in the manure was lost to volitization of NH_4 before the crop was even planted. The anhydrous ammonia applied 4 weeks after planting would be much more readily available for plant uptake and growth.

At KBS the compost was applied much closer to the time when the plants would have used the N, however since the compost was also surface applied and not incorporated, it is likely that the majority of the available N in the form of NH4 was lost due to volitization before the crop required the additional N. The lack of differences between organic matter treatments for the corn cropping system shows that this lost N did not play a role in affecting forage quality for this crop.

Differences in forage quality between the alfalfa/orchardgrass cropping treatments and the pure alfalfa cropping treatments were significant at both the UP location and the KBS location. This was due to the higher fiber content of the grass and because the grass matured more quickly than the alfalfa (Wiersma et al., 1999). At the UP location, ADF was not different in 2002, but it was significantly greater in 2004 (30.8% and 27.3% for the manured and non manured 2002 Alfalfa treatments compared with 31.8% and 32% for the manured and non manured 2002 Alfalfa/Orchardgrass treatments). In 2004, NDF content was 33.3% and 32.1% for the manured and non manured Alfalfa treatments respectively while the Alfalfa/Orchardgrass treatment NDF averaged 38.2% and 35.9% for the manured and non manured treatments respectively. NDF content was similar to the differences found in ADF levels with higher NDF content in the Alfalfa/Orchardgrass treatment than the Alfalfa monoculture treatment. This is because alfalfa matures more slowly than orchardgrass resulting in increased NDF and ADF at harvest time in the Alfalfa/Orchardgrass treatments. Alfalfa/Orchardgrass CP measured in 2002 and 2004 was significantly lower than the Alfalfa cropping treatment CP. This is due to alfalfa maturing more slowly than the alfalfa/orchardgrass mixture (Sheaffer et al., 1990; Sleugh et al., 2000). At the KBS location, those trends were the same for the Alfalfa and Alfalfa/Orchardgrass cropping treatments. These differences are shown in Tables 9 and 11.

GREENHOUSE GAS FLUXES

Soil greenhouse gas fluxes were sampled and analyzed each year of the study; however, due to equipment problems and different 1st year protocols, only the 2004 data is presented here. In 2002 gas fluxes were measured only twice and were not reliable measures of greenhouse gas fluxes for that growing season. As a result that data is not reported here. In 2003 gas fluxes were measured 4 times at KBS and 6 times at UP however problems with analytical equipment made these data unreliable. In 2004, with the exception of one set of samples taken at KBS (5/20/2004), and two sets of samples taken at UP (5/4/2004 and 10/18/04), the majority of the problems with the equipment and sampling protocol were corrected. Data reported here include only gas samples collected in 2004.

The measured gas fluxes at both locations were extremely variable through time. This high level of variability is attributed to differences in weather, soil moisture, ground cover, as well as the crop and manure or compost treatments at each location and through time. At the UP location in 2004, statistical analysis (Table 12 and 13) of seasonal greenhouse gas fluxes showed significant effects from manure on N_2O fluxes ($P<0.0405$). This was probably because the manure provided a much more readily available source of N than the 28% N applied to the corn treatments two months earlier. Differences in N_2O fluxes from crop effects were not significant ($P<0.09$). The greater variability in soil moisture, differences in spatial distribution of available N early in the season, differences in field microtopography, and other factors likely had greater influences on N_2O fluxes than the effect of plant species (Ambus and Christensen, 1995; Anderson et al., 1983; Ball et al., 1997). The alfalfa/orchardgrass cropping treatment with manure had the largest cumulative flux of N_2O (266 g N_2O ha^{-1} $growing^{-1}$ season) of all the cropping treatments (Table 13), however this cropping treatment also had a large amount of variability between samples.

CO_2 fluxes at the UP location were not significantly different between manure and non-manured treatments, however, all manured treatments with the exception of the alfalfa/orchardgrass treatment, resulted in higher fluxes of CO_2 than their non-manured counterparts did. The manure may have provided a readily available source of N and C to the soil bacteria that consumed it which would have produced more CO_2 as a result (Dao and Cavigelli, 2003; Liebig et al., 1995; Min et al., 2003). The effects of cropping treatments were not significant ($P< 0.0583$). The Alfalfa/Orchardgrass plots with manure resulted in the greatest CO_2 flux (88.29 kg ha^{-1} $season^{-1}$) similar to previous research (Paul et al., 1999), while the non-manured Corn treatments resulted in the lowest recorded fluxes (35.37 kg ha^{-1} $season^{-1}$).

At the UP location, CH_4 fluxes were not significantly different due to manure or cropping treatment. The fluxes at the UP location were all negative indicating that CH_4 uptake was occurring. CH_4 uptake was greater at UP than at KBS. This was most likely because the environmental conditions in the UP were more conducive to CH_4 uptake. Cooler temperatures tend to result in moist soil conditions through the summer which provided optimal conditions for methanophilic bacteria in the soil at the UP location. Higher soil organic matter levels and sand content also helped keep soil moist and well aerated for good CH_4 uptake. Uptake was lowest in the Corn treatment without manure (-2.12 g ha^{-1} $season^{-1}$). The Corn without manure received supplemental N (in row). This additional N may have contributed to the reduced CH_4 uptake since CH_4 oxidation has been shown to be competitive with de-nitrification (Hutsch, 1998; Hutsch, 2001). CH_4 uptake under manure treated plots tended to be greater than plots without manure. The greatest CH_4 uptake took place under the Alfalfa/Orchardgrass with manure treatment (-4.57 g ha^{-1} $season^{-1}$).

At the KBS location, measured greenhouse gas fluxes were only statistically different for N_2O and then only by crop treatments ($P<0.0327$) (Table 16). The measured greenhouse gas fluxes tended to be greater than at UP (Table 13). At KBS, with the exception of the Corn treatment, compost amended plots showed a tendency towards lower N_2O fluxes, opposite of the trends at UP for the manured plots. This may have been due to the fact that the N in the applied compost was generally tied up in organic forms not immediately available for plant uptake (Hartz et al., 2000; Paul and Beauchamp, 1993; Paul and Beauchamp, 1994) and that the high levels of lignified carbon applied in the compost may have tied up any free nitrogen in the soil. This is in contrast to the N applied in the manure which would have been much more readily available in the ammonium and organic N forms. The Alfalfa treatment had the highest measured N_2O flux (2.91 g ha^{-1} $season^{-1}$). The Alfalfa/Orchardgrass had the lowest measured N_2O flux (1.58 g ha^{-1} $season^{-1}$).

CO_2 fluxes at KBS were not significant for crop or for compost treatments. There was a tendency for plots amended with compost to have lower CO_2 fluxes through the season than the plots not receiving compost (109.05 and 115.97 kg ha^{-1} $season^{-1}$ respectively). This may also be tied to the large amounts of lignified carbon applied in the compost which may have had the effect of tying up free nitrogen which would have been required for the breakdown of the respiration of CO_2 by microorganisms. The Alfalfa plots had the highest measured CO_2 fluxes (132.20 kg ha^{-1} $season^{-1}$) and the Corn plots had the lowest measured CO_2 fluxes (83.64 kg ha^{-1} $season^{-1}$). The higher fluxes under alfalfa may have been due to additional organisms within the soil matrix, namely the nitrogen fixing bacterial residing in the roots of the alfalfa plants. The higher CO_2 fluxes may also have been due to fine root decomposition each time the alfalfa and orchardgrass plots were harvested. However, the Alfalfa/Orchardgrass treatment only had a measured flux of 105.33 kg ha-1 season-1 which was greater than the corn (83.64 kg ha-1 season-1), but still less than the Corn/Alfalfa treatment (114.01 kg ha-1 season-1). One would assume that the Alfalfa/Orchardgrass treatment would have the most fine roots of any of the cropping treatments.

CH_4 fluxes at KBS were all negative, as in the UP, and while differences were not statistically different, there appeared to be a trend for lower CH_4 uptake following compost additions (-2.28 and -2.47 g ha^{-1} $season^{-1}$ for the composted and non composted plots respectively). The greatest CH_4 uptake was in the Corn/Alfalfa treatment (-2.83 g ha^{-1} $season^{-1}$). The Alfalfa treatment resulted in the lowest uptake of CH_4 (-2.07 g ha^{-1} $season^{-1}$) potentially due to the increased availability of NH4 and the non-selective enzyme mono-oxygenase which is used by the methanotrophs to oxidize CH_4 (Mosier and Schimel, 1991). Overall, CH_4 uptake at KBS was 2-3 times lower than at UP. This was likely due to drier soil conditions which occurred at the KBS site, which led to poorer conditions for the methanophilic bacteria.

GREENHOUSE GAS FLUXES AS CO_2 EQUIVALENTS

The differences between cropping systems with and without organic matter additions at both locations were evident after converting the accumulated greenhouse gas fluxes into 100-year CO_2 equivalents (comparison based on the 100-year global warming potential, GWP, of each gas; N_2O = 310 times the relative thermal absorption of CO_2 and

CH_4 = 21 times the relative thermal absorption of CO_2 (Robertson et al., 2000). This system allows a common scale for comparison purposes. The differences between locations were significant, however between treatments, differences were not statistically significant. There appear to be some trends however. In this experiment, the UP location had much lower fluxes of N_2O and much greater uptake of CH_4 than KBS location (Table 16 and 17). This resulted in a higher GWP for the KBS compared with the UP location. Greenhouse gas production at the UP was higher under manured treatments for all cropping systems except the Corn/Alfalfa treatment. The Corn and Alfalfa treatments without manure resulted in the lowest overall greenhouse gas fluxes.

In 2004, the seasonal greenhouse gas fluxes from the cropping systems at the KBS location (like at the UP location), were driven primarily by the N_2O fluxes. Treatments with high N_2O fluxes included the Corn with compost, and un-amended Corn/Alfalfa treatments. The cropping system which appeared to result in the lowest greenhouse gas fluxes was the Alfalfa/Orchardgrass with compost.

TOTAL SOIL C AND POM

Total soil C (TSC) in the 0-5 and 5-25 cm soil horizons at the UP location and the 5-25 cm soil horizon at the KBS location measured in 2004 were not significantly different due to crop or manure treatments (Table 18). The lack of detectable differences was probably most likely due to the small amounts of C added by the treatments in comparison to the large amounts of background C. Cropping treatment means are presented in Table 19 and manure treatment means in Table 20. TSC concentration in the 0-5 cm horizon at KBS in 2004 were nearly half that at the UP location. TSC in the 0-5 cm soil horizon at the KBS location was significantly different for the compost treatments ($P > 0.0214$). Plots receiving compost had an average TSC of 0.943 kg m^{-2} while plots without compost averaged 0.798 kg m^{-2}. The addition of the compost which was comprised of sawdust and dairy manure provided a high lignin source which was not easily broken down, in comparison to the dairy manure slurry applied at the UP location which was easily broken down by soil micro-organisms.

There are methods which can measure soil C accurately, however, small changes in soil C levels are difficult to detect due to factors of seasonal variability, spatial variability, and the difficulties inherent in detecting changes with large background levels of C (Barnwell et al., 1992; Conen et al., 2003; Paul et al., 2001; Paustian et al., 1995). The mean soil C sampled at the KBS location had a standard error of 0.017 % C at the 0-5 cm depth and, 0.02 % C at the 5-25 cm depth while the UP location the mean soil C standard error was 0.048 % C for the 0-5 cm depth, and 0.046 % C for the 5-25 cm depth in the first year of the study (2002).

The minimum detectable difference in soil C can be estimated in a one-tailed, one sample t-test as a product of the standard error and the sum of the critical t values for type I and II error probabilities (Zar, 1999). To achieve a statistical power of 0.90, that sum is 2.978. Therefore the minimum detectable difference is 0.05, 0.06, 0.14, and 0.13 % change in C for KBS 0-5 cm, 5-25 cm, Chatham 0-5 cm, and 5-25 cm respectively, assuming variability did not increase. However, as a result of the different treatments and temporal variation, variability did in fact increase. This increase was greatest at KBS, where the CV increased from 9.6 to 15 and from 14 to 16 in the 0-5 and 5-25 cm horizons respectively. These results follow previous research by Bird et al., Conant and Paustain, and Conant et al. (Bird et al., 2002; Conant and Paustian, 2002; Conant et al., 2003).

The increase in the variability of these data resulted from the combination of changes in bulk density (which can be very susceptible to changes in soil moisture), small scale spatial variability, and the effects of cropping treatments and organic matter inputs. Since the amount of C in the soil expressed as mass per volume requires the soil bulk density for the calculation, the variability of the bulk density and its changes were added into the calculations for total soil C. The increase in variability of the bulk density is translated into variability of the measured total soil C. Bulk density was not uniformly variable over the 3-year study. The background bulk density CV was 8 and 9 in the 0-5 cm horizons at KBS and Chatham respectively. Bulk density in 2004 declined to 5 g cm^{-3} and increased to 10 g cm^{-3} at KBS and Chatham respectively.

We hypothesized that adding large amounts of C in the forms of manure and compost it would be possible to significantly affect soil organic matter differences in a short time period. Initial POM levels were not measured in 2002 due to the high cost of analysis and time constraints. It was also felt that since calculating POM requires the use of soil bulk density (which is very susceptible to changes in soil moisture and time of year), the best course of action would be to work with one year's soil. The resulting comparison of POM levels between organic matter treatments for the same cropping system treatment would then be sufficient for detecting changes in soil POM without confusing the data with temporal, moisture, and various other factors which could have affected soil POM more than the treatments applied in this experiment.

C was added at a rate of 350 g C m^{-2} y^{-2} at both locations to the plots receiving organic matter inputs (manure at Chatham, compost at KBS). This represented approximately 48% of the background C in the top 5 cm at KBS and 25% of the background C present in the top 5 cm at Chatham. Since the organic matter was not incorporated into the soil at either location, increases in the amount of soil organic matter in the 5-25 cm horizon would only be expected to result through the action of cropping system root biomass inputs. Those differences are much harder to detect as the process of C sequestration due to plant roots is much slower than amending with compost or manure and thus detecting those changes was not possible in the time allotted for this experiment.

Both the compost and the manure were surface applied rather than incorporated at both locations to achieve no-till planting. At the KBS location, that surface application of compost may have resulted in increased surface soil C. By applying the compost on the surface, it was more exposed to sunlight and environmental conditions which kept it drier than the manure applied at the UP location, which was applied as slurry. The compost also was composed of a more lignified form of C, namely sawdust which made it less susceptible to degradation by soil microbes (Honeycutt et al., 1993). These two sources of organic matter were very different, and resulted in different fates for the two types of organic matter. For example, compost was still visible on the soil surface 7 months after application, while the manure was broken down by microorganisms within three weeks of application. The manure provided readily available sources of organic N, phosphorus, and easily degraded forms of C that were utilized more quickly by the crops and soil microbes. The compost, on the other hand, had much lower available N and greater amounts of lignified material which takes much longer to break down in the soil (Baldock et al., 1997; Chantigny et al., 2002). The composted treatments also had half the available N of the non-composted plots as measured by KCl extraction. The large amount of C (compost had 5 times more carbon on a percent basis than the manure) in the applied compost resulted in N immobilization in the soil as measured in 2003. At the KBS location a pre-sidedress nitrogen test (PSNT) was taken (July 18, 2003) after the corn stand failed due to seed predation. Treatments which received compost had reduced available N (2.8 ppm) compared to plots not receiving compost (5.6 ppm).

Because of difficulties associated with measuring changes in total soil C, our research focused on the POM fraction (which is thought to be responsive to changes in tillage regimes and possibly cropping systems within a shorter time period)(Cambardella and Elliott, 1992). There were no significant differences between any of the cropping or manure treatments at the UP location (Table 20). The lack of significant differences between treatments at the UP location was likely due to high background levels of soil C inherent in the soils which averaged 0.72 kg POM C m^{-2} in the 0-5 cm soil horizon, and 1.91 kg POM C m^{-2} in the 5-25 cm soil horizon (Table 20). Although total soil C concentration did not change significantly between treatments at the UP location over the 3-year study, POM C means with manure treatments were 10% lower than non-manured plot treatments for both depths (0.52 and 0.56 kg POM C m^{-2} for the manured and non-manured 0-5 cm soil horizons respectively). There also appeared to be a trend in that plots with the highest measured POM C were the Corn treatments at both depths (0.69 and 2.08 kg POM C m^{-2} for the 0-5 cm and 5-25 cm soil horizons respectively) while the Alfalfa/Orchardgrass cropping treatments had the lowest measured POM C (0.51 and 1.69 kg POM C m^{-2} for the 0-5 cm and 5-25 cm soil horizons respectively).

POM C levels at KBS were approximately half those at the UP; (0.27 kg POM C m^{-2} for the 0-5 cm soil horizon and 0.72 kg POM C m^{-2} for the 5-25 cm soil horizon).

Significant differences were detected in POM C between compost treatments in the 0-5 cm soil horizon (Table 26). The plots receiving compost had 0.94 kg POM C m^{-2} while the plots not receiving compost had 0.80 kg POM C m^{-2}. This slight increase may have been due to additional inputs of large amounts of lignified C present as decomposed sawdust in the compost. Any changes occurring in the 5-25 cm soil horizon was from changes in plant root material inputs, since the organic matter applied at both locations was not incorporated.

The effect of cropping system was not significant. However, in contrast to the UP location where the Alfalfa/Orchardgrass cropping treatment had the lowest measured POM C, at the KBS location, the Alfalfa/Orchardgrass had the highest measured amount of POM C for both soil depths (0.30 and 1.23 kg POM C m^{-2} for the 0-5 cm and 5-25 cm soil horizons respectively). The Alfalfa treatment resulted in the lowest measured POM C in the 0-5 cm soil horizon (0.19 kg m^{-2}) and the Corn/Alfalfa cropping treatment resulted in the lowest POM C in the 5-25 cm soil horizon (0.59 kg m^{-2}).

The increase in measured POM C under the Alfalfa/Orchardgrass cropping treatment may have been due to the addition of fine roots from the Orchardgrass after each harvest (Fu et al., 2002; Robertson et al., 1995; Urquiaga et al., 1998). It may have been that due to the higher amount of clay in the soil at the KBS location there was a greater capacity to sequester carbon while at the UP location, the capacity for additional carbon inputs in the form of fine root material had already been filled.

While soil C levels can be rapidly depleted by tillage, increases due to changes in management practices happen slowly and over long periods of time resulting in significant time spans for soil C stocks to reach new equilibriums(Robertson et al., 2000).

It is likely that the short time frame allotted for this experiment was not adequate to allow the soil C stocks or the soil structure to stabilize and therefore it was not possible to detect the changes in soil C for most of the treatments. If additional time had been available for this study, additional changes in soil C may have been detected.

CONCLUSIONS

There were significant forage quality differences between species, but these differences were not tied to organic matter treatments. These differences were due to differences in protein and fiber content of the different plants used in this study, namely alfalfa, corn, and orchardgrass. Each of these crops has differing amounts of protein and fiber which make them suitable as forage crops.

The higher Corn yields at the UP location were due to pests found at the KBS site primarily from ground squirrels feeding on newly emerged corn seedlings. Higher Alfalfa/Orchardgrass yields at KBS were greater mainly due to the shorter growing season and subsequently fewer harvests taken at Chatham. Chatham's corn growing season is limited by late frosts until from late May, while at KBS; corn could be planted in early May without fear of frost damaging the stand. Frost can appear in September at the UP location while at KBS it is usually delayed by 2-3 weeks.

The slightly lower yields of the Alfalfa/Orchardgrass treatment at KBS compared with the Alfalfa treatment indicate that while the system may not yield as high as the Alfalfa treatment, it still may an option for a more diverse cropping system that can be incorporated into forage cropping rotations to increase soil carbon. It was hypothesized that the Alfalfa/Orchardgrass cropping system would help build soil C due to the diversity of roots in the soil (fibrous roots from Orchardgrass, and the deep taproots of alfalfa) as well as the orchardgrass scavenging excess N from the alfalfa plants. That was not the case at the UP location where there was a high level of background soil C. It was the case at the KBS location and may have been due to increased clay content in the soil.

When comparing the differences between greenhouse gas fluxes, the UP location resulted in lower N_2O, and CO_2 fluxes while having greater CH_4 uptake, compared to the KBS location which had high N_2O and CO_2 fluxes and very little CH_4 uptake. This resulted in a lower overall GWP for the UP location compared to the KBS location. This was most likely due to differences in climate and higher amounts of soil organic matter which lead to moist soil conditions and were more conducive to CH_4 uptake at the UP location. The warmer climate at the KBS location was more favorable for increasing N_2O production and reducing CH_4 uptake. There were no differences seen in the two organic matter treatments at the two locations, however if gas fluxes had been measured immediately following application of the manure and compost at both locations, differences may have been apparent between the treatments.

The UP location had a higher background level of soil C present at the beginning of the experiment compared to the KBS location. This indicates that the climate has been more conducive to soil C building over a long period of time than the KBS location. However, significant changes in soil C due to additions of organic matter or different cropping treatments were not evident at the UP location in the time allotted for this experiment. It was interesting to note however that at the UP there appeared to be a trend for the plots amended with manure to have lower amounts of POM C than the plots which did not receive manure.

There were no significant differences in POM C due to cropping treatment after 3 years; however there was a trend which resulted in the Alfalfa/Orchardgrass cropping treatment exhibiting the highest POM C for both 0-5 and 5-25 cm soil horizons. This shows the potential for increasing POM significant by cropping systems over time. The significant difference in soil C in the 0-5 cm soil horizon at the KBS location may have been the start of a change in soil C levels or it may have just been due to a buildup of lignified C from the sawdust in the compost. If it was the beginning of a change in soil C levels, it may be that the higher clay content of the soil helped contribute to this increase by improving POM stability (Six et al., 2002a).

The cooler summers, cold winters, and short growing season may provide challenges for growing crops at the UP location. However, compared to the KBS location, it appears that this more northerly climate may reduce the GWP of similar farming operations taking place further south. This reduction may not enough to offset the higher GWP at the more southerly location however it helps provide additional information for reducing the GWP of certain farming activities. The significant effects of additional carbon inputs from compost at the KBS location point to potential sources for offsetting the negatives associated with the higher GWP of this site.

TABLES

Table 1 Cropping and organic matter input treatments at UP

Treatment	First Year Crops and Seeding Rates	Second and Third Year Crops and Seeding Rates	Organic matter input
Corn	**Corn** Pioneer 39T71 (69,160 seeds ha^{-1})	**Corn** Pioneer 39T71 (69,160 seeds ha^{-1})	Manure
Corn	**Corn** Pioneer 39T71 (69,160 seeds ha^{-1})	**Corn** Pioneer 39T71 (69,160 seeds ha^{-1})	None
Alfalfa	**Alfalfa** Pioneer 53H81 (33 kg ha^{-1})	**Alfalfa**	Manure
Alfalfa	**Alfalfa** Pioneer 53H81 (33 kg ha^{-1})	**Alfalfa**	None
Corn/Alfalfa	**Corn** Pioneer 39T71 (69,160 seeds ha^{-1})	**Alfalfa** Pioneer 53H81 (33 kg ha^{-1})	Manure
Corn/Alfalfa	**Corn** Pioneer 39T71 (69,160 seeds ha^{-1})	**Alfalfa** Pioneer 53H81 (33 kg ha^{-1})	None
Alfalfa/ Orchardgrass	**Alfalfa/Orchardgrass** Pioneer 53H81 (13 kg ha^{-1}) and Ampac "Tekapo" (4.5 kg ha^{-1})	**Alfalfa/Orchardgrass**	Manure
Alfalfa/ Orchardgrass	**Alfalfa/Orchardgrass** Pioneer 53H81 (13 kg ha^{-1}) and Ampac "Tekapo" (4.5 kg ha^{-1})	**Alfalfa/Orchardgrass**	None

Table 2. Cropping and organic matter input treatments at KBS

Treatment	First Year Crops and Seeding Rates	Second and Third Year Crops and Seeding Rates	Organic matter input
Corn	**Corn** Pioneer 34M95 (74,100 seeds ha^{-1})	**Corn** Pioneer 34M95 (74,100 seeds ha^{-1})	Compost
Corn	**Corn** Pioneer 34M95 (74,100 seeds ha^{-1})	**Corn** Pioneer 34M95 (74,100 seeds ha^{-1})	None
Alfalfa	**Alfalfa** Pioneer 53Q60 (33 kg ha^{-1})	**Alfalfa**	Compost
Alfalfa	**Alfalfa** Pioneer 53Q60 (33 kg ha^{-1})	**Alfalfa**	None
Corn/Alfalfa	**Corn** Pioneer 34M95 (74,100 seeds ha^{-1})	**Alfalfa** Pioneer 53Q60 (33 kg ha^{-1})	Compost
Corn/Alfalfa	**Corn** Pioneer 34M95 (74,100 seeds ha^{-1})	**Alfalfa** Pioneer 53Q60 (33 kg ha^{-1})	None
Alfalfa/ Orchardgrass	**Alfalfa/Orchardgrass** Pioneer 53Q60 (13 kg ha^{-1}) and Ampac "Tekapo" (4.5 kg ha^{-1})	**Alfalfa/Orchardgrass**	Compost
Alfalfa/ Orchardgrass	**Alfalfa/Orchardgrass** Pioneer 53Q60 (13 kg ha^{-1}) and Ampac "Tekapo" (4.5 kg ha^{-1})	**Alfalfa/Orchardgrass**	None

Table 3. Dry matter forage yield at the UP location ANOVA

Effect	DF(Num)	DF(Den)	F Value	Pr > F
Rep	3	21	4.36	0.0155
Crop	3	21	35.38	<.0001
Manure	1	21	4.45	0.0471
Year	2	47	61.77	<.0001
Crop*Manure	3	21	3.20	0.0442
Crop*Year	5	47	104.27	<.0001
Manure*Year	2	47	0.50	0.6127

Table 4. UP forage dry matter yield treatment means.

	Yield Mg ha^{-1}			
Treatment	2002	2003	2004	Average
Corn (Manure)	14.22	6.91	6.54	9.22
Corn (No Manure)	12.82	8.37	6.64	9.28
Alfalfa (Manure)	1.86	16.62	11.37	9.95
Alfalfa (No Manure)	1.63	13.38	8.12	7.72
Corn/Alfalfa (Manure)	12.62	----	7.61	6.75
Corn/Alfalfa (No Manure)	11.92	----	7.01	6.31
Alfalfa/Orchardgrass (Manure)	3.21	10.84	4.00	6.03
Alfalfa/Orchardgrass (No Manure)	2.48	11.27	3.17	5.64

Table 5. KBS forage yields ANOVA.

Effect	DF(Num)	DF(Den)	F Value	Pr > F
Rep	3	21	3.83	0.0248
Crop	3	21	6.06	0.0039
Compost	1	21	4.51	0.0459
Year	2	54	273.69	<.0001
Crop*Compost	3	21	1.38	0.2769
Crop*Year	6	54	77.17	<.0001
Compost*Year	2	54	2.98	0.0590

Table 6. KBS forage yield treatment means by year and cropping treatment.

Treatment	Yield Mg ha^{-1}			
	2002	2003	2004	Average
Corn	7.37	4.89	12.48	8.24
Alfalfa	2.31	10.26	12.78	8.45
Corn/Alfalfa	8.24	2.68	10.01	6.98
Alfalfa/Orchardgrass	1.78	10.67	11.57	8.01

Table 7. KBS forage yield treatment means by compost treatment.

Treatment	Yield Mg ha^{-1}
Compost	7.78
No Compost	7.09

Table 8. Forage quality at the UP location ANOVA

Effect	DF(Num)	DF(Den)	F Value	Pr > F
Rep	3	57	0.66	0.5795
Manure	1	57	0.52	0.4722
Crop	3	57	156.02	<.0001
Crop*Manure	3	57	1.04	0.3835
Year	2	57	33	<.0001
Manure*Year	2	57	0.39	0.6795
Crop*Year	4	57	54.53	<.0001
Crop*Manure*Year	4	57	3.51	0.0124

Table 9. Forage quality treatment means at the UP location.

	ADF			NDF			Crude Protein		
Treatment	2002	2003	2004	2002	2003	2004	2002	2003	2004
Corn (Manure)	28.6 ab	26.2 a	33.2 ab	56.0 c	48.4 b	56.3 cd	7.4 a	7.1 a	7.2 a
Corn (No Manure)	29.8 ab	27.1 a	32.3 a	57.7 c	49.8 b	54.5 c	8.1 a	7.8 a	9.1 a
Alfalfa (Manure)	30.8 ab	30.9 b	33.3 ab	39.0 a	40.0 a	42.2 a	17.7 cd	18.8 b	19.2 c
Alfalfa (No Manure)	27.3 a	29.8 b	32.1 a	32.6 a	38.7 a	40.0 a	19.9 d	18.2 b	17.3 b
Corn/Alfalfa (Manure)	29.8 ab	-------	32.2 a	57.5 c	-------	39.8 a	7.1 a	-------	20.1 c
Corn/Alfalfa (No Manure)	28.3 ab	-------	31.4 a	55.2 c	-------	39.6 a	8.4 a	-------	19.7 c
Alfalfa/Orchardgrass (Manure)	31.8 b	-------	38.2 c	48.1 b	-------	52.3 c	15.9 bc	-------	14.7 b
Alfalfa/Orchardgrass (No Manure)	32.0 b	-------	35.9 bc	49.5 bc	-------	48.2 b	14.3 b	-------	15.6 b
CV	9.6	5.9	7.7	11.2	5.5	7.7	17.7	3.4	10.9

Table 10. Forage quality at the KBS location ANOVA

Effect	DF(Num)	DF(Den)	F Value	Pr > F
Rep	3	63	4.86	0.0042
Manure	1	63	0.04	0.8497
Crop	3	63	284.1	<.0001
Crop*Manure	3	63	0.35	0.7897
Year	2	63	25.69	<.0001
Manure*Year	2	63	1.27	0.288
Crop*Year	5	63	72.23	<.0001
Crop*Manure*Year	5	63	1.6	0.1729

Table 11. Forage quality treatment means at KBS location.

	ADF			NDF			Crude Protein		
Treatment	2002	2003	2004	2002	2003	2004	2002	2003	2004
Corn (Manure)	20.9 a	-------	24.3 a	40.4 b	-------	43.5 a	6.3 a	-------	7.0 a
Corn (No Manure)	23.2 ab	-------	24.5 a	44.4 c	-------	44.0 a	6.2 a	-------	7.1 a
Alfalfa (Manure)	28.3 bc	30.1 a	33.5 b	37.6 ab	38.7 ab	41.7 a	21.6 b	21.8 c	21.3 b
Alfalfa (No Manure)	27.5 bc	30.4 ab	32.5 b	36.7 a	38.4 a	40.9 a	22.1 b	21.7 c	21.4 b
Corn/Alfalfa (Manure)	22.7 ab	34.0 bc	32.0 b	44.5 c	45.2 cd	40.0 a	5.8 a	16.5 a	21.3 b
Corn/Alfalfa (No Manure)	23.3 ab	31.8 abc	33.2 b	44.9 c	41.8 abc	41.7 a	6.1 a	18.6 b	19.7 b
Alfalfa/Orchardgrass (Manure)	28.2 bc	32.8 abc	38.9 c	37.9 ab	48.9 d	51.6 b	21.9 b	18.5 b	17.1 b
Alfalfa/Orchardgrass (No Manure)	29.6 c	33.6 bc	38.5 c	40.0 b	49.9 d	50.3 b	21.4 b	18.1b	17.0 b
CV	11.7	12.3	11.8	7.1	13.7	10.0	9.3	12.3	9.5

Table 12. UP greenhouse gas flux ANOVA

	Effect	DF(Num)	DF(Den)	F Value	Pr > F
N_2O	Rep	3	21	0.53	0.6640
	Crop	3	21	2.58	0.0810
	Manure	1	21	4.77	0.0405
	Crop*Manure	3	21	0.50	0.6855
CO_2	Rep	3	21	0.32	0.8078
	Crop	3	21	2.91	0.0583
	Manure	1	21	2.49	0.1294
	Crop*Manure	3	21	2.13	0.1268
CH_4	Rep	3	21	2.37	0.0997
	Crop	3	21	1.54	0.2341
	Manure	1	21	1.20	0.2856
	Crop*Manure	3	21	0.40	0.7525

Table 13. UP greenhouse gas flux treatment means.

Treatment	g ha^{-1} day^{-1} N_2O production	kg ha^{-1} day^{-1} CO_2 production	g ha^{-1} day^{-1} CH_4 uptake
Corn (Manure)	2.433	44.28	-2.788
Corn (No Manure)	1.039	35.37	-2.123
Alfalfa (Manure)	1.455	68.24	-3.992
Alfalfa (No Manure)	1.866	51.24	-2.711
Corn/Alfalfa (Manure)	2.757	46.51	-2.620
Corn/Alfalfa (No Manure)	2.015	62.02	-3.052
Alfalfa/Orchardgrass (Manure)	2.010	88.29	-4.566
Alfalfa/Orchardgrass (No Manure)	3.590	52.44	-3.578

Table 14. UP greenhouse gas fluxes by organic matter treatment.

Treatment	N_2O	CO_2	CH_4
Manure	2.211	86.23	-3.57
No Manure	2.136	85.69	-3.80

Table 15. KBS greenhouse gas flux ANOVA.

	Effect	DF(Num)	DF(Den)	F Value	Pr > F
N_2O	Rep	3	21	0.16	0.9220
	Crop	3	21	0.63	0.6029
	Compost	1	21	0.00	0.9463
	Crop*Compost	3	21	0.89	0.4614
CO_2	Rep	3	21	0.35	0.7917
	Crop	3	21	1.44	0.2602
	Compost	1	21	0.13	0.7249
	Crop*Compost	3	21	0.36	0.7836
CH_4	Rep	3	21	0.52	0.6748
	Crop	3	21	0.54	0.6577
	Compost	1	21	0.28	0.6024
	Crop*Compost	3	21	0.74	0.5414

Table 16. KBS greenhouse gas flux treatment means.

Treatment	g ha^{-1} day^{-1} N_2O production	kg ha^{-1} day^{-1} CO_2 production	g ha^{-1} day^{-1} CH_4 uptake
Corn	2.17	83.64	-2.395
Alfalfa	2.91	132.20	-2.078
Corn/Alfalfa	2.88	114.01	-2.834
Alfalfa/Orchardgrass	1.58	105.33	-2.174

Table 17. KBS greenhouse gas fluxes by organic matter treatment.

Organic Treatment	N_2O	CO_2	CH_4
Compost	2.57	155.97	-2.47
No Compost	2.13	109.05	-2.28

Table 18. Total Soil Carbon (TSC) ANOVA.

	Effect	DF(Num)	DF(Den)	F Value	Pr > F
UP 0-5	Crop	3	21	1.49	0.2461
	Manure	1	21	0.01	0.9420
	Crop*Manure	3	21	0.69	0.5681
UP 5-25	Crop	3	21	0.7	0.5607
	Manure	1	21	0.98	0.3330
	Crop*Manure	3	21	0.2	0.8948
KBS 0-5	Crop	3	20	1.9	0.1618
	Compost	1	20	6.23	0.0214
	Crop*Compost	3	20	1.18	0.3442
KBS 5-25	Crop	3	18	0.55	0.6526
	Compost	1	18	0.02	0.8876
	Crop*Compost	3	18	0.47	0.7068

Table 19. TSC cropping treatment means 2004.

Location	Crop Treatment	TSC kg m^{-2}	
		0-5 cm	5-25 cm
UP	Corn	1.555	5.085
	Alfalfa	1.520	5.459
	Corn/Alfalfa	1.518	5.161
	Alfalfa/Orchardgrass	1.509	5.176
KBS	Corn	0.904	2.839
	Alfalfa	0.801	2.926
	Corn/Alfalfa	0.834	2.849
	Alfalfa/Orchardgrass	0.945	3.125

Table 20. TSC organic matter treatment means 2004.

Location	Organic Treatment	TSC kg m^{-2}	
		0-5 cm	5-25 cm
UP	Manure	1.526	5.134
	No Manure	1.525	5.307
KBS	Compost	0.943	2.955
	No Compost	0.798	2.915

Table 21. TSC differences 2004-2002

	Effect	DF(Num)	DF(Den)	F Value	Pr > F
UP 0-5	Crop	3	20	0.33	0.8061
	Manure	1	20	0.19	0.6639
	Crop*Manure	3	20	0.64	0.5986
UP 5-25	Crop	3	20	1.44	0.2609
	Manure	1	20	0.66	0.4264
	Crop*Manure	3	20	1.49	0.2487
KBS 0-5	Crop	3	20	0.89	0.4657
	Compost	1	20	4.36	0.0498
	Crop*Compost	3	20	0.62	0.6128
KBS 5-25	Crop	3	20	0.1	0.9618
	Compost	1	20	2.14	0.1591
	Crop*Compost	3	20	1.1	0.4062

Table 22. TSC difference 2004-2002 cropping treatment means

Location	Crop Treatment	kg TSC m^{-2}	
		0-5 cm	5-25 cm
UP	Corn	0.159	0.453
	Alfalfa	0.135	1.137
	Corn/Alfalfa	0.061	0.739
	Alfalfa/Orchardgrass	0.047	1.139
KBS	Corn	0.007	-0.109
	Alfalfa	-0.123	-0.111
	Corn/Alfalfa	-0.101	-0.147
	Alfalfa/Orchardgrass	-0.069	0.029

Table 23. TSC difference 2004-2002 organic matter treatment means

Location	Organic Treatment	kg TSC m^{-2}	
		0-5 cm	5-25 cm
UP	Manure	0.12	0.75
	No Manure	0.08	0.96
KBS	Compost	-0.01	0.12
	No Compost	-0.14	-0.27

Table 24. POM Soil Carbon (POM C) ANOVA

	Effect	DF(Num)	DF(Den)	F Value	Pr > F
UP 0-5	Rep	3	21	0.17	0.9128
	Crop	3	21	0.06	0.9803
	Compost	1	21	0.00	0.9926
	Crop*Manure	3	21	1.13	0.3601
UP 5-25	Rep	3	21	1.42	0.2640
	Crop	3	21	0.45	0.7225
	Compost	1	21	0.50	0.4881
	Crop*Manure	3	21	0.21	0.8866
KBS 0-5	Rep	3	21	3.05	0.0508
	Crop	3	21	1.89	0.1619
	Compost	1	21	10.65	0.0037
	Crop*Compost	3	21	0.61	0.6137
KBS 5-25	Rep	3	21	0.20	0.8947
	Crop	3	21	0.71	0.5580
	Compost	1	21	0.28	0.6055
	Crop*Compost	3	21	0.55	0.6563

Table 25. POM C cropping treatment means 2004

Location	Crop Treatment	kg POM C m $^{-2}$	
		0-5 cm	5-25 cm
UP	Corn	0.598	2.084
	Alfalfa	0.515	1.971
	Corn/Alfalfa	0.520	1.896
	Alfalfa/Orchardgrass	0.512	1.688
KBS	Corn	0.297	0.609
	Alfalfa	0.187	0.702
	Corn/Alfalfa	0.260	0.588
	Alfalfa/Orchardgrass	0.318	1.125

Table 26. POM C organic matter treatment means 2004

Location	Organic Treatment	kg POM C m $^{-2}$	
		0-5 cm	5-25 cm
UP	Manure	0.815	1.787
	No Manure	0.555	2.033
KBS	Compost	0.211	0.758
	No Compost	0.202	0.809

APPENDICES

Table 27. Agronomic field activities for KBS 2004.

Date	Field Activity	Treatment
4/14/04	Oats planted, Kura Clover killed	(Trt. 9 & 10)
4/20/04	Gas sample # 1	(All)
4/27/04	Soil sample	(All)
4/29/04	Compost applied	(Trt. 1 & 9)
4/30/04	Corn planted	(Trt. 1 & 2)
5/10/04	Rye harvested	(Trt. 1 & 2)
5/18/04	Oats harvested	(Trt. 9 & 10)
5/20/04	Sorghum planted	(Trt. 9 & 10)
5/20/04	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 5, 6, 7 & 8)
5/24/04	Compost applied	(Trt. 3, 5, & 7)
6/16/04	150 lbs/A N applied (28%)	(Trt. 2)
6/21/04	Gas sample # 2	(All)
7/06/04	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 5, 6, 7 & 8)
7/29/04	Gas sample # 3	All)
8/02/04	Fertilize sorghum plots 75 lbs/A N applied (34%)	(Trt. 9 & 10)
8/09/04	Gas sample # 4	(All)
8/13/04	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 5, 6, 7 & 8)
8/19/04	Sorghum harvested	(Trt. 9 & 10)
8/19/04	Sorghum fertilized 75 lbs/A N applied (34%)	(Trt. 9 & 10)
9/09/04	Corn harvested	(Trt. 1 & 2)
9/16/04	Sorghum harvested	(Trt. 9 & 10)
9/23/04	Gas sample # 5	(All)
9/30/04	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 5, 6, 7 & 8)

Table 28. Agronomic field activities for KBS 2003.

Date	Field Activity	Treatment
5/01/03	Gas sample # 1	(All)
5/14/03	Alfalfa, Alfalfa/Orchardgrass and Kura harvested	(Trt. 3, 4, 7, 8, 9 & 10)
5/19/03	Rye harvested	(Trt. 1 & 2)
5/22/03	Compost applied	(Trt. 1, 3, 5, 7 & 9)
5/23/03	Alfalfa planted	(Trt. 5 & 6)
5/27/03	Corn planted	(Trt. 1 & 2)
6/03/03	Gas sample # 2	(All)
7/02/03	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 7 & 8)
7/17/03	Corn killed (1.5 oz Roundup/A) Sorghum planted	(Trt. 1 & 2)
7/21/03	Poast and Baythroid applied to new alfalfa	(Trt. 5 & 6)
7/31/03	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 7 & 8)
8/05/03	Gas sample # 3	(All)
8/28/03	Sorghum harvested	(Trt. 1 & 2)
8/28/03	90 lbs/A N applied (34%)	(Trt. 1 & 2)
9/11/03	Sorghum harvested	(Trt. 1 & 2)
9/12/03	90 lbs/A N applied (34%)	(Trt. 1 & 2)
10/17/03	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 5, 6, 7 & 8)
10/23/03	Gas sample # 4	(All)

Table 29. Agronomic field activities for KBS 2002.

Date	Field Activity	Treatment
4/17/02	Field cultivator run over field (North to South)	(All)
4/23/02	Soil sampling	(Rep. A & B)
4/24/02	Soil sampling	(Rep. C & D)
4/30/02	Compost applied (9000 lbs/A)	(Trt. 1, 3, 5, 7 & 9)
5/03/02	0-0-60 (450 lbs/A) 0-46-0 (156 lbs/A) applied	(Trt. 1, 3, 5, 7 & 9)
5/03/02	0-0-60 (500 lbs/A) 0-46-0 (182 lbs/A) applied	(Trt. 2, 4, 6, 8 & 10)
5/05/02	Coulter-mulcher run over Alfalfa and Alfalfa/Orchardgrass plots	(Trt. 3, 4, 7 & 8)
5/05/02	Alfalfa and Alfalfa/Orchardgrass planted	(Trt. 3, 4, 7 & 8)
5/05/02	Corn planted	(Trt. 1 & 2)
5/08/02	Corn planted	(Trt. 5 & 6)
7/09/02	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 7 & 8)
7/14/02	Gas Sample # 1	(Rep. A, B & D)
8/05/02	Gas Sample # 2	(Rep. A, B & D)
8/14/02	Alfalfa and Alfalfa/Orchardgrass harvested	(Trt. 3, 4, 7 & 8)
9/13/02	Corn harvested	(Trt. 1, 2, 5 & 6)
9/26/02	Winter-rye planted	(Trt 1, 2, 5 & 6)
9/26/02	Gas sample # 3	(Rep. A, B & D)

Table 30. Agronomic field activities for UP, 2004.

Date	Field Activity	Treatment
4/03/04	Soil sample	(All)
4/04/04	Gas sample # 1 (was not analyzed)	(All)
4/04/04	Manure applied	(Trt. 1, 3, 5, 7 & 9)
5/17/04	Corn planted	(Trt. 1 & 2)
6/07/04	Gas sample # 2	(All)
6/15/04	Alfalfa/Orchardgrass harvested	(Trt. 7 & 8)
6/20/04	150 lbs/A N applied to corn (28%)	(Trt. 2)
6/28/04	Alfalfa harvested	(Trt. 3, 4, 5 & 6)
6/30/04	Gas sample # 3	(All)
7/08/04	50 lbs/A N applied to oats (28%)	(Trt. 10)
7/20/04	Oats harvested	(Trt. 9 & 10)
7/27/04	Gas sample # 4	(All)
7/28/04	Alfalfa/Orchardgrass harvested	(Trt. 7 & 8)
8/05/04	Alfalfa harvested	(Trt. 3, 4, 5 & 6)
8/28/04	Gas sample # 5	(All)
9/28/04	Alfalfa harvested	(Trt. 3 & 4)
10/11/04	Corn harvested	(Trt. 1 & 2)
10/18/04	Gas sample # 6	(All)

Table 31. Agronomic field activities for UP, 2003.

Date	Field Activity	Treatment
5/05/03	Soil sample # 1	(All)
5/06/03	Gas sample	(All)
5/06/03	Manure applied	(Trt. 1, 3, 5, 7 & 9)
5/21/03	Corn planted	(Trt. 1 & 2)
6/03/03	Alfalfa planted	(Trt. 4 & 5)
6/23/03	Alfalfa, Alfalfa/Orchardgrass and Kura harvested	(Trt. 3, 4, 7, 8, 9 & 10)
6/26/03	150 lbs/A N applied to corn (28%)	(Trt. 2)
7/08/03	Gas sample # 2	(All)
7/28/03	Gas sample # 3	(All)
8/06/03	Alfalfa, Alfalfa/Orchardgrass and Kura harvested	(Trt. 3, 4, 7, 8, 9 & 10)
8/15/03	Gas sample # 4	(All)
9/05/03	Gas sample # 5	(All)
9/25/03	Corn harvest	(Trt. 1 & 2)
10/04/03	Gas sample # 6	(All)

Table 32. Agronomic field activities for UP, 2002.

Date	Field Activity	Treatment
5/14/02	Soil sample	(Rep. A)
5/15/02	Soil sample	(Rep. B & C)
5/16/02	Soil sample	(Rep. D)
5/20/02	Manure applied (10,000 gal/A)	(Trt. 1, 3, 5, 7 & 9)
6/04/02	Plant Corn, Alfalfa, Alfalfa/Orchardgrass and Kura	(All)
7/19/02	Alfalfa, Alfalfa/Orchardgrass and Kura harvested	(Trt. 3, 4, 7, 8, 9 & 10)
7/20/02	Gas sample	(Rep. A, C & D)
8/23/02	Gas sample	(Rep A, C & D)
9/23/02	Corn harvest	(Trt. 1, 2, 5 & 6)
9/24/02	Winter-rye planted	(Trt. 1, 2, 5 & 6)

Table 33. Organic matter treatment characteristics.

	Compost (KBS)	**Manure (UP)**
Application Rate	35,858 kg ha^{-1}	84,200 L ha^{-1}
DM	47%	8%
C:N	5.22	13.34
Total C	18.8%	13.3%
Total N	3.6%	3.8%
N Applied (Available)	45 kg ha^{-1}	180 kg ha^{-1}
P Applied	42 kg ha^{-1}	180 kg ha^{-1}
K Applied	498 kg ha^{-1}	115 kg ha^{-1}
C Applied	3168 kg ha^{-1}	3476 kg ha^{-1}

Table 34. Soil bulk density at start and end of study

		2002 g cm^{-2}	**2004 g cm^{-2}**
KBS	**0-5 cm**	1.248	1.331
	5-25 cm	1.355	1.499
UP	**0-5 cm**	1.195	1.240
	5-25 cm	1.101	1.246

Table 35. Soil total N at start and end of study

		2002 g N m^{-2}	**2004 g N m^{-2}**
KBS	**0-5 cm**	70.14	91.86
	5-25 cm	279.57	333.39
UP	**0-5 cm**	119.49	128.22
	5-25 cm	351.69	411.61

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