DISSSERTATION

PRECISION MANURE MANAGEMENT ACROSS SITE-SPECIFIC MANAGEMENT ZONES

Submitted by

Matshwene Edwin Moshia

Department of Soil and Crop Sciences

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY MATSHWENE MOSHIA ENTITLED “PRECISION MANURE MANAGEMENT ACROSS SITE-SPECIFIC MANAGEMENT ZONES” BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate work

Dr. Rajiv Khosla
Advisor

Dr. Dwayne G. Westfall

Dr. Jessica G. Davis

Dr. Robin M. Reich

Dr. Gary A. Peterson
Department Head

ABSTRACT OF DISSERTATION

PRECISION MANURE MANAGEMENT ACROSS SITE-SPECIFIC MANAGEMENT ZONES

In the western Great Plains of the USA, animal agriculture is an important contributor to the agricultural economy, and many livestock farms are close to water bodies where manure can potentially contaminate the environment. Animal manure is a valuable resource that contains essential crop nutrients and could be recycled beneficially on agricultural lands for enhancement of maize grain yield and improvement of topsoil quality by supplying soils with organic matter. Loss of nitrogen (N), phosphorus (P) and other nutrients into the environment can occur when nutrients supplied by animal manure and other sources exceed the demand by crops. Precision manure management is a relatively new concept that merges the best agronomic and manure management practices along with precision agriculture techniques such as site-specific management zones (MZs) for agricultural productivity and environmental quality. This project investigated several aspects of precision manure management across site-specific management zones, which were maize grain yield and economic analysis, topsoil and environmental quality, and finally N mineralization.

The objectives of the study were to (i) assess the influence of variable rate applications of animal manure on grain yield in continuous maize production fields across MZs in dryland and limited irrigation cropping systems, (ii) to compare the economic efficiency of variable and constant yield goal manure management strategies across MZs for maize production under dryland and irrigated conditions, (iii) to study the effects of variable rate application of animal manure on selected surface soil quality

parameters across MZs, (iv) to evaluate the variable rate application of manure using environmental risk assessment tools of N leaching and P runoff index and to understand its impact on environmental quality, and (v) to evaluate and compare the N mineralization of variable rates of dairy cattle manure applied on low, medium and high management zones in a controlled environment.

To accomplish objectives (i) through (iv), the study was conducted under a continuous maize cropping system on dryland and limited furrow-irrigated fields in northeastern Colorado, USA. Fields were classified into low, medium and high site-specific management zones. The soil profile was classified as fine-loamy, mixed, mesic, Aridic Haplustalfs. Experimental strips were 4.5 m wide and 540 m long spanning across all MZs with manure and N fertilizer management strategies nested within MZs. Variable rate manure applications of 22, 44 and 67 Mg ha^{-1} were considered for variable yield goal (VYG) and constant yield goal (CYG) manure management strategies. Topsoil quality parameters evaluated in this study included bulk density, water holding capacity, electrical conductivity, and particle size analysis.

For objective (v), a 120 day laboratory incubation study was conducted. This incubation experiment was set as a 2 factor factorial design with 4 manure treatments and 2 management zones. Treatments for the incubation study were arranged in a completely randomized design.

The results of this project indicated that maize grain yield was significantly different across MZs with low MZ showing a significantly ($P \leq 0.05$) higher grain yield under CYG manure management strategy. However, the use of animal manure alone for maize grain yield production was found to be economically inefficient using enterprise budget analysis. The study suggests that manure can, therefore, be used in conjunction with synthetic N fertilizer to meet crop N requirements at early growth of maize while animal manure improve soil quality of low productivity soils over time.

For topsoil and environmental quality, animal manure significantly ($P \leq 0.05$) increased electrical conductivity, and water holding capacity and decreased bulk density of low and medium MZs but had no significant impact on topsoil bulk density of high management zone. The maximum manure application rate increased soil electrical conductivity to 1.0 dS m^{-1}, which was below levels that could significantly alter the growth and activities of maize and microorganisms. The Colorado P Index indicated no environmental hazard associated with variable rate application of animal manure across management zones; however the N leaching Index suggested that the field could be at medium risk of N leaching. Overall this study indicated that variable rate application of animal manure across management zones has potential to improve or maintain soil quality parameters over time without impairing the environment.

For N mineralization, the study showed a significant difference ($P \leq 0.05$) in mineralized N across zones when dairy animal manure treatments were compared. However, there was no significant different in mineralized N when low and high management zones were compared. Based on the observation and recorded results of this laboratory incubation study, it was sufficient to deduce that N from animal manure does not mineralize differently between low and high management zones. Nevertheless, the results of this study could be an indicator of effective timing for manure application to match stages of higher N demand by the crop and consequently minimize N leaching into the environment. The mineralized N can be a useful parameter for determining the potential impact of animal manure across spatially variable soils, and for estimating the N-supplying capacity of animal manure on low and high management zones. The key in precision manure management was to find a balance between economically, agronomically and environmentally sound manure management strategies across spatially variable soils.

Matshwene E. Moshia
Dept. Soil and Crop Sciences
Colorado State University
Fort Collins, CO 80523
Summer 2009

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Adversity is often one of our best teachers. This process of getting a Ph.D degree was a true litmus test for my patience and strength, for there is longer days ahead of me that require a tested material. I think it should be placed on record that my research project was one of the unique researches that even the "self-acclaimed angels" who graduated in this field could not comprehend. They are those who were always engaged in "negative analysis" and lack of constructive contributions.

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The completion of this research project for the purpose of getting a Ph.D degree is not and will not be my measure of success. What measure my victory are my actions beyond this point. Knowing that learning does not necessarily happen as a result of being taught, this process, my inquisitive mind, and self-determination helped me to decolonize my mind.

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CHAPTER 1: PRECISION MANURE MANAGEMENT ACROSS SITE-SPECIFIC MANAGEMENT ZONES: GRAIN YIELD AND ECONOMIC ANALYSIS.

INTRODUCTION

Precision manure management is a relatively new concept that combines the best manure management practices with precision agricultural techniques, such as production level site-specific management zones (MZs). Site-specific management zones are subregions of a field that express a homogeneous combination of yield limiting factors (Doerge, 1999). Application of nutrients to soil using MZs has shown to improve nutrient use efficiency, maintain or increase grain yield, and potentially reduce environmentally sensitive nutrient loading (Khosla et al., 2002; Hornung et al., 2003). The use of MZs in managing spatial variability has been proposed as a cost effective approach to using spatial information for improved crop management (Fleming et al., 1999; Koch et al., 2004; Luchiari et al., 2001).

Issues with manure management and the environment

In the western Great Plains of the United States, animal agriculture is an important contributor to the agricultural economy, and many livestock farms are located close to water bodies (Davis et al., 1997). With the increased concentration of livestock industry, there are many confined-animal feeding operations (CAFOs) and associated manure stocks (Fleming and Long, 2002). Agricultural producers who focus on making economic management decisions regarding manure utilization in their production systems are often in conflict with environmental interests (Fleming and Long, 2002). Livestock farmers have recycled manure on the land where it was produced primarily because of high transportation costs (Kellogg et al., 2000; Janzen et al., 1999).

The challenge with agricultural lands receiving manure is worsened when manure is applied uniformly on spatially variable fields over long periods of time (Fleming and Long, 2002). It has been widely documented that because of inherent spatial variability of soils, not all areas of a field may require the same level of nutrient inputs. Uniform application of inputs such as manure often results in various areas of the field receiving greater nutrient inputs than is necessary. Perhaps one of the greatest opportunities for modern agriculture lies in the challenge of effectively incorporating best manure management practices into cropping systems that will minimize environmental risks (Schepers et al., 2000).

When the nutrient supplied by manure is not given accurate credit, or when manure is applied at excessive rates to soil, the nutrients in manure may pollute the environment by contaminating surface and ground water (Burkart and James, 1999; Smith et al., 2001a, 2001b). The nutrients in animal manure that are of greatest environmental concerns are nitrogen (N) and phosphorus (P). Runoff and leachate from over-fertilized areas may contaminate water supplies, while crop yield may be restricted in under-fertilized areas (Cahn et al., 1994). When manure is applied annually to meet N requirements of a crop, P accumulation may occur in the soil (Eghball and Power, 1999). Any P that is not taken up by crops accumulates in soil, potentially to levels that far exceed the amounts needed for optimal crop growth (Toth et al., 2006). As a result, concerns have arisen that crops are not fully assimilating nutrients present in the applied manure (Ribaudo et al., 2003). Unlike N, P is relatively immobile in the soil system.

Apparent nitrogen budget

Nitrogen budgets have been used as a quantitative means of assessing soil and cropping system N use for over 100 years (Lawes et al., 1882; Watson and Atkinson, 1999), and the approach is still common (Breembroak et al., 1996). Repeated N applications to field crops, either as inorganic fertilizers or animal manures, can lead to N buildup in soils and potential long-term environmental hazards (Munoz et al., 2003). Nitrogen in excess of 50 to 100 kg N ha^{-1} (≈45 to 90 lb ac^{-1}) over the agronomic rate has been proposed as a limit beyond which the environment will be degraded, particularly by agricultural activities (Paris-Convention for the Prevention of Marine Pollution, 1993).

Both for economic and environmental reasons, the use of fertilizer N should be as efficient as possible (Van Cleemput et al., 1981). By quantifying both, the inputs to and outputs from a given system, N budgets can identify surplus N within the system (Watson and Atkinson, 1999). Such an approach will help ensure that the non-efficient part of the fertilizer should be as small as possible and in such a form that pollution of the environment is limited (Van Cleemput et al., 1981). While studies on N budget and balances have been published, the present study uniquely deals with N balance under manure management across spatially variable soils classified into management zones on fields planted to maize under irrigation and dryland conditions.

Precision manure management on spatially variable soils

To make informed decisions concerning the application of animal manure on crop fields, farmers must consider several parameters, such as manure quality, where to apply, when to apply, and how much manure to apply in specific areas of the field (Morris et al., 1999). Variable rate technology is a major element of precision agriculture that allows for varying application of crop inputs throughout a field in a cost effective way. Precision agriculture is an integrated information and technology based agricultural management system, with the intent to manage spatial and temporal variability associated with all aspects of agricultural production for optimum profitability, sustainability and protection of the environment (Robert et al., 1995; Pierce and Nowak, 1999). Bouma, (1999) suggested that variable rate application practices could avert environmental effects by reducing the loss of agricultural chemicals. Studies have emphasized the potential of variable rate application of nutrients in protecting the environment because no nutrients would be applied to field areas with above optimum levels of nutrients for crop production (Mulla, 1993; Franzen and Peck, 1995; Schepers et al., 2000).

Review of literature indicates that there are no published sources which have previously investigated the utilization, agronomic use efficiency and economic effectiveness of animal manure applied across management zones as a part of best manure management practices. Even though most costs associated with manure management are on loading, transportation and application, Massey and Payne (2008) and Ribaudo et al. (2003) stated that solid manures are the least expensive to transport because most of the bulk transported is dry organic matter containing nutrients. The U.S. Environmental Protection Agency (EPA) regulations under the Clean Water Act of Concentrated Animal Feeding Operations (CAFOs) are driving the need for improved record keeping and accountability of manure applications (Ribaudo et al., 2003). There is a need to investigate whether traditional (uniform) manure management practices can be improved by taking advantage of the site-specific management zones approach.

Economic analysis

Irrigated maize and livestock farming are major agricultural activities broadening and strengthening the economy of the state of Colorado (U.S. Dept. of Commerce, Bureau of economic analysis). The economic efficiency of utilizing animal manure from livestock farms as a nutrient source for maize production across management zones has not been previously investigated. One tool that can be used for economic analysis and planning purposes is enterprise budget (Bitzer and Herbek, 2001). Enterprise budgets can be used to estimate net return by incorporating quantities and prices of all costs associated with maize production. Likewise, sensitivity analysis can also be used to create a set of scenarios to determine how changes in grain yield and maize price could impact the net return (Saltelli et al., 2008). The hypothesis of this study was that, variable rate application of animal manure based on the productivity potential of management zones will economically enhance grain yield of low producing management zones and maintain or improve the grain yield of medium and high MZs over time.

Objective

The objectives of the study were (i) to assess the influence of variable rate applications of animal manure on grain yield under continuous maize (*Zea mays* L.) production across MZs in dryland and irrigated cropping systems, and (ii) to compare the economic efficiency of variable and constant yield goal manure management strategies across management zones for maize production under dryland and irrigated conditions.

MATERIALS AND METHODS

Experimental sites

This study was conducted during the crop growing seasons of 2006, 2007 and 2008 as part of a large multi-disciplinary site-specific management zones project (Khosla et al., 2008). The study was conducted over six site years (2 sites x 3 years). Study sites were located in the proximity of 40°39' N, 104°59' W in northeastern Colorado near Fort Collins, CO, and have been under continuous maize production for the last three growing seasons. Fig. 1.1 refers to the field where maize was grown under dryland conditions, and Fig. 1.2 refers to the field where maize was grown under furrow-irrigation conditions in 2006, 2007 and 2008. The soil profiles of the study sites were classified as fine-loamy, mixed, mesic, Aridic Haplustalfs with a 1 to 2% slope (Soil Survey Staff, 1980).

Management Zone delineation

Productivity level management zones were previously delineated as a part of a large multi-disciplinary project. The details of the management zone delineation process can be found in Khosla et al. (2002; 2008). The management zone delineation process involved a commercially available AgriTrak Professional Software to delineate the MZ boundaries (AgriTrak, 1998). A gray scale bare soil aerial imagery of the field, farmer's perception of the topography data and farmer's past crop and soil management experiences were included in the delineation process (Hornung et al., 2006). Regions of darker color on the aerial image, areas of low-lying topography, and areas of historic high yields as reported by the farmer were designated as high zones and vice-versa (Hornung et al., 2006).

It is important to understand two aspects of the study under furrow-irrigation: (i) the weather conditions during the three growing seasons in this study were variable, and (ii) availability of irrigation water was limited, meaning this was a limited irrigation study. At the experimental sites, maize was irrigated only on certain days contingent upon availability of water. Irrigation water was expected to be available once every other week for a limited time and during the times when water was available; water was shared among many different crops in different fields at the study sites.

Soil sampling and manure applications

Pre-plant soil samples were collected each year using a systematic unaligned sampling design at depth intervals of 0-20 and 20-60 cm. MapInfo Professional Software (MapInfo Corp., Troy, NY) was engaged to FarmGPS Software (Red Hen Systems Inc., Fort Collins, CO) connected to Trimble AgGPS® 114 (Trimble Navigation Ltd., Sunnyvale, CA) for navigation to the sampling locations. Soils were sampled precisely at the same locations throughout the study using a management zone map and a differential global positioning system (DGPS). Soil samples were collected using a JMC Backsaver probe (Clements Assoc., Newton, IA). Soil samples were sent to a commercial laboratory (AgSource Harris Lab., Lincoln, NE) for routine soil analysis which included, soil pH, electrical conductivity, organic matter, N, P, K, and particle size distribution (Table 1.1).

Animal manure was applied to the field each year in spring prior to planting using a tractor-drawn Hesston S320 (Hesston Corporation, Inc., Hesston, KS) manure spreader calibrated with the tarp calibration method (Davis and Meyer, 1999). Dairy cattle and beef feedlot manure were applied annually on dryland and limited irrigation condition respectively. Manure was incorporated into soil on the same day after application using a

Lely 300.35 rotary cultivator (Lely USA, Inc., Naples, FL). Manure samples were collected at the time of application and transported immediately to a commercial laboratory for analysis (Colorado Analytical Lab., Brighton, CO) of N, P, OM, EC, pH, C/N ratio, Total N, Total P, and ash in manure (Table 1.2).

Experimental design and methods

Grain yield and manure management strategies

The experimental strips in this study were 4.5 m wide (i.e., 6 rows of crop) and 540 m long spanning the entire length of the field across low, medium and high MZs. In addition, there were eight rows of buffer strips of maize giving experimental strips a distance of 5 m away from the borders. The management strategies were nested within MZs. The management strategies evaluated in this study were:

(i) Variable manure applications based on MZs using a Constant Yield Goal (CYG) strategy. The CYG manure management strategy was suggested by the cooperating farmers in this project. In this strategy it is assumed that grain yield can be increased in low producing areas (low MZs) of the field to the same levels as that of high zones by additional applications of manure to the low zones. Hence the expected yield is kept at a constant for the entire field, or across all three MZs. Resulting in higher rate of application of manure on low zone and low rate of manure on high zone.

(ii) Variable manure applications based on MZs using a Variable Yield Goal (VYG) strategy. In the VYG management strategy, manure applications are based on the productivity potential of the management zones, high, medium and low. Hence higher rate of manure are applied on high zones and low rate of manure are applied on low zones.

(iii) Variable commercial N fertilizer applications based on MZs using VYG N management strategy. The N fertilizer rate was determined using Eq. [1] based on the soil samples acquired from within each management zone, with a unique yield goal for each MZ. In 2006, 2007 and 2008 on a dryland study, variable yield goals for VYG N fertilizer management strategy expected for the three MZs were 5.0, 3.8, and 2.5 Mg ha^{-1} for the high, medium and low management zones, respectively, and a yield goal of 11.3, 10.0, and 8.8 Mg ha^{-1} for high, medium and low MZs for the irrigated study, respectively. The manure rates in this study were selected to provide a wide range of application rates, encompassing farmer's application rates, lower and higher than those used by farmers.

(iv) Uniform manure management strategy based on representative manure rate applied uniformly across a field by farmers in northeastern Colorado. A uniform manure rate of 44 Mg ha^{-1} was applied across low, medium and high management zones.

Variable rate manure applications were of, 22, 45, and 67 Mg ha^{-1} for VYG strategy and 67, 45, and 22 Mg ha^{-1} for CYG strategy across low, medium and high MZs respectively. The variable and uniform manure rates were independent of soil analysis results across management zones. Manure applications were made across management zones such that every manure rate passed through each management zone at least once (Fig 1.1. and 1.2).

Application of N fertilizer in the variable yield goal management strategy was based on the N-rate algorithm of Mortvedt et al. (1996).

$$\text{N rate} = 35 + 1.2\ \text{EY} - 8\ (\text{soil } NO_3 - N) - 0.14\ (\text{EY})(\text{OM}) - (\text{other N credits}) \qquad \text{[Eq. 1]}$$

where EY is the expected yield and OM is the organic matter. The N fertilizer was injected in the soil as undiluted Urea-NH_4NO_3 of 32% (UAN 32).

Maize was harvested in the month of November or December (contingent upon weather conditions) using a Massey Fergusson combine harvester equipped with a yield monitor. Weight of the harvested grain was corrected to a moisture content of 155 g kg^{-1} for determining grain yield.

Apparent nitrogen budget

The apparent N budgets were calculated for CYG and VYG manure management strategies for each management zone based on total N inputs from animal manure, residual soil N, and N supplied through organic matter. The total available N in each management zone was calculated as follows;

$$(N_{man} + N_{res} + N_{min}) = N_{tot} \qquad \text{[Eq. 2]}$$

where N_{man} is potentially available mineralized N applied as manure (kg N ha^{-1}) (Table A9), N_{res} is residual soil NO_3-N before planting, N_{min} is soil organic matter N mineralization during the growing season (kg N ha^{-1}), and N_{tot} is total available N (kg N ha^{-1}). The N mineralization rate used in this study was 35 kg ha^{-1} for every 1% soil organic matter (30 lbs N $acre^{-1}$ for every 1 % organic matter) in the western Great Plains (Waskom, 1997; Marx, 2008).

Fertilizer N requirement was calculated using N-rate algorithm of Mortvedt et al. (1996) as presented in [Eq. 1]. Additional N fertilizer needed for the maize crop across low, medium and high MZs was calculated as:

Fertilizer N requirement (kg N ha^{-1}) – Total Available N (kg N ha^{-1}) = additional N fertilizer needed in each zone (kg N ha^{-1}).

[Eq. 3.]

The total available N represented N that was theoretically available to the crop during the growing season given no N losses. Apparent N losses were not included in the N budget because Van Wychen (2006) found that there was no significant difference ($P \leq 0.01$) in apparent N losses of a control treatment, VYG N fertilizer management strategy, and uniform N fertilizer treatment across management zones on the same field where this study was conducted. According to Van Wychen (2006), apparent N losses were considered to include ammonia volatilization, denitrification, gaseous losses of N from the crop system, NO_3-N leached below 150 cm, and N contained in the root system of the crop.

Economic analysis of manure management strategies

The economic analysis of this precision manure management study builds upon a previous study conducted by Koch et al. (2004) on economic analysis of nutrient management across site-specific management zones.

To determine the levels of grain yield at which one can realize positive net returns at current maize prices, the revenues associated with harvested maize grain yield were weighed against the cost of production for maize related to manure and fertilizer management. The costs of production were developed using enterprise budget analysis as suggested by Koch et al. (2004). The N fertilizer price of \$3.50 bu^{-1} (October, 2008) was obtained from agricultural service retailers in the region. In addition, manure costs including hauling, transportation and application were included in the budget. The management practices and operation schedules for this study include general farm overhead and taxes associated with operations, the number of tillage operations, seeding, planting, irrigation practices, amount of pesticide applied, harvest operations, labor force, and operations per hour or hectare of use.

A 2-dimensional sensitivity analysis for variable rates of manure application across management zones was constructed using various levels of grain yield and maize prices. The process involved various ways of changing amount of grain yield and maize prices in the sensitivity model to evaluate the effect on the net returns to the land and management. While keeping the total cost of production constant, the price of maize or maize grain yield, which were the variables in the model, were changed incrementally. We simulated grain yields from 3.8 to 7.5 Mg ha^{-1} (60 to 120 bu ac^{-1}) under dryland and 10.0 to 13.8 Mg ha^{-1} (160 to 220 bu ac^{-1}) under limited irrigation conditions. Likewise, we simulated maize grain prices from \$78.8 to \$295.5 Mg^{-1} (\$2.0 to \$7.5 bu^{-1}) at increments of \$19.7 Mg^{-1} (\$0.50 per bushel). These maize prices are typical of the maize trading market for the last 2 years.

Grain yield data analysis

Grain yield for manure management strategies was subjected to analysis of variance with PROC GLM in SAS (Littell et al., 2002). Mean separation tests were done with Tukey-Kramer at alpha level of 0.05. Response curves of CYG and VYG manure management strategies were fitted using mean grain yield versus year of manure application and produced using Microsoft Excel 2003 (Redmond, WA).

RESULTS AND DISCUSSION

To understand the field observations that were recorded during the crop growing season, it is important to understand the climatic conditions that prevailed. The climate in this region is classified as semi-arid with mean annual temperatures of this region of 10.9°C, 9.9°C, and 9.5°C in 2006, 2007 and 2008 respectively. The 2006 mean annual temperature was almost 2°C above the long-term averages (8.9 °C), making 2006 the second warmest year in the history of weather in the state of Colorado since 1889 (Doesken, 2006). The cumulative growing degree days for maize in 2006, 2007, and 2008 were 1444°C, 1518 °C, and 1548 °C respectively. The months of June, July and August in 2006 were under extreme drought conditions (Miskus, 2006). The total annual precipitation recorded during 2006, 2007 and 2008 from a nearby weather station were 286.2, 346.7 and 336.8 mm respectively. It is interesting to note that out of the total annual precipitation of 286.2 mm for 2006, about 25% (68.58 mm) occurred in the month of December as snow, i.e., non-contributing to the crop growing season. By the end of September, 2006 total precipitation was only 140.7 mm, whereas the year 2007 had 263.4 mm. A significant portion of precipitation, 91.4 and 140.7 mm occurred in the month of August, 2007 and 2008, respectively. This amount of precipitation helped the crop in a positive manner because moisture, or any form of environmental stress two weeks before or after silking can result in a large grain yield reduction (McWilliams et al., 1999).

Grain yield under limited irrigation condition

The range of grain yield observed under limited irrigation conditions ranged from 2.5 to 8.8 Mg ha^{-1} for manure management strategies across all management zones over three years (Fig. 1.3). The grain yields were significantly different across low, medium and high management zones in four of the six site-years of manure management strategies and also significant in all three site-years of variable yield goal N fertilizer management strategies across all management zones.

Variable Yield Goal manure management strategy

Grain yield for VYG manure management strategies was significantly different ($P \leq 0.05$) between low and high zones in 2006 and 2008 under limited irrigated conditions with high zone producing higher yields than low management zone. Across all zones, there was a substantial increase in grain yield in 2007 and 2008 as compared to the drought-affected growing season of 2006 (Fig. 1.3). Severe drought in the months of June, July and August during the growing season of 2006 could have had negative impact on grain yield; for example, 2.5 Mg ha^{-1} on low zone in 2006 within VYG manure management strategy. June, July and August are considered the critical months for nitrogen mineralization from manure in Colorado (Marx, 2008). Koelsch (2005) and Bacon (1995) reported that soils that are dry throughout most of the growing season have low mineralization and nitrification rates. However, microbial activities in manure amended soils that remained dry throughout most of the growing season are reported to be greatest immediately after rainfall or irrigation events as may be the case in our study (Koelsch, 2005). This fact can be linked to increased grain yield from manure application in 2007 when weather and precipitation were close to normal (Fig. 1.4).

The grain yield increased from 2006 to 2007 and then decreased in 2008. While this decrease in grain yield may be partially be attributed to a hail storm that occurred at the V17 maize crop growth in 2008, which perhaps negatively impacted the grain yield across all zones and may be the cause of observed low grain yields as compared to previous year of 2007. However, a decrease in grain yield was not observed on VYG N fertilizer management strategy that was on the same field, showing that hail was not a primary cause of significant decrease ($P \leq 0.05$) in grain yields on manure management strategies. A complete assessment of nutrient balance and review of literature indicates that repeated application of manure can negatively impact crop grain yield. That's because repeated applications of manure nutrients on the same land over a period of time leads to accumulation of high level nutrients that can potentially affect crop yield over time (Glendining et al., 2009).

Constant Yield Goal manure management strategy

Under the CYG manure management strategy, grain yield for the low zone was significantly different and higher than medium and high MZs in 2006 (Fig. 1.3). Historically, areas classified as low zones generally produce lower grain yields compared to high zones when nutrients are applied uniformly across the field (Hornung et al., 2006; Inman et al., 2005), but with CYG manure management strategy, low zone produced 2 Mg ha^{-1} grain yield higher than that of the high zone in the first year of this study (Fig. 1.3). In two out of three site-years (i.e. 2006 and 2008) higher applications of manure on low management zones increased grain yield levels to a level higher than those of high management zones ($P \leq 0.05$). The higher grain yields on low zone than that of high zone in 2008 can be associated with increased precipitations in this limited irrigation study that potentially catalyzed mineralization and nitrification (Fig. 1.4; Bacon, 1995). Based on the findings of this study, CYG based manure application has potential to enhance grain yield of historically low producing areas of a field under limited irrigation condition.

Uniform manure management strategy

Maize grain yield for uniform manure management strategy under limited irrigation condition averaged 4.6, 8.4, and 7.7 Mg ha^{-1} in 2006, 2007 and 2008 (Fig. 1.3). There was no difference in maize grain yield of uniform and CYG manure management strategy. However, uniform manure management strategy does not account for spatial variability; hence, maize grain yield was averaged across the field independent of MZs. Similar to other strategies, grain yield increased from 2006 to 2007, and then declined in 2008, suggesting that there could be a two-year threshold when manure is used as the only source of fertilizer for grain yield production at rates applied in our study. The decline in grain yield, which was also observed in VYG and CYG manure management strategies, was linked to drought in 2006, hail and excessive nutrients loading in 2008, and potentially to other factors that were beyond what has been measured in this study.

Variable Yield Goal N fertilizer management strategy

In the first year (2006) of VYG commercial N fertilizer management strategy, grain yields were higher than the yields of CYG and VYG manure management strategies (Fig. 1.3). This was not a surprise because the animal manure was applied in the spring prior to planting and manure needs time to mineralize before nutrients are released for crop availability. Adequate environmental conditions such as adequate soil moisture necessary for effective N mineralization did not prevail in 2006. In 2007, all manure management strategies produced grain yields that were equivalent to that of VYG N fertilizer management strategy. But in 2008, grain yields declined for manure management strategies while the VYG N fertilizer management strategy produced higher grain yields than VYG and CYG manure management strategies.

Comparing the three management strategies (3 manure and 1 N fertilizer), while manure application may have potential to improve grain yields of low producing areas of the field, it does have agronomic and environmental limitations. While manure management strategies failed to positively impact grain yield under limited irrigation, N fertilizer management strategy succeeded to continuously improve grain yield. Perhaps there is a two year threshold for using weight based manure management strategies for maize grain yield across MZs, beyond which a positive impact on grain yield will not be realized. Therefore, it may be logical to combine manure management with N fertilizer management such that manure applications continuously impact soil properties/quality slowly over time, while in-season N fertilizer management provides enough impetus to boost the grain yield of crops each year without negatively inpacting the environment and grain yield. One source of nutrient, either manure or N fertilizer alone, may not optimize environmental and agronomic goals needed for sustainability of crop production.

Grain yield under dryland condition

The mean grain yield across low, medium and high MZs for three nutrient management strategies in 2006, 2007 and 2008 is shown in Fig 1.5 for the dryland study. In 2006, the first year the CYG and VYG manure management strategies produced an average maize grain yield of 3.4 and 3.7 Mg ha^{-1} across all zones. In 2007, after two repeated manure applications maize grain yields increased to 4.8 Mg ha^{-1} in both CYG and VYG manure management strategies when weather and precipitation were closer to normal. Bacon (1995) reported that soils that are dry throughout most of the growing season have a low mineralization and nitrification rates. However, microbial activities in manure amended soils that remained dry throughout most of the growing season are reported to be the greatest immediately after rainfall or irrigation events as may be the case in our study (Koelsch, 2005).

Year 2008 growing season was after three repeated manure applications and moisture was adequate (Fig. 1.4). It was interesting to note that in 2008 although precipitation was higher as compared to the previous two years (2006 and 2007), the grain yield levels declined from the previous year of 2007. This indicates that there was something else other than water that negatively impacted grain yield under dryland conditions. This can potentially be attributed to excessive amount of N from three repeated applications of animal manure and a hail that occurred at V17 growth stage of maize. In another site-specific and uniform manure application study, Eghball et al. (2001) reported an increase in grain yield from year I to year II and a grain yield decline in year III of manure applications on uniform and site-specific manure application strategy. Maize grain yield decline in year III of the study conducted by Eghball et al. (2001), and this study surprisingly resulted from similar reasons associated with nutrient availability to crops. Eghball et al. (2001) winter applied 56 Mg ha^{-1} of animal manure as uniform treatment to provide N crop requirements. In this study while nutrients were present in the soil, these nutrients were not available to maize because of lack of moisture. Based on our results, it is evident that there are risks of producing lower maize grain yields under dryland in the semi-arid state of Colorado due to insufficient amount of precipitation (Fig. 1.5. Nielson et al., 2009).

Economic analysis

Massey and Payne (2008) reported that dollars may not be the only metric for discussing costs; however, in this precision manure management study, all costs and revenues have been reported in dollars for simplicity. Table 1.4 shows the net sensitivity corresponding to increases and decreases in maize price and grain yield for VYG manure management strategy on low, medium and high MZs under limited irrigated conditions. The net returns to the land and management for maize grain yield were based on current (October, 2008) maize market price of \$137.9 Mg^{-1} (\$3.5 bu^{-1}). The grain yield and prices associated with maize were directly proportional to the net return to the land and management (Table 1.3).

Economic analysis of limited Irrigation condition

Over a three year period, this study averaged maize grain yields of 6.5 Mg ha^{-1} (104 bu ac^{-1}) on VYG manure management strategy. Based on the economic analysis, the study indicates that maize producers can realize a positive net return by marketing maize at \$118.2 Mg^{-1} (\$3.0 bu^{-1}), which is below the current (October, 2008) market price (Table 1.3).

Variable rate application of manure based on constant and variable yield goal nutrient management strategies under limited irrigation was advantageous over time based on net returns to the land and management. In 2006, under the VYG manure management strategy, there was an economic loss, and the year 2007 averaged a net return to land and management of \$448 ha^{-1} (\$181.4 ac^{-1}). While high management zone within VYG manure management strategy produced higher grain yield than low and medium zones, the net returns were negative because of the total costs of production associated manure transportation and application on high MZs. A similar situation happened to low management zone of CYG manure management strategy where an economic loss was reported while grain yield was higher than that of medium and high zones in all three years. Nevertheless, CYG and VYG manure management strategies realized a positive net return to land and management in 2007.

The 2 dimensional sensitivity analysis performed for this study logically suggests that producers will benefit economically by producing and marketing maize at higher grain prices. While this is not surprising, the challenge is that the maize market prices are controlled by a broader economic market and not farmers, but increased grain yield is part of farmers' crop management production.

The VYG N fertilizer management strategy in this field study resulted in positive net return across management zones in 2006, 2007 and 2008. The net returns to land and management for VYG N fertilizer management strategies diverge from the results reported by Koch (2003) using similar management strategy. Koch (2003) reported negative net returns to land and management. This could be attributed to the fact that Koch (2003) performed economic analysis at the then prevailing maize price of \$78.8 Mg^{-1} (\$2.0 bu^{-1}) versus \$137.9 Mg^{-1} (\$3.50 bu^{-1}), the current maize price used to estimate net \$ returns for this study.

Economic analysis of dryland condition

In the state of Colorado, reports have established that the long-term average maize grain yield under dryland condition is approximately 2.2 to 2.5 Mg ha^{-1} (35 to 40 bu ac^{-1}) (United States National Agricultural Statistical Services, 2007). In our study, an average maize grain yield of 4.0 Mg ha^{-1} (63.8 bu ac^{-1}) was recorded on VYG manure management strategy over a three year period. The recent (October, 2008) maize price recorded in the state of Colorado was \$137.9 Mg^{-1} (\$3.5 bu^{-1}). Such high levels of maize prices were observed as a result of floods in the Midwest region of the USA that damaged the maize crop, increased beef prices, increased gas prices, which apparently affected demand and supply of maize and consequently affecting maize prices (O'Hare, 2008). It is apparent that under dryland conditions a financial loss may be inevitable when manure alone is applied as a source of nutrients for maize production across management zones, even when maize is being marketed at high prices (>\$3.50). The sensitivity analysis has showed that with a maize grain yield of 5.0 Mg ha^{-1} (80 bu ac^{-1}), producers can realize a net positive return only when trading maize at a market price of \$256.1 Mg^{-1} (\$6.5 bu^{-1}) (Table 1.4). Due to lower levels of grain yield for CYG manure management strategy, a negative net return in all three years was inevitable. Based on the results of this study, it would be fair to conclude that under dryland condition, CYG and VYG manure management strategies would not be good strategies, in a "for-profit" farming business.

Apparent nitrogen budget

The goal of determining the apparent N budget was to evaluate the amount of N that could be supplemented through animal manure application for enhancing maize grain yield. When the apparent N budget was calculated, it was used to assess the potential damage to the environment as a result of over application of nutrients from manure. There was excess nitrogen of 190 to 567 Kg ha^{-1} (170 to 506 lb ac^{-1}) and 259 to 674 Kg ha^{-1} (231 to 602 lb ac^{-1}) across management zones for the two manure management strategies evaluated in this study (i.e. variable yield goal and constant yield goal), respectively. In 2008, which was the third year of manure applications, there was an excess N of 334 Kg ha^{-1} (298 lb ac^{-1}) on low zone of VYG manure management strategy. The excess amount of N was even higher (674 kg ha^{-1}) for CYG manure management strategy on low zone in 2008 (Table 1.5). Generally, low management zones have been reported to be characterized by lower productivity potential and lower nutrient and water holding capacity as opposed to high management zones (Mzuku et al., 2005; Hornung et al., 2006). This excess N on low zone could potentially degrade the environment through leaching of nitrate, should applications of manure be continued on this field.

Constant yield goal manure management strategy was implemented to enhance maize grain yield of historically unproductive or low management zones. The surplus N loaded on CYG strategy was because of higher amount of manure applications that were repeatedly applied on low management zone of CYG strategy. While the purpose of enhancing maize grain yield of low zone with animal manure was achievable to some extent (Fig. 1.3), the CYG manure management strategy had more than two times excess N on low zone than the VYG manure management strategy. This indicates that CYG manure management strategy has a potential to negatively impact the environment through excessive nitrogen in the soil by manure applications.

Variable and constant yield goal manure management strategies had agronomic use efficiency (AUE) of 15.7 to 37.5 and 16 to 37% across management zones, respectively. Agronomic use efficiency by maize, based on manure management strategies increased from low to high MZs under CYG strategy, while under VYG strategy a decrease in AUE from low to high MZs was observed (Table 1.5). Based on N algorithm used in the region for fertilization of maize (Morvedt et al. 1996), for every pound of N applied, 1.2 bu of maize grain yield is expected. In this precision manure management study, a pound of total available inorganic N (sources of N as animal manure, residual soil N, and organic matter) yielded 0.19 to 0.45, and 0.20 to 0.44 bu lb^{-1} for VYG and CYG manure management strategies. While the agronomic use efficiency is expected to be lower (approximately 36 %) under furrow irrigated fields (Halvorson et al., 2002), the results of this study suggest a need for improvement of agronomic use efficiency under precision manure management strategies. Perhaps synchronization of N mineralization in manure with maize N use across MZs can improve the agronomic use efficiency.

CONCLUSIONS

The underlying hypothesis of this study was that maize yields could be increased in low producing areas of the field, i.e. low management zones. Under limited irrigation maize grain yield of low management zones were enhanced with the CYG manure management strategy; however, the apparent N budget revealed that this approach is overloading the field with nitrogen and poses a potential for nitrate leaching. Secondly, the CYG manure management strategy was not profitable due to costs associated with animal manure transportation (distance), application, and harvesting on low management zones. Therefore, CYG is also not an environmentally friendly strategy for manure input. Agriculture today is under pressure to meet environmental targets and, therefore, we had to weigh agronomic and economic against environmental burdens. We, therefore, suggest that CYG manure management strategy be used in conjunction with N fertilizers to meet crop N requirements at early maize growth stages. Given the law of diminishing marginal returns and its applications to the manure management strategies, we further suggest not to exceed two consecutive repeated manure applications if N fertilizer is not used in conjunction for profitable crop production and environmental quality under irrigated conditions. The key to precision manure management is to find a balance between economical and environmentally sound manure management strategy which is capable of improving soil fertility status of low producing areas of the field and consequently enhancing grain yield across zones.

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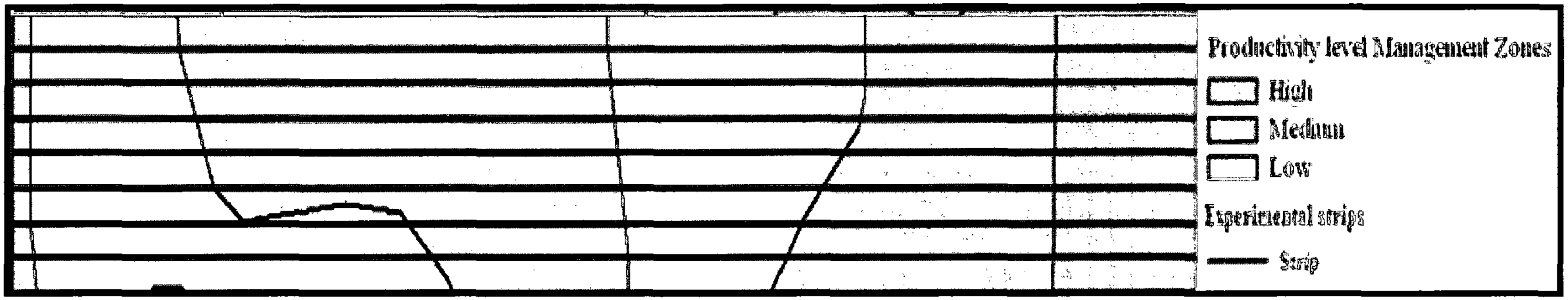


Fig. 1.1. Dryland study site in 2006, 2007 and 2008 with experimental strips spanning across productivity level management zones

Fig. 1.2. Limited irrigation study site in 2006, 2007 and 2008 with experimental strips spanning across productivity level management zones

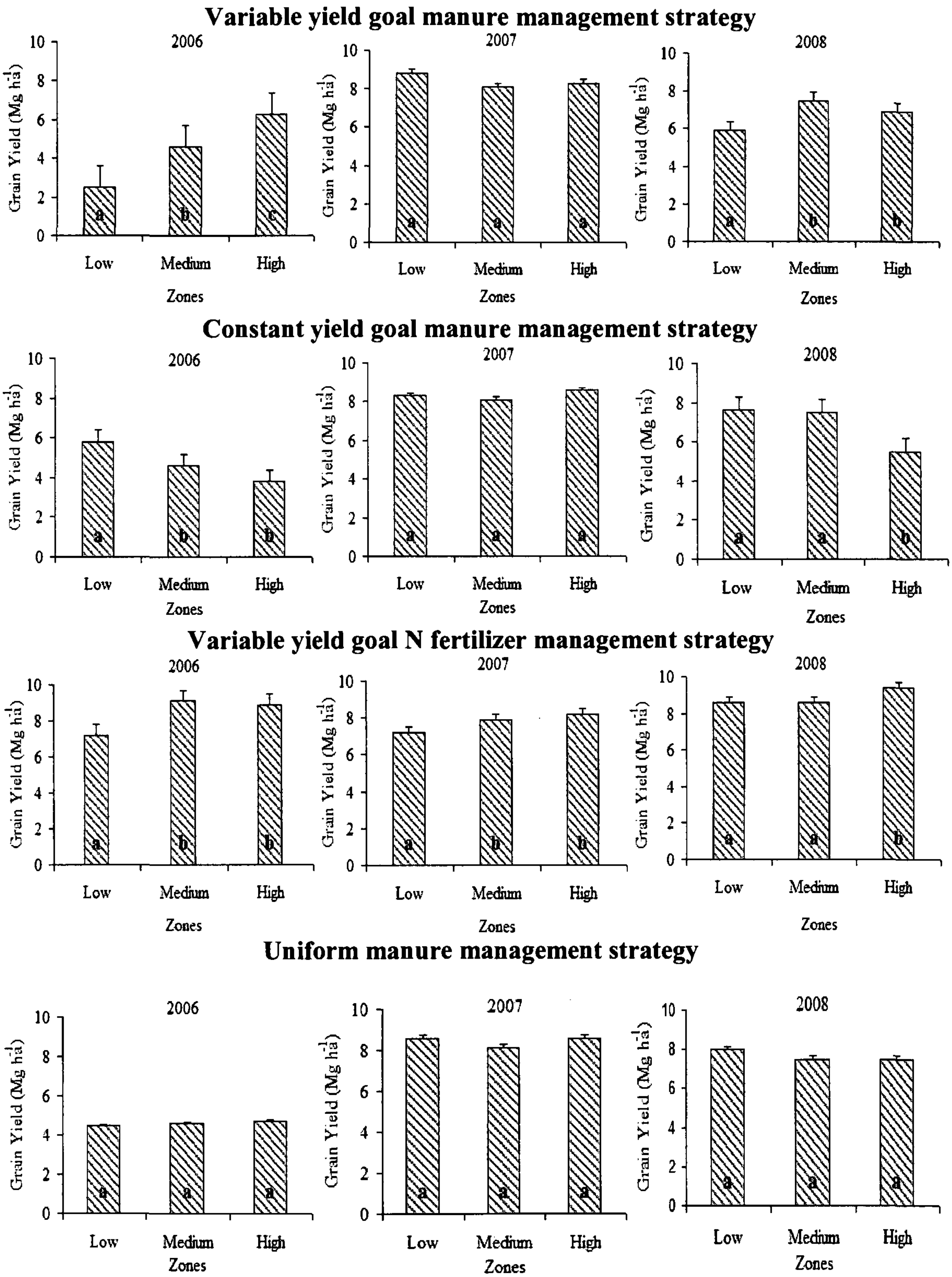
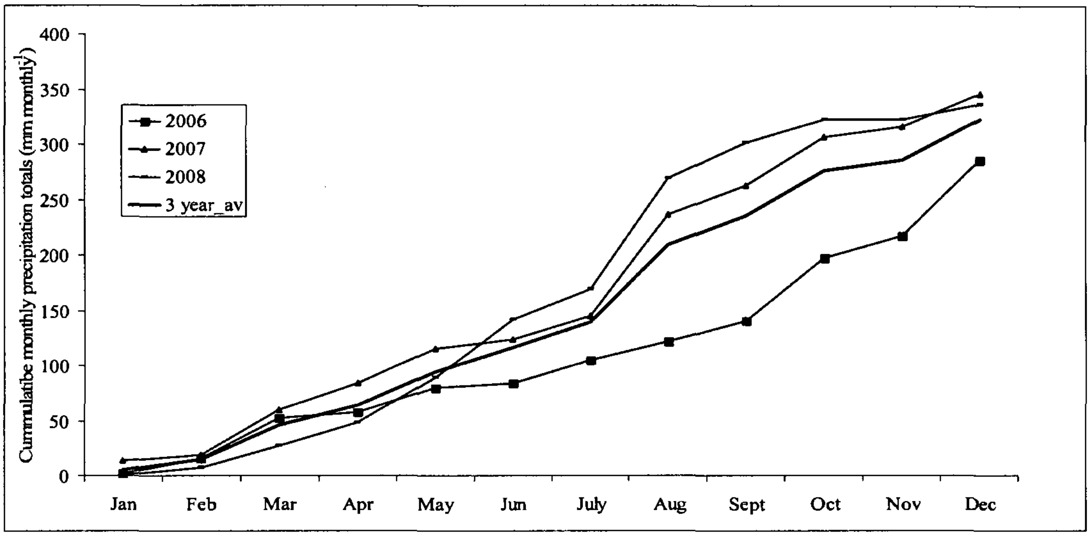


Fig 1.3. Mean grain yield across low, medium and high management zones for variable yield goal manure, constant yield goal manure, variable yield goal N, and uniform manure management strategies under limited irrigation conditions. Within a site-year, bars with different letters are significantly different at $P \leq 0.05$ level of significance.



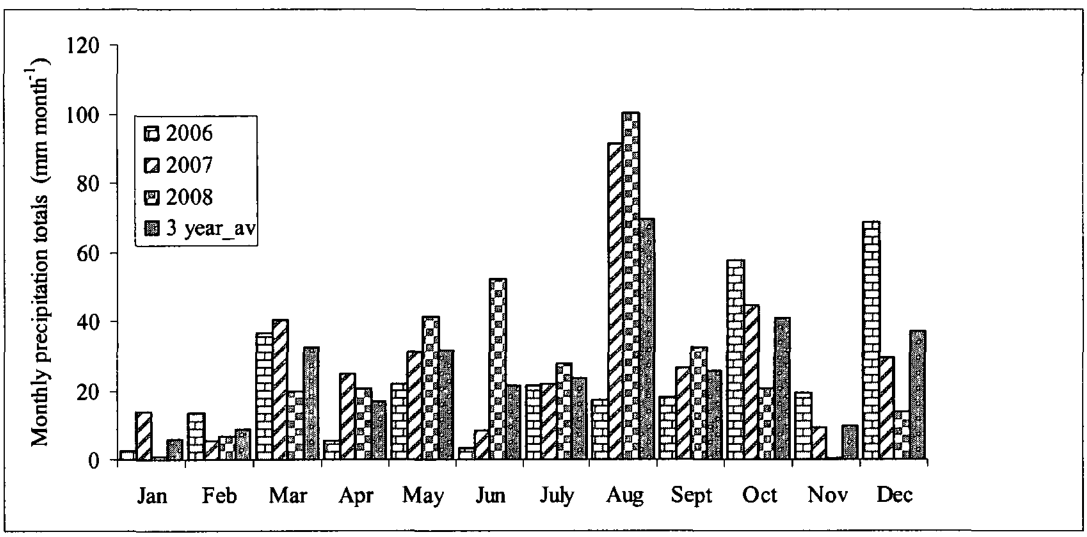


Fig. 1.4. Cumulative monthly (top) and monthly total (bottom) precipitation recorded in 2006, 2007, and 2008 at a weather station closer to the experimental sites.

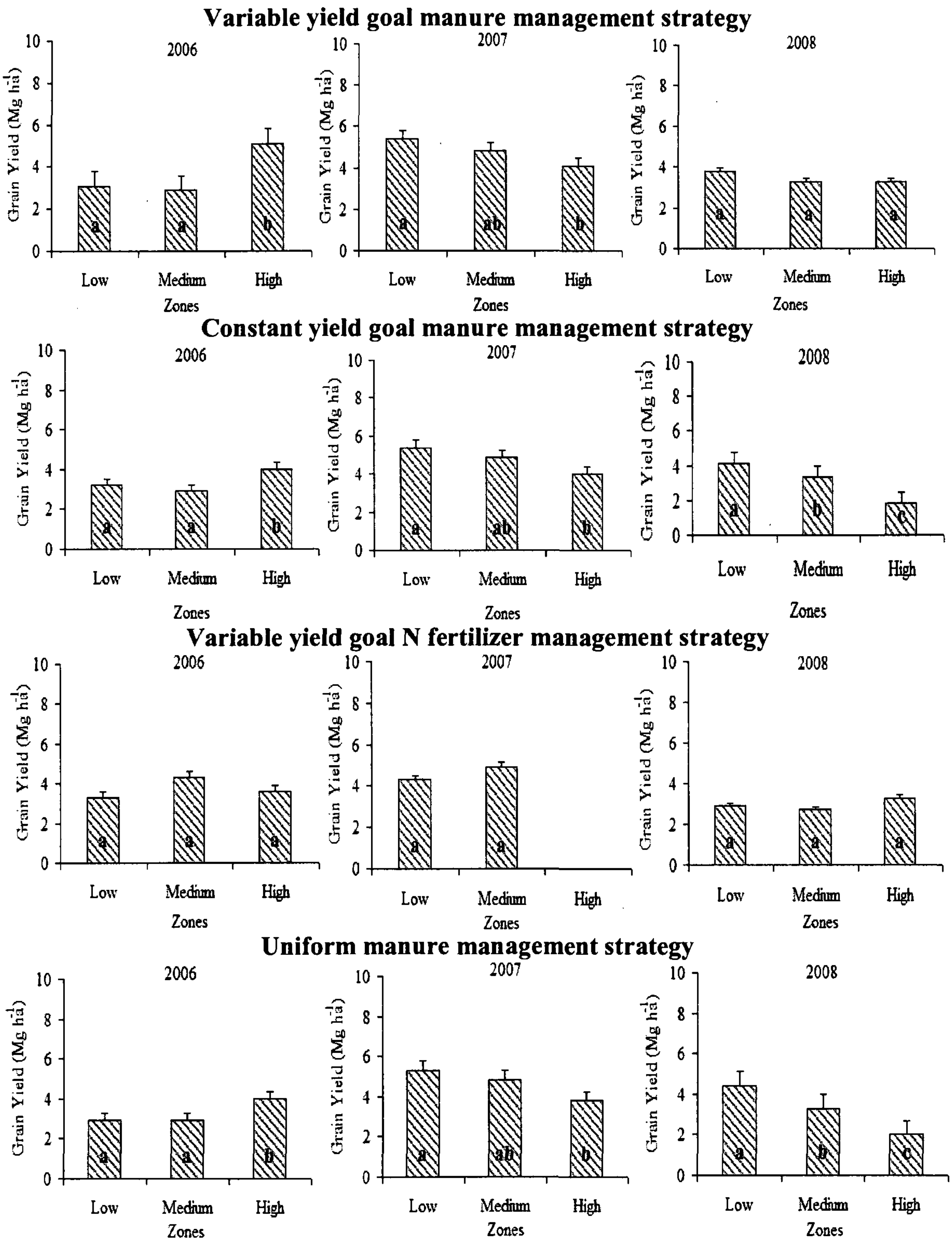


Fig 1.5. Mean grain yield across low, medium and high management zones for variable yield goal manure, constant yield goal manure, variable yield goal N, and uniform manure management strategies under dryland conditions. Within a site-year, bars with different letters are significantly different at $P \leq 0.05$ level of significance.

Table 1.1. Selected soil properties of soils samples acquired at 0-20 and 20-60 cm depth prior to planting in 2006 across the low, medium and high management zones.

Management	Sampling	Soil Properties					
Zone	Depth	pH	†EC	‡OM	§NO_3-N	¶P	Soil textural Class
	cm		dSm^{-1}	$g\ kg^{-1}$	—— $mg\ kg^{-1}$	——	
High	0-20	7.4	0.9	18	22.0	11.8	Clay Loam
	20-60	7.5	1.3	19	26.8	11.2	
Medium	0-20	7.5	0.7	16	4.8	5.6	Sandy Clay Loam
	20-60	7.6	0.7	15	2.7	4.3	
Low	0-20	7.5	0.7	16	7.4	7.8	Sandy Clay Loam
	20-60	7.6	0.7	15	4.6	7.4	

†EC is soil electrical conductivity
‡OM is soil organic matter
§Soil nitrate-N
¶Bray 1 soil phosphorus

Table 1.2. Characteristics of dairy cattle manure (DCM) and beef cattle feedlot manure (BCFM) applied in 2006, 2007 and 2008. Nutrients, organic matter and ash contents are reported on a dry weight basis.

Year and Source	Total N	Total P	Organic Matter	Ash	Water Content	NO_3-N	NH_4-N	EC†	pH†	C/N ratio
	$g\ kg^{-1}$					$mg\ kg^{-1}$		$dS\ m^{-1}$		
2006										
DCM	21.72	6.28	626	374	418	33.5	2111	7.83	7.08	15
BCFM	13.43	8.48	290	710	59	1118	137	3.38	7.81	11
2007										
DCM	9.80	2.47	392	608	604	22.3	1171	4.75	7.25	21
BCFM	11.18	3.88	290	710	188	15.6	3082	6.64	7.85	14
2008										
DCM	4.03	1.10	129	871	409	53.1	610.2	4.42	6.86	17
BCFM	17.24	8.67	506	494	433	73.8	10,441.6	10.22	7.34	15

†Electrical conductivity (EC) and pH were determined on 5:1 water to dry manure ratio.

Table 1.3. Net return sensitivity corresponding to increases and decreases in maize price and grain yield for variable yield goal manure management strategy on low, medium and high zones under limited irrigation conditions.

Yield	Maize Price ($ Mg^{-1})											
Mg ha^{-1}	78.8	98.5	118.2	137.9	157.6	177.3	197.0	216.7	236.4	256.1	275.8	295.5
	†Net return ($ ha^{-1})											
	Low zone											
10.0	-79.6	118.0	315.6	513.2	710.8	908.4	1106.0	1303.6	1501.2	1698.8	1896.4	2094.0
10.7	-30.2	179.8	389.7	599.7	809.6	1019.6	1229.5	1439.5	1649.4	1859.4	2069.3	2279.3
11.3	19.2	241.5	463.8	686.1	908.4	1130.7	1353.0	1575.3	1797.6	2019.9	2242.2	2464.5
11.9	68.6	303.3	537.9	772.6	1007.2	1241.9	1476.5	1711.2	1945.8	2180.5	2415.1	2649.8
12.5	118.0	365.0	612.0	859.0	1106.0	1353.0	1600.0	1847.0	2094.0	2341.0	2588.0	2835.0
13.2	167.4	426.8	686.1	945.5	1204.8	1464.2	1723.5	1982.9	2242.2	2501.6	2760.9	3020.3
13.8	216.8	488.5	760.2	1031.9	1303.6	1575.3	1847.0	2118.7	2390.4	2662.1	2933.8	3205.5
	Medium zone											
10.0	-217.9	-20.3	177.3	374.9	572.5	770.1	967.7	1165.3	1362.9	1560.5	1758.1	1955.7
10.7	-168.5	41.4	251.4	461.3	671.3	881.2	1091.2	1301.1	1511.1	1721.0	1931.0	2140.9
11.3	-119.1	103.2	325.5	547.8	770.1	992.4	1214.7	1437.0	1659.3	1881.6	2103.9	2326.2
11.9	-69.7	164.9	399.6	634.2	868.9	1103.5	1338.2	1572.8	1807.5	2042.1	2276.8	2511.4
12.5	-20.3	226.7	473.7	720.7	967.7	1214.7	1461.7	1708.7	1955.7	2202.7	2449.7	2696.7
13.2	29.1	288.4	547.8	807.1	1066.5	1325.8	1585.2	1844.5	2103.9	2363.2	2622.6	2881.9
13.8	78.5	350.2	621.9	893.6	1165.3	1437.0	1708.7	1980.4	2252.1	2523.8	2795.5	3067.2
	High zone											
10.0	-358.7	-161.1	36.5	234.1	431.7	629.3	826.9	1024.5	1222.1	1419.7	1617.3	1814.9
10.7	-309.3	-99.3	110.6	320.6	530.5	740.5	950.4	1160.4	1370.3	1580.3	1790.2	2000.2
11.3	-259.9	-37.6	184.7	407.0	629.3	851.6	1073.9	1296.2	1518.5	1740.8	1963.1	2185.4
11.9	-210.5	24.2	258.8	493.5	728.1	962.8	1197.4	1432.1	1666.7	1901.4	2136.0	2370.7
12.5	-161.1	85.9	332.9	579.9	826.9	1073.9	1320.9	1567.9	1814.9	2061.9	2308.9	2555.9
13.2	-111.7	147.7	407.0	666.4	925.7	1185.1	1444.4	1703.8	1963.1	2222.5	2481.8	2741.2
13.8	-62.3	209.4	481.1	752.8	1024.5	1296.2	1567.9	1839.6	2111.3	2383.0	2654.7	2926.4

†.Shaded net returns indicate a financial loss based on produced maize grain yield and associated maize price

Table 1.4. Net return sensitivity corresponding to increases and decreases in maize price and grain yield for variable yield goal manure management strategy on low, medium and high management zone under dryland conditions.

Yield	Maize Price ($ Mg^{-1})											
Mg ha^{-1}	78.8	98.5	118.2	137.9	157.6	177.3	197.0	216.7	236.4	256.1	275.8	295.5
	†Net return ($ ha^{-1})											
	Low zone											
3.8	-484.1	-410.0	-335.9	-261.8	-187.7	-113.6	-39.5	34.6	108.7	182.8	256.9	331.0
4.4	-434.7	-348.3	-261.8	-175.4	-88.9	-2.5	84.0	170.4	256.9	343.3	429.8	516.2
5.0	-385.3	-286.5	-187.7	-88.9	9.9	108.7	207.5	306.3	405.1	503.9	602.7	701.5
5.6	-335.9	-224.8	-113.6	-2.5	108.7	219.8	331.0	442.1	553.3	664.4	775.6	886.7
6.3	-286.5	-163.0	-39.5	84.0	207.5	331.0	454.5	578.0	701.5	825.0	948.5	1072.0
6.9	-237.1	-101.3	34.6	170.4	306.3	442.1	578.0	713.8	849.7	985.5	1121.4	1257.2
7.5	-187.7	-39.5	108.7	256.9	405.1	553.3	701.5	849.7	997.9	1146.1	1294.3	1442.5
	Medium zone											
3.8	-622.5	-548.4	-474.3	-400.2	-326.1	-252.0	-177.9	-103.8	-29.7	44.4	118.5	192.6
4.4	-573.1	-486.6	-400.2	-313.7	-227.3	-140.8	-54.4	32.1	118.5	205.0	291.4	377.9
5.0	-523.7	-424.9	-326.1	-227.3	-128.5	-29.7	69.1	167.9	266.7	365.5	464.3	563.1
5.6	-474.3	-363.1	-252.0	-140.8	-29.7	81.5	192.6	303.8	414.9	526.1	637.2	748.4
6.3	-424.9	-301.4	-177.9	-54.4	69.1	192.6	316.1	439.6	563.1	686.6	810.1	933.6
6.9	-375.5	-239.6	-103.8	32.1	167.9	303.8	439.6	575.5	711.3	847.2	983.0	1118.9
7.5	-326.1	-177.9	-29.7	118.5	266.7	414.9	563.1	711.3	859.5	1007.7	1155.9	1304.1
	High zone											
3.8	-763.3	-689.2	-615.1	-541.0	-466.9	-392.8	-318.7	-244.6	-170.5	-96.4	-22.3	51.8
4.4	-713.9	-627.4	-541.0	-454.5	-368.1	-281.6	-195.2	-108.7	-22.3	64.2	150.6	237.1
5.0	-664.5	-565.7	-466.9	-368.1	-269.3	-170.5	-71.7	27.1	125.9	224.7	323.5	422.3
5.6	-615.1	-503.9	-392.8	-281.6	-170.5	-59.3	51.8	163.0	274.1	385.3	496.4	607.6
6.3	-565.7	-442.2	-318.7	-195.2	-71.7	51.8	175.3	298.8	422.3	545.8	669.3	792.8
6.9	-516.3	-380.4	-244.6	-108.7	27.1	163.0	298.8	434.7	570.5	706.4	842.2	978.1
7.5	-466.9	-318.7	-170.5	-22.3	125.9	274.1	422.3	570.5	718.7	866.9	1015.1	1163.3

†Shaded net returns indicate a financial loss based on produced maize grain yield and associated maize price

Table 1.5. Apparent nitrogen (N) budget for variable and constant yield goal manure management strategies on limited irrigation corn grown in 2006, 2007 and 2008 across low, medium and high management zones.

Management Zone	Total available N from different N sources in the soil†	Observed Yield	Fertilizer N recommendation‡	Excess N available to the crop§	Agron. use eff.¶
	lbs ac^{-1}	bu ac^{-1}	lb ac^{-1}		bu lb^{-1}
Variable yield goal manure management strategy					
2006					
Low	196	40.0	26	170	0.20
Medium	306	73.4	50	256	0.23
High	416	100.5	74	342	0.24
2007					
Low	309	140.4	37	272	0.45
Medium	414	129.2	45	369	0.31
High	551	132.4	35	516	0.24
2008					
Low	308	94.1	10	298	0.30
Medium	432	119.6	59	373	0.28
High	562	110.1	56	506	0.19
Constant yield goal manure management strategy					
2006					
Low	393	92.5	83	310	0.23
Medium	306	73.4	-50	356	0.24
High	240	60.6	9	231	0.25
2007					
Low	581	132.4	4	577	0.23
Medium	414	129.2	45	369	0.31
High	308	137.2	35	273	0.44
2008					
Low	615	121.2	13	602	0.20
Medium	432	119.6	49	383	0.28
High	311	87.7	2	309	0.28

† Animal manure, residual soil nitrogen and organic matter were sources of nitrogen in the soil.

‡ Crop N requirement is calculated using Mortvedt *et al.* (1996) N algorithm based on observed yield for each management zone, residual soil N and soil organic matter.

§ Excess N available to the crop is under optimum conditions for N mineralization.

¶ Agronomic use efficiency is calculated as observed yield/total available N.

APPENDIX

Table A1. Details of study site and various field operations performed during the growing season over three site years at two locations in northeastern Colorado.

Site details and Field Operations	Site-year I (2006)	Site-year II (2007)	Site-year III (2008)
Soil sampling	March 16	March 06	March 05
Manure application	May 11	April 21	April 14
Planting date	May 17	May 04	May 12
Cultivar	Corn - GARST 88-81	Corn - GARST 88-81	Corn NK N40T-GT/CB/LL
Seeding rate (irrigated field)	36 000/acre	34 000/acre	33 000/acre
Seeding rate (dryland field)	17 000/acre	19 000/acre	18 000/acre
Row spacing	0.76 m	0.76 m	0.76 m
UAN Application	June 19	July 03	June 24
Harvesting (irrigated)	Nov 08	Nov 12	Nov 11
Harvesting (dryland)	Nov 09	Nov 14	Dec 01
Irrigation method	furrow	furrow	furrow
Rotation	Continuous corn	Continuous corn	Continuous corn

Table A2. Example of calculating net returns to land and management of variable goal nitrogen (N) management strategies.

Management Zone	UAN Applied	Price of N	Application cost	Total Cost of production	Price of corn	Corn harvested	Gross† income	Net ‡ returns
	(lb ac^{-1})	(\$ lb^{-1})	(\$ ac^{-1})	(\$ ac^{-1})	(\$ bu^{-1})	(bu ac^{-1})	(\$ ac^{-1})	(\$ ac^{-1})
Low	80	0.80	5	325.16	3.5	114.8	401.8	76.64
Medium	133.8	0.80	5	368.16	3.5	126.0	441.0	72.84
High	113.4	0.80	5	351.16	3.5	130.8	457.8	106.64

† Gross income (\$/ac) = Price of corn (\$/bu) * Corn harvested (bu/ac).
‡Net return (\$/ac) = Gross income (\$/ac) - Total Cost of production (\$/ac).
Total cost of production = (total on summary budget of operation) + (UAN applied*price of N) + Cost of application.
This table was used for 2006, 2007 and 2008 data.

Table A3. Example of calculating net returns to land and management of variable yield goal manure management strategies.

Management Zone	manure Applied	Price of hauling	Application and spreading	Total Cost of production	Price of corn	Corn harvested	Gross† income	Net ‡ returns
	(tons ac^{-1})	(\$ ton^{-1})	(\$ ton^{-1})	(\$ ac^{-1})	(\$ bu^{-1})	(bu ac^{-1})	(\$ ac^{-1})	(\$ ac^{-1})
Low	10	$57/10 tons	$20.59/10 tons	352.22	3.5	-	-	-
Medium	20	$113/20 tons	$20.59/10 tons	408.22	3.5	-	-	-
High	30	$170/30 tons	$20.59/10 tons	465.22	3.5	-	-	-

† Gross income ($/ac) = Price of corn ($/bu) * Corn harvested (bu/ac)
‡Net return ($/ac) = Gross income ($/ac) - Total Cost of production ($/ac)
This table was used for 2006, 2007 and 2008 data

Table A4. Example of calculating net returns to land and management of constant yield goal manure management strategies.

Management Zone	manure Applied	Price of hauling	Application and spreading	Total Cost of production	Price of corn	Corn harvested	Gross† income	Net ‡ returns
	(tons ac^{-1})	(\$ ton^{-1})	(\$ ton^{-1})	(\$ ac^{-1})	(\$ bu^{-1})	(bu ac^{-1})	(\$ ac^{-1})	(\$ ac^{-1})
Low	30	$170/30 tons	$20.59/10 tons	465.22	3.5	-	-	-
Medium	20	$113/20 tons	$20.59/10 tons	408.22	3.5	-	-	-
High	10	$57/10 tons	$20.59/10 tons	352.22	3.5	-	-	-

† Gross income ($/ac) = Price of corn ($/bu) * Corn harvested (bu/ac)
‡Net return ($/ac) = Gross income ($/ac) - Total Cost of production ($/ac)
This table was used in 2006, 2007 and 2008

Table A5. Example of varying corn harvested and prices for sensitivity analysis on manure amended low management zone of variable yield and high management zone constant yield goal manure management strategies.

Total Cost of production	Price of corn	Corn harvested	Gross income	Net profit
($ lb^{-1})	($ bu^{-1})	(bu ac^{-1})	($ ac^{-1})	($ ac^{-1})
352.22	3.5	160	560	207.78
352.22	3.5	170	595	242.78
352.22	3.5	180	630	277.78
352.22	3.5	190	665	312.78
352.22	3.5	200	700	347.78
352.22	3.5	210	735	382.78
352.22	3.5	220	770	417.78

† Gross income ($/ac) = Price of corn ($/bu) * Corn harvested (bu ac^{-1})
‡Net return ($/ac) = Gross income ($/ac) - Total Cost of production ($ ac^{-1})
Price of corn was varied from $3.5 to $7.5 while corn harvested varied from 160 to 220 bu ac^{-1}

Table A6. Example of varying corn harvested and prices for sensitivity analysis on manure amended medium management zone of variable and constant yield goal manure management strategies

Total Cost of production	Price of corn	Corn harvested	Gross income	Net profit
($ lb^{-1})	($ bu^{-1})	(bu ac^{-1})	($ ac^{-1})	($ ac^{-1})
408.22	3.5	160	560	151.78
408.22	3.5	170	595	186.78
408.22	3.5	180	630	221.78
408.22	3.5	190	665	256.78
408.22	3.5	200	700	291.78
408.22	3.5	210	735	326.78
408.22	3.5	220	770	361.78

† Gross income ($/ac) = Price of corn ($/bu) * Corn harvested (bu ac^{-1})
‡Net return ($/ac) = Gross income ($/ac) - Total Cost of production ($ ac^{-1})
Price of corn was varied from $3.5 to $7.5 while corn harvested varied from 160 to 220 bu ac^{-1}

Table A7. Example of varying corn harvested and prices for sensitivity analysis on manure amended high management zone of variable yield gial and low management zone of constant yield goal manure management strategies

Total Cost of production	Price of corn	Corn harvested	Gross income	Net profit
($ lb^{-1})	($ bu^{-1})	(bu ac^{-1})	($ ac^{-1})	($ ac^{-1})
465.22	3.5	160	560	94.78
465.22	3.5	170	595	129.78
465.22	3.5	180	630	164.78
465.22	3.5	190	665	199.78
465.22	3.5	200	700	234.78
465.22	3.5	210	735	269.78
465.22	3.5	220	770	304.78

† Gross income ($/ac) = Price of corn ($/bu) * Corn harvested (bu ac^{-1})
‡Net return ($/ac) = Gross income ($/ac) - Total Cost of production ($ ac^{-1})
Price of corn was varied from $3.5 to $7.5 while corn harvested varied from 160 to 220 bu ac^{-1}

Table A8. Example of summary budget by Operation (i.e. Low management zone in 2006)

Crop: Corn

Year: 2006
Field: ARDEC

Management strategy: **Uniform N rate**
Field condition: Furrow irrigated

Month of harvest	Yield	Units	Price of corn	Gross receipts
November	151.5	Bushels	$3.5	**$530.25**

DIRECT COSTS:

Operation type	Name	Variable Machine cost	Material costs	Operating interest	Total Operating	Ownership costs	Total costs
Other	Chop stalks	1.88	0.00	0.16	2.04	2.39	4.43
Other	Soil sample	0.00	2.00	0.15	2.15	0.00	2.15
Tillage	Chisel plough	3.72	0.00	0.26	3.98	4.84	8.82
Tillage	Disc-rip	3.70	0.00	0.26	3.96	4.70	8.66
Tillage	Mulch finish	1.67	0.00	0.11	1.78	3.53	5.31
Tillage	Mulch finish	1.67	0.00	0.10	1.77	3.53	5.30
Tillage	Land plane	3.08	0.00	0.16	3.25	2.53	5.77
Tillage	Bed/Furrow	2.62	0.00	0.13	2.75	3.45	6.20
Pest control	Herbicide	0.00	23.30	1.14	24.45	0.00	24.45
Planting	Plant Corn	6.68	52.64	2.88	62.20	6.52	68.72
Pest control	Herbicide	0.00	19.10	0.83	19.93	0.00	19.93
Irrigation	Furrow irrigate	0.00	35.00	1.21	36.21	0.00	36.21
Harvest	Harvest	7.97	3.73	0.00	11.70	27.62	39.32
Other	Dry corn	0.00	18.65	0.00	18.65	0.00	18.65
Fertilization	Uniform N	0.00	0.00	0.00	0.00	0.00	96.20†
Total Per Acre							**370.11**

TOTAL NET RECEIPTS PER ACRE = Gross receipts – Total costs of production per acre (\$530.25 - \$370.11 = 160.14)

Table A9. Costs and returns per hectare for management zones as a function of variable, constant yield goal, and N management strategies for 2006, 2007 and 2008 under limited irrigation.

Management Strategy†	Management Zone‡	Gross revenue§	Total cost of production	Net Returns¶
		$ ha^{-1}$		
		2006		
VYG-N	Low	1286	870	416
	Medium	1254	951	303
	High	1117	633	484
VYG-manure	Low	345	870	-525
	Medium	635	1008	-373
	High	869	1149	-280
CYG-manure	Low	890	1149	-259
	Medium	631	1008	-377
	High	519	870	-351
		2007		
VYG-N	Low	992	803	189
	Medium	1089	909	180
	High	1131	867	264
VYG-manure	Low	1213	870	343
	Medium	1117	1008	109
	High	1145	1149	-4
CYG-manure	Low	1133	1149	-17
	Medium	1115	1008	107
	High	1184	870	314
		2008		
VYG-N	Low	1186	865	321
	Medium	1186	892	294
	High	1296	939	357
VYG-manure	Low	801	870	-69
	Medium	1037	1008	29
	High	954	1149	-195
CYG-manure	Low	1044	1149	-105
	Medium	1106	1008	98
	High	758	870	-112

† VYG-manure and CYG-manure were variable rate manure management strategies based on variable yield goal and constant yield goal respectively.
‡ Level of soil productivity potential (low, medium and high).
§ Gross revenue is the product of mean zone yield (Mg ha^{-1}) and maize price ($137.9 Mg^{-1}).
¶ Net returns is the difference in gross revenue and total costs.

Table A10. Example of Nitrogen calculation for Variable Yield Goal manure management strategy

Manure applied = 10 tons/acre
Moisture content = 5.94 %
Therefore, dry matter = 10 tons/acre (100 – 5.94%)/100
= 9.406 tons/acre

Nitrogen present in manure on dry basis = 1.343% **(from lab. manure analysis results)**
Therefore, N applied through manure = 9.406 * 1. 343%/100
= 0.126 tons/ac
Only 40% of applied N through manure is available for the 1st year (Colorado-manure sources)
=0.126 * 40/100
=0.051 tons/acre * 2000 lb/ton
=101.1 lb N/ac (1st year, Low zone)
=202.1 lb N/ac (1st year, Medium zone)
=303.2 lb N/ac (1st year, High zone)
From this applied animal manure, 20 % N is available in the 2nd year and 10 % is available in the 3rd year.

Manure varies with N and other nutrients content, moisture content, and general chemical composition.

Table A11. Soil analysis conversion: (ppm to lb/acre) – deriving conversion factor as used in;
Mortvedt, J.J., D.G. Westfall, and R.L. Croissant. 1996. Fertilizing corn. Colorado State Univ. Coop. Ext., Service in Action no. 0.538. Colorado State Univ., Ft. Collins.

1 acre = 43560 sq ft
6″ = 0.5 ft
Therefore 43560 sq ft * 0.5 ft = 21780 cubic ft

Depth: 8″ = 0.667 ft

0.667 ft * 43560 sq ft = 29054.52 cubic ft
Soil bulk density = 1.60 g/cm^3 = 99.88 lb/cubic ft
29054.52 cubic ft * 99.88 lb/cubic ft = 2901965.4576 lb of soil to an acre
≈ 2.9 million lb

24″ = 2ft
2ft * 43560 sq ft = 87120 cubic ft
Soil bulk density = 1.60 cm^3 = 99.88 lb/cubic ft
87120 cubic ft * 99.88 lb/cubic ft = 8701545.6 lb of soil to an acre
≈ 8.7 million lb

Maize grain yield response to manure management strategies under limited irrigation

Figure 1.6 shows the response of maize grain yield as a function of constant and variable yield goals manure management strategies on low and high management zones in 2006, 2007 and 2008. Grain yield for low and high management zones responded positively to all manure management strategies under limited irrigated conditions. In this study, manure was applied in spring before planting of maize. The lower grain yields in 2006 could have been impacted by insufficient nutrients at critical early maize growth stages (Bacon, 1995). In 2007, precipitation and weather conditions were close to normal; maize appeared to have benefitted from mineralization of nutrients from previous and current (2007) year's manure applications (which is reflected in high grain yields in 2007). This may imply that manure management strategy when coupled with adequate weather conditions, may increase grain yield. One would expect that such a trend of increasing grain yield would continue over time. However, quite contrary to the expected outcome, we observed a decline in grain yield the following year (2008) even when weather was close to normal. This could be attributed to over accumulation of nutrients such as N in the soil. A decline in grain yield as a result of three repeated manure applications was previously reported by Eghball et al. (2001) in a site-specific manure application study as was observed in this study. These results are akin to the law of diminishing marginal returns (Addiscott et al., 1991). According to which; if animal manure or nutrients are increased on the same land for crop production, the overall yield will relatively decrease after a certain point.

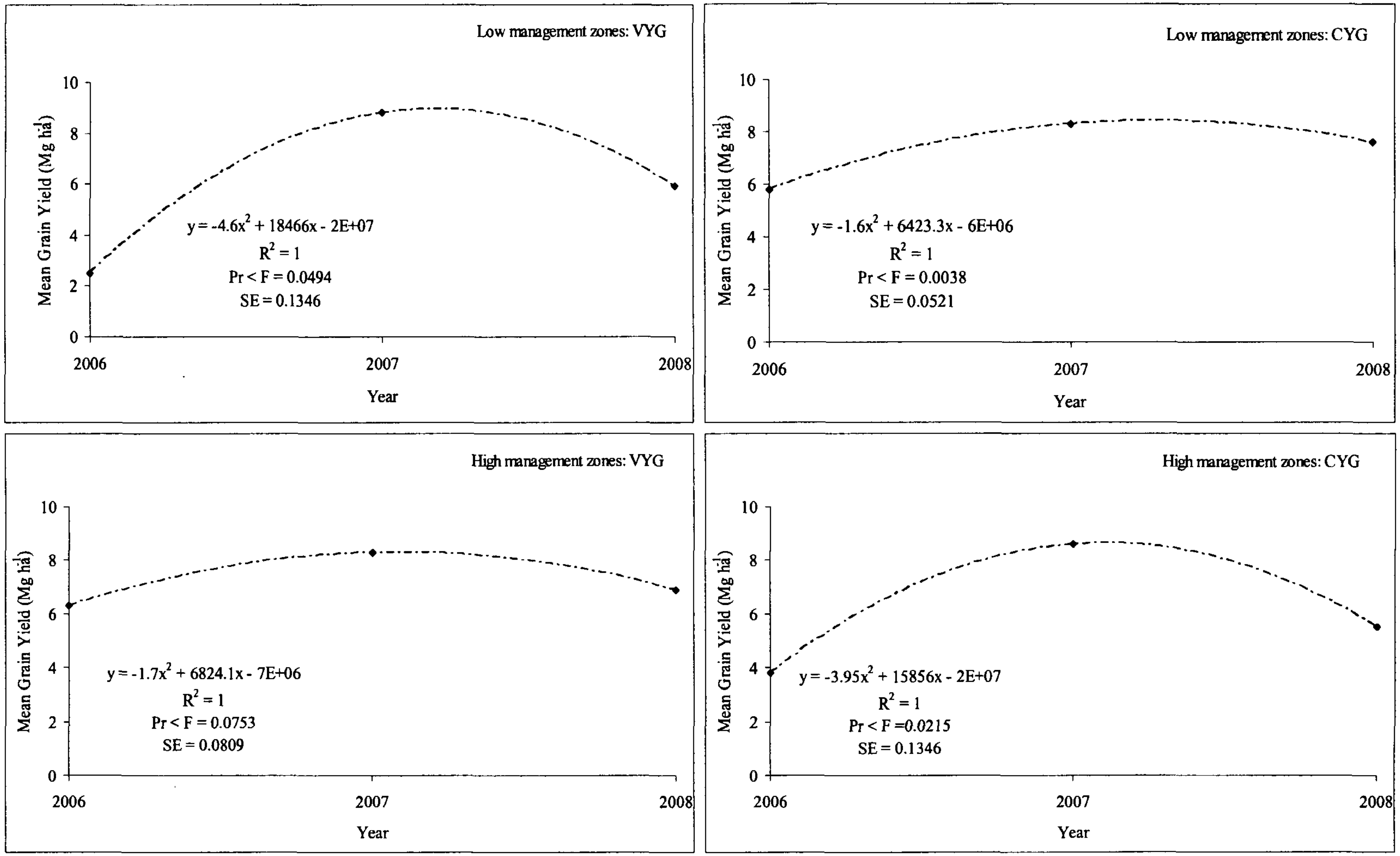


Figure 1.6. The response of maize grain yield as a function of constant and variable yield goals manure management strategies on low and high management zones in 2006, 2007 and 2008 under limited irrigated condition. $Pr \leq 0.05$ was considered as a significant level and SE is the standard error of the means. Whole data was used for statistical analysis, and only means were used in plotting.

CHAPTER 2: PRECISION MANURE MANAGEMENT ON SITE-SPECIFIC MANAGEMENT ZONES: TOPSOIL QUALITY AND ENVIRONMENTAL IMPACT

INTRODUCTION

Precision manure management is a multidimensional concept that combines the best manure management practices along with precision agricultural techniques, such as site-specific management zones. Site-specific management zones (MZs) are subregions in a field that express a homogeneous combination of yield limiting factors (Doerge, 1999), and can be managed uniformly within each zone (Khosla et al., 2002). In recent years, researchers have developed methods for delineating MZs to efficiently apply agricultural inputs such as fertilizers and herbicides across spatially variable soils (Fleming et al., 2000; Khosla et al., 2002; Koch et al., 2004).

Maintenance and improvement of topsoil quality across spatially variable soils in continuous cropping systems is critical to sustaining agricultural productivity and environmental quality for future generations (Reeve, 1997). Field studies have shown the capability of MZs as a legitimate tool for sustaining agricultural productivity. In addition, MZs have also been reported to be economically viable as compared to traditional methods of input application (Clay et al., 1998; Swinton and Lowenberg-DeBoer, 1998; Koch et al., 2004). Previous field studies have shown that MZs have potential to reduce environmentally sensitive nutrient loads into the environment (Delgado et al., 2005). The use of MZs for precision manure management has potential to improve soil quality, especially for low productivity areas of the field by enriching the soil with organic matter which has a significant influence on the improvement of soil physical and chemical properties (Eghball et al., 2001).

Issues in manure management

Traditionally, animal feeding operations have recycled manure on fields close to where it was produced (Kellogg et al., 2000). Traditionally, manure cannot be moved far from where it was produced due to high transportation costs (Janzen et al., 1999). Increase in facility size and regional concentrations of livestock operations have resulted from economic factors due to demand for meat products, and livestock concentration has given rise to concerns over the management of manure and potential impacts on environmental quality (USDA, 2003). In recent years, the proliferation of large-scale livestock producers has created a situation where manure is concentrated in specific regions (Kellogg et al., 2000). Increased integration of the livestock industry has resulted in large Confined Animal Feeding Operations (CAFOs) and associated manure stocks (Fleming and Long, 2002). The U.S. Environmental Protection Agency (EPA) regulation of concentrated animal feeding operations under the Clean Water Act is driving the need for improved recordkeeping and accountability for manure applications (Ribaudo et al., 2003). There is a need to investigate whether current manure management practices can be improved by taking advantage of the MZ approach.

Manure in the western Great Plains

In the western Great Plains, animal agriculture is an important contributor to the agricultural economy, and many livestock farms are close to rivers and other water bodies (Davis et al., 1997). Animal manure stocks are a growing concern to the public that fears contamination of surface and ground water (Fleming and Long, 2002). Ground water contamination caused by NO_3-N leaching from animal manure has been the driving force behind the implementation of best management practices (Sims and Wolf, 1994). Unlike nitrogen (N), phosphorus (P) is relatively immobile in the soil system, and P not taken up by plants can accumulate in soil, potentially to levels far in excess of amounts needed for optimal crop growth (Toth et al., 2006). The challenge with animal manure is that eroded soil containing high levels of P from animal manure can runoff into surface water and can cause eutrophication in aquatic ecosystems (Sims et al., 1998). To address this environmental threat to water resources, nitrogen leaching and phosphorus runoff risk assessments are required to meet water quality criteria for land application included in comprehensive nutrient management plans.

Nitrogen leaching and phosphorus runoff indices

Nitrogen and P are the nutrients of greatest environmental quality concern in agricultural crop production; animal manure is a source of both. Manure application may pose an environmental threat when applied at rates above crop nutrient requirements, and N and P supply of animal manure to soil is often not accurately credited (Smith et al., 2001a; 2001b). Farmers may unintentionally overload soils with P through repeated animal manure applications on the same land with a goal of meeting crop N requirements and improving topsoil quality through organic matter additions from animal manure. Czymmek et al. (2003) reported that high levels of P in streams and reservoirs have led to local, state and federal attempts to regulate manure application on large CAFOs that tend to have the most unbalanced nutrient budgets. To address P accumulation and excess N leaching on agricultural lands and reduce P runoff to the environment, researchers have developed risk assessment tools such as N leaching and P runoff indices (Sharkoff et al., 2006; 2008).

Soil electrical conductivity

Soil quality is an evaluation of the ability of a soil to perform agricultural and environmental functions (Doran and Parkin, 1994). Soil electrical conductivity (EC) is one of the soil quality parameters that are often studied, and soil EC is a direct indicator of salinity, nutrient levels, and soil texture (Sudduth et al., 2003). In precision agriculture, apparent soil EC (ECa) is an important soil parameter used mostly for delineation of MZs (Fleming et al., 2004). Farahani and Buchleiter (2004) reported apparent soil EC measurements as an economical tool to create potential MZs that may benefit from varying management inputs and practices in order to be environmentally friendly. While soils studied in this project were not saline, Grisso et al. (2007) warned about measuring soil EC following application of high rates of manure because soil EC measurement after manure application may result in misleading soil maps. Grisso et al. (2007) and Davis et al. (1997) suggested that soils may contain excessive salts from manure application, and soil EC values obtained in this type of situation may not represent soil conductivity but rather reflect variations in manure applications.

Manure and topsoil quality improvement

Soil physical properties are considered a critical component of soil quality. Studies have shown that addition of animal manure can improve soil physical properties and fertility levels since animal manure contains organic matter and various nutrients necessary for crop production (Epstein, 1975; Kutilek, 2004). Animal manure applications to agricultural lands may also reduce soil erosion on sandy or low productivity soils through increased soil organic matter levels which result in improvement in soil structure, aggregate stability, reduced runoff and increased infiltration (Eghball and Schepers, 1997). By reducing soil erosion, the amount of P transported by runoff was also reduced (Eghball and Gilley, 2001). Vitosh et al. (1973) measured a soil organic matter increase of 0.1% in a sandy loam soil with a one time application of 67.2 Mg ha^{-1} cattle manure. Organic matter supplied by animal manure to soil may also decrease bulk density. Fraser et al. (2006) reported that cattle manure decreases bulk density of soils with low organic matter; however, manure had little or no impact on soils that already had high levels (31 g kg^{-1}) of organic matter. Over application, or continuous application of animal manure on the same agricultural land over a period of time, can cause dispersion of soil particles due to high amounts of salt (sodium in particular) and consequently degrade soil structure. It is therefore necessary to determine where and how much animal manure can be applied on a specific area in order to improve soil organic matter and avoid overloading spatially variable soils with salt (Morris et al., 1999).

Variable rate application of animal manure

To avoid challenges related to over application of animal manure on agricultural soils, there is a need to identify alternatives and perhaps more appropriate uses of animal manure on low productivity and spatially variable soils (Sharpley and Withers, 1994). Bouma (1999) suggested that variable rate application of farming inputs on spatially variable soils could limit the overloading of soils with agricultural chemicals. Variable rate application technology allows for variation in application of farming inputs like animal manure throughout a field in an environmentally conscious and cost effective way.

Anderson-Cook et al. (1999) reported that variable rate application has potential to reduce costs in areas where uniform application would result in over application of farming inputs. Soil properties and nutrients often vary across a field such that uniform applications of farming inputs like animal manure may result in over and under application of nutrients contained in animal manure (Cahn et al., 1994; Long et al., 1996). Of major concern is that spatial variability in soil properties, crop growth, and yield is raising economic and environmental questions about sustainable crop production systems (Schepers et al., 2000).

Previous studies have investigated soil quality improvement as a result of animal manure application to agricultural lands; however, the spatial variability of soils was not considered. There is a need to determine whether variable rate applications of animal manure result in differential improvements in topsoil quality parameters on spatially variable soils without negative impact to the environment. The objectives of this project were (i) to study the effects of variable rate application of animal manure on selected topsoil quality parameters across MZs under dryland and irrigated conditions, and (ii) to evaluate the variable rate application of manure using the N leaching and P runoff indices to understand its impact on environmental quality.

MATERIALS AND METHODS

Study sites

The study was conducted under dryland and irrigated conditions in 2006 and 2007 on corn (*Zea mays* L.) fields. Study sites were located at 40°39' N, 104°59' W in northeastern Colorado near Fort Collins, CO. The soil profiles of the experimental sites were classified as fine-loamy, mixed, mesic, Aridic Haplustalfs with a 1 to 2% slope (Soil Survey Staff, 1999). The climate of the area is classified as semi-arid. Mean annual temperatures for the experimental site were 10.9 and 9.9°C for 2006 and 2007, respectively. The 2006 mean annual temperature was almost 2°C above the long-term averages, making 2006 the second warmest year in the history of weather recordkeeping in the state of Colorado since 1889 (Doesken, 2006). The months of June, July and August in 2006 were under extreme drought conditions (Miskus, 2006; Doesken, 2006). The total annual precipitation recorded during 2006 and 2007 from a nearby weather station were 286 and 347 mm, respectively (Fig. 2.1).

Management zone delineation

Productivity level MZs were previously delineated on the fields as a part of a large multi-disciplinary project. The details of the MZs delineation process can be found in Hornung et al. (2006) and Fleming et al. (1999). The MZ delineation process involved commercially available AgriTrak Professional Software to delineate the MZ boundaries (AgriTrak, 1998). A gray scale, bare soil aerial image of the field, farmers' perception of the topography data and farmers' past crop and soil management experience were included in the delineation process (Hornung et al., 2006; Khosla et al., 2008). Regions of darker color on the aerial image, areas of low-lying topography, and areas of historic high yields (as reported by the farmer) were designated as high zones and vice-versa (Hornung et al., 2006).

Soil sampling and analysis

Pre-plant and post study soil sampling methods used in this study were different depending on soil parameters of interest to be sampled. Pre-plant soil samples were collected each year in the month of March before application of manure using a systematic unaligned sampling design at a depth of 0-20 cm. MapInfo Professional Software (MapInfo Corp., Troy, NY) was engaged to FarmGPS Software (Red Hen Systems Inc., Fort Collins, CO) connected to Trimble AgGPS® 114 (Trimble Navigation Ltd., Sunnyvale, CA) for navigation to the sample locations. Soils were sampled precisely at the same locations throughout the study using a MZ map and a differential global positioning system (DGPS). Soil samples were collected using a JMC Backsaver probe (Clements Assoc., Newton, IA). Soil samples were sent to a commercial laboratory (AgSource Harris Lab, Lincoln, NE) for routine soil analysis which included soil pH, EC, organic matter, NO_3-N, Bray-1 P, and particle size distribution (Table 2.1).

After two years of manure applications in November 2007, topsoil bulk density, electrical conductivity, soil organic matter, EC, particle size analysis, soil water holding capacity, soil NO_3-N and P content were evaluated. Soil organic matter was determined by Modified Walkey-Black method and Loss on ignition in 2006 and 2007, respectively (Alison, 1965; Nelson and Sommers, 1982). Soil EC was analyzed in saturated paste extract (Rhoades, 1982). Soil P content was determined by the Bray 1 method (Bray and Kurtz, 1945), and NO_3-N extract was determined by cadmium reduction (Huffman and Barbarick, 1981). Particle size distribution was determined by Bouyoucos hydrometer method (Day, 1965).

For the measurement of bulk density and water holding capacity at field capacity and wilting point, four replicate soil cores were sampled to a depth of 10 cm after two repeated manure applications in November 2007. After harvesting of maize, sampling was consistently done between rows to avoid plant roots. Soil cores were sampled from geo-referenced locations across MZs. These samples were collected using a hammer-driven soil corer with brass cylinders fitted in the soil corer. The soil water holding capacity characteristics were determined from undisturbed soil cores by pressure plate apparatus (Soil Moisture, CA; Parent and Caron, 1993). Soil bulk density was determined from the same set of soil samples (Culley, 1993).

Manure application and analyses

Manure was applied each year in the spring prior to planting of maize using a tractor-drawn Hesston S320 manure spreader calibrated with the tarp calibration method (Davis and Meyer, 1999). Dairy cattle and beef feedlot manures were applied on dryland and irrigated fields, respectively. Manure was incorporated on the same day after application using a Lelyterra 300.35 incorporator. Manure samples were collected at the time of application and transported immediately to a commercial laboratory (Colorado Analytical Laboratory, Brighton, CO) for analysis of selected properties (Table 2.2).

Experimental design and data analysis

Experimental strips of 4.5 m wide and 540 m long spanned across all MZs, with treatments nested within MZs in the field. Manure treatments for this study included 0, 22, 45, and 67 Mg ha^{-1}. The experimental control of 0 Mg ha^{-1} served as a reference from which to compare soil quality improvements over time. Soil bulk density and EC data were subjected to paired t-test statistical analysis where pre-study soil data was compared with post-study soil data of soil samples taken from geo-referenced locations (Littell et al., 2002). Soil organic matter and water holding capacity data were subjected to analysis of variance with PROC GLM in SAS (Littell et al., 2002). Mean separation tests were done with the Least Significant Difference test ($P \leq 0.05$). The USDA soil texture triangle was used to classify soil particle size analysis of low, medium and high management zones into soil textural classes. The Colorado P runoff and N leaching indices (Sharkoff et al., 2006; 2008) were used to evaluate the environmental risk associated with variable rates of repeated manure applications across MZs.

RESULTS AND DISCUSSION

Topsoil quality parameters evaluated included organic matter, bulk density, water holding capacity, EC, and particle size analysis. The improvements of soil quality due to variable rate applications of animal manure were compared across manure application rates and MZs.

Organic matter

Soil sampling for organic matter analysis was performed in March 2008, four months after maize was harvested in November 2007. The low and medium MZs had a lower topsoil organic matter content (16 g kg^{-1}) compared to the high MZ, which had 18 g kg^{-1} on a control treatment where manure was not applied (Table 2.3). Two repeated variable rates of animal manure applied under irrigated conditions significantly increased topsoil organic matter of low and medium MZs. A previous study conducted in the state of Pennsylvania, USA showed that more than 44 Mg ha^{-1} of animal manure is required to maintain soil organic matter levels, and higher manure rates are necessary to increase soil organic matter content (Duiker, 2001). While Duiker (2001) made observations under uniform fields, accounting for spatial variability in our study has proved different on low and medium MZs but not on the high MZ. In the high MZ under irrigated conditions, only the highest manure rate of 67 Mg ha^{-1} increased topsoil organic matter as compared to a control treatment of no manure application.

Under dryland conditions, two repeated variable rates of animal manure maintained topsoil organic matter across MZs. The 44 Mg ha^{-1} manure application rate, which is the manure rate commonly applied by farmers on Colorado agricultural land, significantly increased topsoil organic matter. Manure rates higher than 44 Mg ha^{-1}, could not increase topsoil organic matter of low, medium and high MZs, but there is no plausible scientific explanation for this observation. The results of the study on a dryland field did not follow trends previously established in the literature. What is known about organic matter response to animal manure is that, soil organic matter increases in response to animal manure applications (Haynes and Naidu, 1998). The addition of manure to the soil improves soil microbial activity, and the microbes in turn, break down organic matter (Fraser et al., 2006). However, the process of breaking down organic matter requires adequate moisture for microbial activity and in the dryland field moisture was a limiting factor based on the climatic data (Fig. 2.1).

Bulk density

The difference between pre-study and post-study topsoil bulk density as impacted by variable rate applications of animal manure under irrigated and dryland conditions across low, medium and high management zones is shown in Table 2.4. Applications of variable rates of animal manure across MZs under irrigated conditions significantly ($P \leq 0.05$) decreased topsoil bulk density in the low and medium zones. The decrease in soil bulk density is due to improved soil structure resulting from increased porosity and a dilution effect resulting from the mixing of added organic matter with the denser mineral fraction of the soil (Powers et al., 1975). Two repeated manure applications of 44 and 67 Mg ha^{-1} significantly decreased topsoil bulk density of low and medium MZs when compared with pre-study soil bulk density (Table 2.4). The lowest levels of manure treatment (22 Mg ha^{-1} of animal manure) had no significant impact ($P \leq 0.05$) on topsoil bulk density across MZs under irrigated conditions. Similarly, Unger and Stewart (1974) reported no significant difference between 22 Mg ha^{-1} animal manure treatment and a control treatment of no manure application in a field study that received four annual applications of animal manure.

Interestingly, variable rate applications of animal manure treatments had no significant impact on topsoil bulk density under irrigation of the high MZ (Table 2.4). The top soil of the high MZ included higher clay content, organic matter content, and lower bulk density as compared to the low MZ prior to manure application. The results of this study are supported by previously published work of Zacharias (2005) that animal manure is useful in improving quality of soils that are low in productivity. Tiarks et al. (1974) reported a decrease in bulk density as a result of animal manure application under furrow irrigation similar to this study. In a similar study, Haynes and Naidu (1998) reported that animal manure significantly decreased bulk density of low productivity soils by 4 to 14% and had no impact on soils that had higher productivity levels. Fraser et al. (2006) and Eghball (2002) reported that cattle manure had little or no impact on bulk density of soils that already had relatively high organic matter content and clay content and relatively low bulk density, which is comparable to what was observed in this study.

Under dryland conditions, variable rate applications of animal manure significantly ($P \leq 0.05$) decreased topsoil bulk density on low, medium and high MZs at all application rates (Table 2.4). In 2006, the first year of this study, the dairy manure had an organic matter content of 627 g kg^{-1} as opposed to 290 g kg^{-1} in the beef manure applied under irrigated conditions (Table 2.2). The year 2006 was a severe drought year in the region which would probably adversely affect mineralization of organic matter under dryland conditions, because the dry soil conditions would not support microbial activity and mineralization of the manure. The months of June through August were particularly dry in this region (Marx, 2008). Manure requires enough soil moisture and adequate temperature to support microbial activity and the resultant mineralization (Bacon, 1995). Most manure apparently remained in the soil unmineralized and consequently influenced topsoil bulk density. The significant decrease in topsoil bulk density due to unmineralized animal manure caused by drought conditions under dryland conditions can potentially be temporary in nature, and topsoil bulk density may increase again under favorable conditions for manure mineralization. The increase in topsoil bulk density may occur when enough precipitation in the form of rainfall activates soil microbes and results in increased mineralization of organic matter (Bacon, 1995). Tiarks et al. (1974) reported a decrease in bulk density after two years and then an increase in the third year due to environmental conditions contributing to freezing-thawing of the soil. Interestingly, there was a significant change in topsoil bulk density of a control treatment in high MZ under dryland condition, for which there is no plausible explanation.

Soil electrical conductivity

Soil EC values observed under irrigated conditions (Table 2.5), 0.7 – 1.0 dS m^{-1}, were within the threshold of 0.8–1.0 dS m^{-1} (soil: water, 1:1), above which the growth and activity of crops and microorganisms can be significantly altered (Eigenberg et al., 2002; Smith and Doran, 1996). Based on the observations and recorded soil EC results under irrigated conditions in this study, we can deduce that manure induced soil EC after two repeated applications of manure at the rates applied did not cause agronomic threat to maize across MZs.

The EC of the dairy manure applied under dryland conditions in 2006 was EC of 7.8 dS m^{-1} (Table 2.2). The increase in soil EC under dryland conditions in this drought-affected year was due to lack of plant available water to leach salts applied in animal manure. As a result, under dryland conditions, variable rates of animal manure (22, 44, and 67 Mg ha^{-1}) significantly increased soil EC across MZs (Table 2.5). Repeated applications may compound the effect over time. Eghball et al. (2004) also reported an increase in soil EC on manured treatments under dryland conditions. Nevertheless, the increase in soil EC levels under dryland conditions was not high enough to affect maize grain yield because soil EC of less than 2 dS m^{-1} determined by saturated paste method is classified as non-saline (USDA, 2008).

Soil water holding capacity

Soil volumetric water content at field capacity (θ_{fc}) and wilting point (θ_{wp}) have been reported to be affected by the addition of animal manure. The increase in soil volumetric water content is known to be driven by the increase in soil organic matter content and reduction in soil bulk density (Gupta et al., 1977; Unger and Stewart, 1974). The results of this precision manure management study support these observations. Animal manure induced increases in soil volumetric water content under both dryland and irrigated conditions (Table 2.6). Increases in soil volumetric water content under dryland and irrigated conditions were recorded at both field capacity (θ_{fc}, at -33 kPa) and wilting point (θ_{wp}, at -1500 kPa). Sanchez et al. (1989) reported that since soil organic matter content and soil biological activity increase when animal manure is applied to soils, it is not surprising that soil physical properties such as bulk density and water holding capacity typically improve (Table 2.4 and 2.6). Significant increases ($P \leq 0.05$) in θ_{fc} and θ_{wp} were observed between the control treatment (no manure application) and manure treatments on each MZ.

While cation exchange capacity was not measured in this study, it may be interesting to note that previous studies have reported the following problems associated with large applications of animal manure, (i) dispersion caused by accumulated K^+, Na^+, and NH_4^+ in the soil, and (ii) production of water-repellant substances by basidiomycete decomposer fungi (Haynes and Naidu, 1998). Haynes and Naidu (1998) further reported that when monovalent Na^+ and NH_4^+ ions accumulate in soils in large amounts, they can become dominant exchangeable cations which favor dispersion of soil colloids. The author hypothesizes that dispersion of soil colloids resulted in no significant difference ($P \leq 0.05$) in soil volumetric water content at wilting point on medium zones that received repeated applications of the highest manure treatment of 67 Mg ha^{-1} as compared to control treatment (Table 2.6), even though lower manure application rates did increase θ_{wp}.

Soil water holding content at field capacity is influenced by soil texture, porosity and most importantly soil organic matter. According to the USDA-Natural Resources Conservation Service, clay loam and sandy clay loam soils with organic matter content of 5 to 30 g kg^{-1} (0.5 to 3%) usually have soil available water content (AWC) of 0.15 to 0.19

and 0.16 to 0.18 cm^3 cm^{-3}, respectively (USDA, 2009). High management zones (clay loam), and medium and low management zones (sandy clay loam) in this study had much lower AWC as compared to those previously established in the literature (USDA, 2009; Table 2.6). None of the manure treatments significantly increased AWC as compared to the control. Nevertheless, the primary observation in this study was that animal manure applications on low, medium and high management zones increased soil water content at field capacity and wilting point under dryland and irrigated conditions. This is based on a 2 year annual application of animal manure. One can only surmise that further repeated applications of animal manure may further increase soil water holding capacity; however, further manure applications may or may not be environmentally suitable based on other soil parameters, such as salt accumulation, nutrients, etc.

Particle size analysis

Particle size analysis of the soil samples collected from all management zones after two years revealed an unexpected change in the texture of soils across MZs. Our findings indicate that two repeated applications of animal manure at 67 Mg ha^{-1} on irrigated fields significantly increased the sand content of the soil and consequently affected soil texture of the high management zone (Table 2.7). Soil texture on the high zone changed from clay loam to sandy clay loam. It is highly unlikely that two repeated applications of animal manure would affect soil particle size. While these results were unusual, there were two possible explanations for this change in soil texture. Firstly, manure used in the irrigated study was scraped from a beef feedlot overlying a soil that may possibly have a coarser texture than the study site. Beef feedlot manure used in 2006 and 2007 had ash contents of 710 g kg^{-1} and organic matter contents of 290 g kg^{-1} (Table

2.2). Secondly, the particle size of the soil was at the upper margin of the soil texture triangle class such that addition of coarser textured soil that came with animal manure could change the textural class of the soil. Whalen and Chang (2002) reported a change in soil texture as a result of long-term (25 years) application of beef feedlot animal manure apparently having finer textured soil than that of the study site.

The observations made under dryland conditions about particle size analysis were not different from that of the irrigated conditions. Changes in soil textural class were observed in the high zone where 44 or 67 Mg ha^{-1} manure treatments were applied (Table 2.7). Dairy animal manure applied under dryland conditions carried 374 and 608 g kg^{-1} of ash in 2006 and 2007, respectively, which could be linked to a change in soil textural class due to soil particle sizes also being at the upper margin of the soil textural triangle class. Based on the similarity of the results observed under irrigated and dryland conditions, it is fair to conclude that irrigation did not have anything major to do with the change in soil textural class, but the variability in animal manure had an impact on soil textural class.

Nitrogen leaching and phosphorus runoff risk assessment

Table 2.8 shows how the Colorado N leaching and P runoff risk assessment indices are interpreted. Ground water contamination by NO_3-N from animal manure and commercial fertilizers has been the thrust behind the exercise of best management practices (BMPs) (Sims and Wolf, 1994). The Colorado N leaching risk assessment index indicated that NO_3-N leaching from 3 years of variable manure application rates across MZs pose a "medium" risk of ground water contamination at the rates of manure used under irrigated conditions only. The NO_3-N leaching index score of 10 was observed across MZs (Table 2.9). According to Shaffer and Delgado (2002) and Sharkoff et al. (2006), a N leaching index score of 8 to 11 indicates that the field is at medium risk of ground water contamination. Application of N as animal manure above the agronomically recommended rates by more than 56 kg ha^{-1} (50 lb ac^{-1}) for more than one consecutive year under moderately low irrigation application efficiency were major factors that placed the field under "medium" risk of N leaching to ground water (Sharkoff et al., 2006). While manure in this field was not applied based on nutrient concentration in soil prior to planting, the risk assessment index recommended that manure be applied based on nitrogen at agronomic rates. Manure rates were set at the beginning of the study, and manure was spring applied yearly at weight based rates. This weight based manure application posed an environmental risk by overloading management zones with NO_3-N and although the N leaching risk assessment index suggested that N application be split-in season at or below agronomic rate (Table 2.8), splitting solid manure applications is not practical.

The Colorado N leaching risk assessment index failed to detect differences between low, medium and high management zones as all zones showed a net score of 10 for the 22, 44, and 67 Mg ha^{-1} application rates (Table 2.9). This indicates that the Colorado N leaching risk assessment index was insensitive to spatial variability across low, medium and high management zones for this location. This verifies that N leaching index does not estimate the actual presence or leaching of NO_3-N (Shaffer and Delgado, 2002), hence all three MZs were classified as having the same environmental risk of N leaching.

The Colorado P index risk assessment recommends that the tool for P risk assessment not be used if there are no water bodies that can be impacted. However, runoff from this field is discharged into a local creek that eventually connects to the ditch that enters a larger irrigation ditch. The P runoff risk assessment index scores of 9 and 10 were calculated across MZs under irrigated conditions (Table 2.10). While all management zones were certified to have medium risk of P runoff into surface water by a net score of 8 to 11 (Table 2.8 and 2.10), it was interesting to observe that the Colorado P runoff risk assessment index was able to differentiate between low and high management zones (Table 2.10). In this study, soil test P was classified within medium and high environmental risk (Sharkoff et al., 2008). The furrow irrigated field was classified as having medium potential for off-site P movement (Table 2.8 and 2.10). As a result, the best management practice suggested by Sharkoff et al. (2008) for fields with medium potential for off-site P movement was that manure application rates be calculated and applied according to crop N requirements.

All MZs were under moderate environmental risk of N leaching into ground water, and a moderate environmental risk associated with P runoff into surface water bodies. While the N and P risk assessment indices provided a general estimate of the status of the field in relation to leaching and runoff, respectively, there is a need for more detailed N leaching and P runoff indices that would consider the variability across management zones.

CONCLUSIONS

Varying animal manure application rates across management zones is potentially a good approach for maintenance and improvement of bulk density, soil water holding capacity and organic matter of low producing areas; however, the approach was not shown to benefit high productivity management zones. While the soils remained non-saline after two repeated manure applications, soil electrical conductivity under dryland and irrigation conditions were increased. Phosphorus runoff index risk assessment indicated that there are no environmental risks associated with manure applications across MZs; however, the study suggests that the irrigated field could be at medium risk of nitrate leaching. Based on the results of this study, one can only surmise that continued applications of animal manure may further improve topsoil quality in low productivity areas of the field; however, it may not be environmentally suitable for other soil parameters such as salt accumulation and nutrient overloading.

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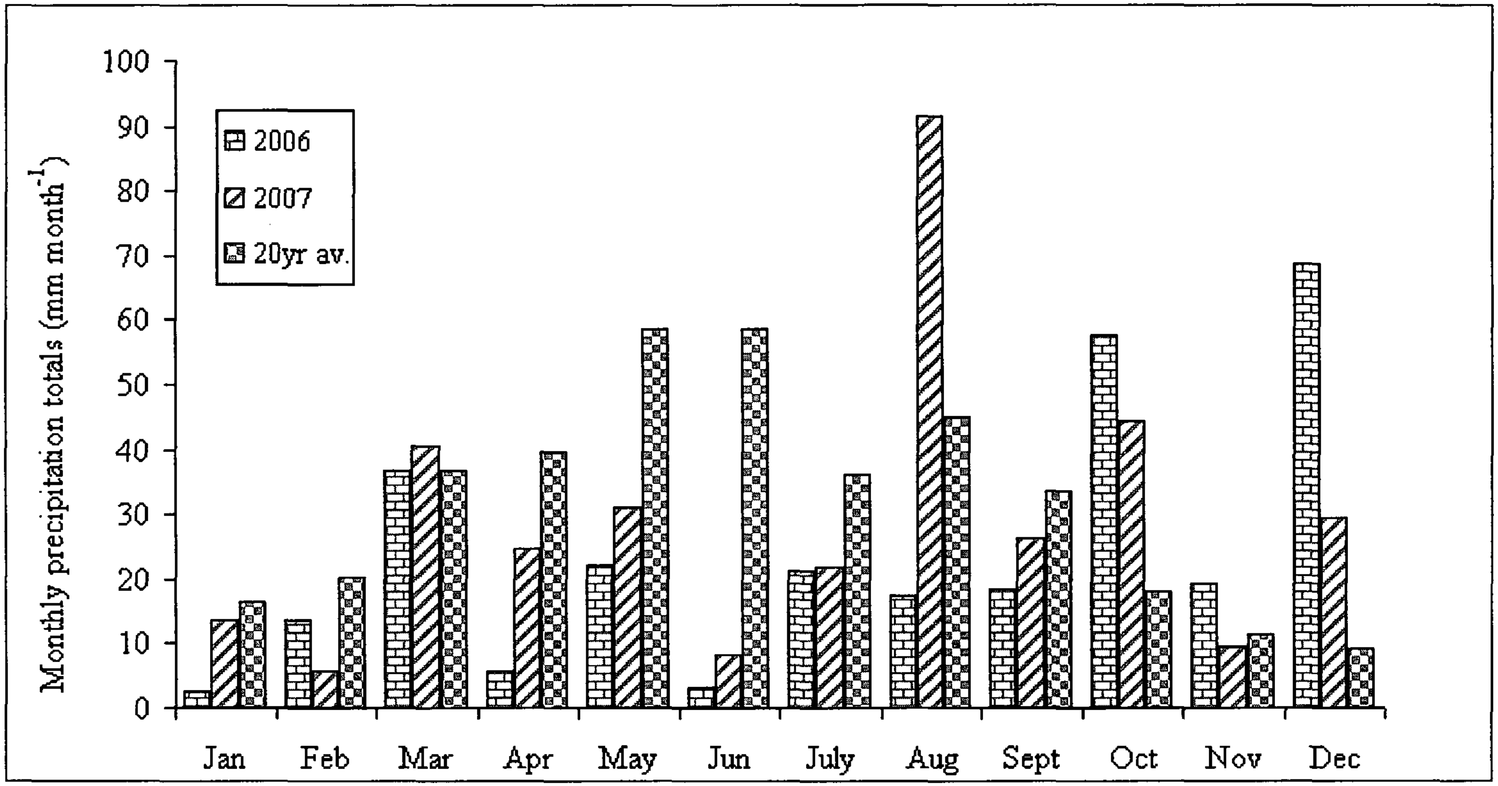

Fig. 2.1. Monthly totals precipitation recorded in 2006 and 2007 at a weather station located 1 mile from the experimental sites.

Table 2.1. Selected soil properties of soil samples acquired at 0-20 and 20-60 cm depth prior to planting across the low, medium and high management zones within irrigated and dryland fields.

Management	Sampling	Soil Properties					
Zone	Depth	pH	†EC	‡OM	§NO_3-N	¶P	Soil textural Class
	cm		dSm^{-1}	$g\ kg^{-1}$	—— $mg\ kg^{-1}$	——	
High	0-20	7.4	0.9	18	22.0	11.8	Clay Loam
	20-60	7.5	1.3	19	26.8	11.2	
Medium	0-20	7.5	0.7	16	4.8	5.6	Sandy Clay Loam
	20-60	7.6	0.7	15	2.7	4.3	
Low	0-20	7.5	0.7	16	7.4	7.8	Sandy Clay Loam
	20-60	7.6	0.7	15	4.6	7.4	

†EC is soil electrical conductivity
‡OM is soil organic matter
§Soil nitrate-N
¶Bray 1 soil phosphorus

Table 2.2. Selected characteristics of dairy cattle manure (DCM) and beef cattle feedlot manure (BCFM) applied to corn in 2006, 2007 and 2008. Nutrients, organic matter and ash contents are on a dry weight basis.

Year and Source	Total N	Total P	Organic Matter	Ash	Water Content	NO_3-N	NH_4-N	EC[†]	pH[†]	C/N ratio
	g kg^{-1}					mg kg^{-1}		dS m^{-1}		
2006										
DCM	21.7	6.3	627	374	418	33.5	2111	7.8	7.1	15
BCFM	13.4	8.8	290	710	59	1118	137	3.4	7.8	11
2007										
DCM	9.80	2.5	392	608	604	22.3	1171	4.7	7.3	21
BCFM	11.2	3.9	290	710	188	15.6	3082	6.6	7.9	14
2008										
DCM	4.03	1.1	130	870	409	53.1	610.2	4.4	6.9	17
BCFM	17.2	8.7	507	493	433	73.8	10,442	10.2	7.3	15

[†]Electrical conductivity (EC) and pH were determined on 5:1 water to dry manure ratio.

Table 2.3. Soil organic matter content after two repeated annual manure treatments of 0 to 67 Mg ha^{-1} in three management zones under irrigated and dryland conditions.

	Management Zone		
Treatment	Low	Medium	High
Mg ha^{-1}	g kg^{-1}		
Irrigated			
0	16aA†	16aA	18aB
22	19bA	19bA	19aA
44	16.5aA	18.5bB	18aB
67	19bA	19bA	20bA
Dryland			
0	16aA	16aA	18aB
22	17aAB	16aA	18aB
44	20bA	20bA	21bA
67	17aAB	16aA	18aB

†Treatment means within column with different small letters (a, b) are significantly different at $P \leq 0.05$ within a management zone, and treatment means within a row with different capital letters (A, B) are significantly different at $P \leq 0.05$ within a treatment across management zones.

Table 2.4. The difference between pre-study and post-study bulk density, mean difference ± standard error difference across low, medium and high management zones amended with variable rates of animal manure under irrigated and dryland conditions.

Manure	Management Zones								
	Low Zone			Medium Zone			High Zone		
Mg ha^{-1}	Pre	Post	Mean diff. ± SE diff.	Pre	Post	Mean diff. ± SE diff.	Pre	Post	Mean diff. ± SE diff.
	g cm^{-3}								
	Irrigated								
0	1.60	1.54	0.06^{ns} ± 0.07	1.55	1.43	0.12^{ns} ± 0.07	1.50	1.41	0.09^{ns} ± 0.06
22	1.60	1.45	0.15† ± 0.05	1.55	1.50	0.05^{ns} ± 0.04	1.50	1.29	0.21^{ns} ± 0.10
44	1.60	1.42	0.18* ± 0.04	1.55	1.45	0.10* ± 0.02	1.50	1.42	0.08^{ns} ± 0.06
67	1.60	1.43	0.17* ± 0.03	1.55	1.44	0.11* ± 0.03	1.50	1.36	0.14^{ns} ± 0.09
	Dryland								
0	1.60	1.52	0.08^{ns} ± 0.06	1.55	1.43	0.12^{ns} ± 0.06	1.50	1.27	0.23* ± 0.04
22	1.60	1.14	0.46* ± 0.07	1.55	1.30	0.25* ± 0.03	1.50	1.29	0.21* ± 0.03
44	1.60	1.25	0.35* ± 0.04	1.55	1.26	0.29* ± 0.03	1.50	1.32	0.18* ± 0.04
67	1.60	1.36	0.24* ± 0.04	1.55	1.17	0.38* ± 0.06	1.50	1.25	0.25* ± 0.05

*Significant difference at $P \leq 0.05$,
†Significant difference at $P \leq 0.1$,
ns = not significantly different at $P \leq 0.05$ or 0.1.

Table 2.5. The difference between pre-study and post-study soil electrical conductivity, mean difference ± standard error difference across low, medium and high management zones amended with variable rates of animal manure under irrigated and dryland conditions.

Manure	Management Zones								
	Low Zone			Medium Zone			High Zone		
Mg ha^{-1}	Pre	Post	Mean diff. ± SE diff.	Pre	Post	Mean diff. ± SE diff.	Pre	Post	Mean diff. ± SE diff.
	dS m^{-1}								
	Irrigated								
0	0.70	0.53	0.17† ± 0.04	0.70	0.49	0.21† ± 0.04	0.90	0.61	0.29† ± 0.02
22	0.70	0.97	0.27* ± 0.08	0.70	0.76	0.06^{ns} ± 0.08	0.90	1.00	0.10^{ns} ± 0.16
44	0.70	0.78	0.08* ± 0.02	0.70	0.94	0.24* ± 0.02	0.90	0.90	0.00^{ns} ± 0.09
67	0.70	0.80	0.10^{ns} ± 0.16	0.70	0.87	0.13* ± 0.02	0.90	0.73	0.17† ± 0.03
	Dryland								
0	0.70	0.43	0.27† ± 0.03	0.70	0.45	0.25† ± 0.06	0.90	0.61	0.29† ± 0.-4
22	0.70	1.10	0.40* ± 0.10	0.70	1.10	0.40* ± 0.19	0.90	1.30	0.40* ± 0.19
44	0.70	1.30	0.60* ± 0.10	0.70	1.40	0.70* ± 0.15	0.90	1.50	0.60* ± 0.31
67	0.70	1.40	0.70* ± 0.11	0.70	1.30	0.60* ± 0.06	0.90	1.60	0.70* ± 0.06

*Significant difference at $P \leq 0.05$,
ns = not significantly different at $P \leq 0.05$.

Table 2.6. Soil water holding characteristics for low, medium and high management zone soils on dryland and irrigated manure amended sites after two years of repeated applications.

Manure Treatments (Mg ha^{-1})	Management Zones								
	Low Zone (Sandy clay loam)			Medium Zone (Sandy clay loam)			High Zone (Clay loam)		
	Irrigated								
	θ_{fc}	θ_{wp}	AWC	θ_{fc}	θ_{wp}	AWC	θ_{fc}	θ_{wp}	AWC†
	(cm^3 cm^{-3})								
0	0.168a	0.143a	0.025a	0.173a	0.140a	0.033a	0.175a	0.148a	0.027a
22	0.175ab	0.156ab	0.019a	0.176ab	0.144a	0.032a	0.187ab	0.164ab	0.023a
44	0.177b	0.159b	0.018a	0.182b	0.172b	0.010b	0.191b	0.182b	0.009b
67	0.179b	0.160b	0.019a	0.176ab	0.149a	0.027a	0.179a	0.164ab	0.015ab
	Dryland								
	θ_{fc}	θ_{wp}	AWC	θ_{fc}	θ_{wp}	AWC	θ_{fc}	θ_{wp}	AWC
	(cm^3 cm^{-3})								
0	0.152a	0.135a	0.017a	0.159a	0.143a	0.016a	0.165a	0.138a	0.027a
22	0.167b	0.149b	0.018a	0.171b	0.157b	0.014a	0.176ab	0.162b	0.014b
44	0.174b	0.155b	0.019a	0.179b	0.156b	0.023a	0.181bc	0.169b	0.012b
67	0.164b	0.146ab	0.018a	0.170b	0.146a	0.024a	0.190c	0.158b	0.032a

Within a zone, treatments means with different letters are significantly different at $P \leq 0.05$.

†AWC = Available water content (θ_{fc} - θ_{wp})

θ_{fc} and θ_{wp} are soil volumetric water content at field capacity and wilting point respectively

Table 2.7. Sand, silt and clay soil particles as influenced by two repeated animal manure applications across management zones under irrigation and dryland conditions.

Treatment	Management Zone	Sand†	Silt†	Clay†	Textural Class‡
Mg ha^{-1}		———	g kg^{-1}	———	
		Irrigated			
0§	Low	452c	244a	304a	SCL
22	Low	444c	216a	340a	CL
44	Low	472b	200a	328a	SCL
67	Low	492a	220a	288a	SCL
	P>F	**<.0001**	**ns**	**ns**	
	CV	**0.984**			
0	Medium	532b	164a	304b	SCL
22	Medium	504c	196a	300b	SCL
44	Medium	472d	180a	348a	SCL
67	Medium	592a	160a	248c	SCL
	P>F	**<.0001**	**ns**	**0.0003**	
	CV	**1.982**		**4.994**	
0	High	472b	164b	364a	CL
22	High	464bc	196ab	340b	SCL
44	High	452c	220a	328b	SCL
67	High	492a	180b	328b	SCL
	P>F	**0.0005**	**0.0053**	**0.0005**	
	CV	**1.421**	**7.022**	**1.964**	
		Dryland			
0	Low	452c	244a	304b	SCL
22	Low	464b	236ab	300b	SCL
44	Low	532a	200c	268c	SCL
67	Low	424d	216b	360a	CL
	P>F	**<.0001**	**0.0015**	**<.0001**	
	CV	**0.966**	**4.031**	**1.467**	
0	Medium	532a	164b	304b	SCL
22	Medium	444c	236a	320b	CL
44	Medium	492b	180ab	328ab	SCL
67	Medium	444c	196ab	360a	CL
	P>F	**<.0001**	**0.0199**	**0.0239**	
	CV	**2.177**	**12.770**	**4.571**	
0	High	472b	164b	364a	CL
22	High	424c	256a	320b	CL
44	High	492a	180b	328ab	SCL
67	High	492a	220a	288c	SCL
	P>F	**<.0001**	**0.0005**	**0.0006**	
	CV	**1.410**	**8.339**	**4.987**	

†Means in the same column (vertical) with different letters are significantly different at $P \leq 0.05$.
‡SCL and CL refer to Sandy clay loam and Clay loam, respectively.
§The 0 treatments were control treatments for every management zone. Soil was sampled and analyzed in 2006 before manure was applied to management zones.

Table 2.8. Interpretation of the Colorado P runoff (Sharkoff et al., 2008) and N leaching index (Sharkoff et al., 2006) risk assessment tools.

Net score	Phosphorus runoff risk interpretations
<8	This field has a low potential for off-site P movement if managed at the current level. Calculate organic nutrient application rates according to crop N requirements.
8-11	This field has a medium potential for off-site P movement. Consider management changes to decrease risk and support continued long-term organic nutrient applications. Calculate organic nutrient application rates according to crop N requirements.
12-15	This field has a high potential for off-site P movement. Implement management changes to decrease risk. Calculate organic nutrient application rates according to crop P requirements.
16	This field has a very high potential for off-site P movement. Implement management changes to decrease risk. Do not apply organic nutrients to this field without decreasing the risk for off-site transport.

Net score	Nitrogen leaching risk interpretations
<8	This field has a low risk for N leaching if management is maintained at the current level. If there is an underlying aquifer that is shallow 6 m (< 20 ft) or used locally as a public drinking water source, increase the risk to medium.
8-11	This field has a medium risk for N leaching and some management changes may be needed to decrease risk. Apply N at agronomic rates or lower using spring or split in-season applications. If there is an underlying aquifer that is shallow < 6 m (< 20 ft) or used locally as a public drinking water source, increase the risk to high.
12-15	This field has a high risk for N leaching and management changes should be implemented to decrease risk. Manure should be applied at P agronomic rates. Apply N using split in-season applications at or below the agronomic rate. Changes in irrigation management and/or method may also be necessary. If there is an underlying aquifer that is shallow < 6 m (< 20 ft) or used locally as a public drinking water source, increase the risk to very high.
16	This field has a very high risk for N leaching and management changes are needed to decrease risk. Manure applications are not recommended. Apply N using split in-season applications at or below the agronomic rate. Changes in irrigation management and/or method are necessary to protect ground water.Implement all appropriate best management practices.

Table 2.9. Net scores of nitrogen (N) leaching assessment using Colorado N leaching index risk assessment (Sharkoff et al., 2006) on low, medium and high management zones after three repeated manure applications under furrow irrigated conditions. Index scores were the same for the 22, 44, and 67 $Mg\ ha^{-1}$ manure application rates.

Factor	Management Zone		
	Low	Medium	High
1. Permeability Class	1	1	1
2. Irrigation application efficiency	3	3	3
3b.Manure/Effluent Application rate	4	4	4
4. Nitrogen Application Timing	2	2	2
Gross score (Sum of factors 1 to 4)	**10**	**10**	**10**
5. Best Management Practices (BMP's) Implementation Credits	0	0	0
†Net score	**10**	**10**	**10**

†Net score is the sum of risk assessment factors 1 through 4 less factor 5, credit for implementation of BMP.
Scores of 1, 2, 3 or 4 indicates that a risk assessment factor is either low (1), medium (2), high (3) or very high (4).

Table 2.10. Net scores of phosphorus (P) runoff risk assessment using Colorado P runoff index risk assessment (Sharkoff et al., 2008) on low, medium and high management zone after three repeated manure applications of 22, 44, and 67 Mg ha^{-1} under furrow irrigated conditions.

Factor	Manure rates and management zone								
	22 Mg ha^{-1}			44 Mg ha^{-1}			67 Mg ha^{-1}		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
1. Runoff Class (Irrigated sites only)	2	2	2	2	2	2	2	2	2
2. Soil Test P	1	1	2	1	1	1	2	2	1
3. P application rate Annually applied or Rotational average (kg P_2O_5/acre/year)	4	4	4	4	4	4	4	4	4
4. P application method Use highest applicable Risk category for Multiple P applications	2	2	2	2	2	2	2	2	2
Gross score (Sum of factors 1 to 4)	**9**	**9**	**10**	**9**	**9**	**9**	**10**	**10**	**9**
5. Best Management Practices (BMP's) Mitigation factor credits	0	0	0	0	0	0	0	0	0
†Net score	**9**	**9**	**10**	**9**	**9**	**9**	**10**	**10**	**9**

†Net score is the sum of risk assessment factors 1 through 4 less factor 5, credit for implementation of BMP.
Scores of 1, 2, 3 or 4 indicates that a risk assessment factor is either low (1), medium (2), high (3) or very high (4).

CHAPTER 3: PRECISION MANURE MANAGEMENT ON SITE-SPECIFIC MANAGEMENT ZONES: NITROGEN MINERALIZATION

INTRODUCTION

Precision manure management and site-specific management zones

Precision or site-specific nutrient management across spatially variable soils in a field has been practiced for the past two decades. Precision nutrient management refers to variable rate application of nutrients, i.e. right amount of nutrients applied at the right place across a field. This concept of precision nutrient management has been widely employed for the management of nutrients, especially nitrogen (N). It was until recently when researchers in the state of Colorado merged the concept of precision nutrient manure with best manure management practices on field studies; hence, the concept of precision manure management was born. Precision manure management is relatively new (Moshia et al., 2008) and builds upon the concept of managing spatial variability in farm-fields with added potential for enhancing soil quality over time. Although not widely reported in literature, the concept of precision manure management is logical and more practical when coupled with site-specific management zones.

Site-specific management zones (MZs) are sub-regions in a field that express a homogeneous combination of yield limiting factors (Doerge, 1999), and these yield limiting factors can be managed uniformly within each zone (Khosla et al., 2002). Earlier studies reported that the use of MZs in managing field inputs such as N is productive, profitable and environmentally beneficial (Koch et al., 2004; Clay et al., 1998; Swinton and Lowenberg-DeBoer, 1998; Khosla et al., 2002).

Nitrogen mineralization and site-specific management zones

The success of precision manure management depends upon a number of factors, among them being the mineralization rate of nutrients such as N, present in animal manure. Hence, understanding the rate of mineralization for N present in animal manure when applied variably across MZs would be of great value. Understanding the mineralization rate of N across MZs can decrease the potential for ground water contamination via leaching of Nitrate-N (NO_3-N).

Factors influencing N mineralization

Quantification of N mineralized in animal manure could result in efficient and safe utilization of manure as a N source. Mineralization of organic N by microbial decomposition can be difficult to accurately predict when making nutrient recommendations due to the fact that many environmental and management factors affect the rate of N mineralization (Waskom, 1997). The type of manure added to the soil, residual N content of the soil, environmental conditions, and crop and soil management influence the rate of N mineralization (Snapp and Borden, 2005). The quality of animal manure applied is also known to play a key role in controlling the rate of N release (Swift et al., 1979). Additionally, Bechtold and Naiman (2006), Rice and Havlin (1994); and Nahm, (2005) reported that the rate of N mineralization is influenced primarily by the substrate quality, moisture, soil pH, C: N ratio, animal species, temperature, accessibility of organic N to soil microorganisms, and soil particle size.

Schjönning et al. (1999) and Gordillo and Cabrera (1997) confirmed that soil characteristics greatly influence N mineralization rate. Hadas et al. (1983) studied the effect of temperature and soil type on mineral N release from animal manure under controlled environment. The study revealed no significant ($P<0.05$) differences between clay and sandy soils at 25°C, but the authors had no plausible explanation for the results. Previous studies reported that net mineralization of soil organic matter is more rapid in sandy soils than in clay soils (Catroux et al., 1987; Ladd et al., 1990; Hassink et al., 1990; Verberne et al. 1990). Verberne et al. (1990) found that the lower net mineralization in clay soils is assumed to be caused by greater physical protection of soil organic matter and microbial biomass.

Mzuku et al. (2005), in a study on spatial variability of soil properties across MZs, reported that soil texture varied significantly across management zones. The study further reported that the percentage of sand particles increased from the high to low management zones while the percentage of clay particles increased from low to high management zones. Soil texture influences water holding capacity, and soil water content was reported to increase from low to high management zones (Mulla and Bhatti, 1997). Soil texture directly affects soil electrical conductivity (EC) which is one of the key soil properties considered when delineating productivity level management zones (Franzen and Kitchen, 1999).

Nitrogen mineralization and carbon dioxide evolution

Nitrogen mineralization is the conversion of organic N into plant available inorganic N such as ammonium-N (NH_4-N) and NO_3-N. Ammonium-N and NO_3-N are a form of N that plants can absorb, but organic N cannot be used directly by plants (Barbarick, 2006). Nitrogen mineralization and immobilization are important processes in the N cycle (Cabrera et al., 2005). Nitrogen mineralization and immobilization occur simultaneously in soils, with the relative magnitudes determining whether the overall effect is net N mineralization or net N immobilization (Alexander, 1977).

Animal manure with high carbon (C) to N ratios are generally associated with relatively slow N release rates, due to N immobilization and limited soluble carbon to support microbial activity (Trinsoutrot et al., 2000). Under aerobic conditions, microorganisms feed on organic matter and in the process use N and other nutrients (Jezile, 2006). Carbon dioxide evolution from soil originates mainly from soil microbial activities and respiration. Rate of CO_2 evolution from soil has been reported as a common and reliable measure of microbial activity, substrate decomposition and metabolic status in soils (Witkamp, 1966). Inorganic N released from manure, or any organic material in soil, is a result of microbial decomposition and turnover of C and N by soil microbial biomass (Hadas et al., 1996).

Nitrogen mineralization and N fertilizer

Nitrogen contained in animal manure has potential as a valuable fertilizer, but due to environmental constraints, it may also be a factor that limits its use on agricultural lands (Barbarika et al., 1985). Delgado et al. (2005) reported that, although N is an essential nutrient that is a key component of intensive agricultural systems, its management to maximize yields and reduce losses to the environment is difficult. Binder et al. (1996) emphasized the importance of synchronizing manure N mineralization with crop use. Also, environmental loss of N can occur when the supply by animal manure and other sources exceeds crop demand. There is a challenge related to the use of animal manure as N fertilizer and a need to understand the dynamics of N mineralization. Previous laboratory studies have investigated N mineralization from applied animal manure (Castellanos and Pratt, 1981; Chae and Tabatabai, 1986; Bonde and Lindberg, 1988; Cabrera et al., 1993). However, there are no known published sources that reported the investigation of the N mineralization of variable rate applications of dairy cattle manure on MZs. We hypothesized that variable rate applications of animal manure would mineralize differently between and across MZs.

Objective

The objective of this study was to evaluate and compare the N mineralization of variable rates of dairy cattle manure applied on soils collected from low and high management zones in a controlled environment.

MATERIALS AND METHODS

The soil used in this study was classified as fine-loamy, mixed, mesic Aridic Haplustalf (Soil Survey Staff, 1999), sampled from a continuous maize (*Zea mays* L.) field near Fort Collins in northeastern Colorado. The field had no prior history of manure application. Soils were sampled from 0-15 cm depth. The 0-15 cm sampling depth was the depth at which farmers normally incorporate manure after application to a maize field.

The field was previously classified into site-specific management zones of high, medium and low productivity using the technique described by Fleming *et al.* (2000) and Hornung *et al.* (2006). Soils of each of the three management zones were sampled with a JMC Backsaver probe (Clements Assoc., Newton, IA). Soils were air-dried at room temperature and subsequently passed through a 2-mm sieve. Homogenized fraction of the sieved soils was sent to a commercial laboratory (Harris Lab., Lincoln, NE) for the analysis of soil particle size, organic matter, pH, total C, total N, NH_4-N, and NO_3-N (Table 3.1).

Dairy cattle manure was sampled from the manure pile to be used in a precision manure management study (Moshia et al., 2008) and thoroughly mixed after sampling. A portion was sub-sampled and sent to a commercial laboratory (Colorado Analytical Lab., Brighton, CO) for the analysis of pH, EC, total C, total N, NH_4-N, NO_3-N, water content and ash content in manure (Table 3.2). In the laboratory, manure samples were stored in a refrigerator to maintain moisture content and inhibit further microbial activities prior to analysis.

Laboratory procedures

A 120 day laboratory incubation study was conducted at Colorado State University's Natural Resource Ecology Laboratory.

Carbon dioxide evolution

Hundred-gram portions of soil were placed into plastic specimen cups (10 cm tall x 10 cm diameter). Dairy cattle manure was added to soils at rates of 0, 1.12, 2.24, 3.41, and 6.82 g, which was equivalent to field applications of 0, 22, 44, 67, and 134 Mg ha^{-1} (0, 10, 20, 30 and 60 T/A respectively), assuming that 1 ha weighs 2 x 10^6 kg of soil in the 15 cm surface layer.

Manure treatments were mixed with soils before moistening with deionized water. The soil water content was adjusted to 75 % field capacity with addition of deionized water at the beginning of the laboratory incubation study. Field capacity corresponded to gravimetric water contents of the soils in each management zone.

Each specimen cup containing soil-manure mixtures was placed in a 1 liter (0.93 liter volume space) wide mouth mason jar containing 20 ml of water. The 20 ml of water in the jars was for minimizing the loss of moisture from the soil-manure mixture in the plastic specimen cups. Mason jar lids were fitted with rubber septa to allow headspace sampling. The mixtures were incubated at 25 ± 1 °C in the darkroom for 120 days.

Headspace CO_2 was sampled from the mason jars using series A-2 Pressure-Lok® precision analytical syringe (VICI Precision Sampling Inc., Baton Rouge, LA, USA). An analysis of sampled CO_2 concentration was performed using LI-COR IRGA (infrared gas analyzer), Model LI-6252 CO_2 Analyzer (model LI-6252, LICOR, Lincoln, NE). After each sampling, the incubation jars were aerated for 10 minutes. Carbon dioxide evolved was determined at 0, 1, 2, 4, 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91, 98, 105, 112, and 120 days after amendment.

The weight of the cups was monitored weekly to ensure constant water content of the soil-manure mixture during the incubation period. The water content of the soil-manure mixture was adjusted by weighing the samples and dropwise addition of the required amount of deionized water when the loss was greater than 0.05 g.

Nitrogen mineralization

For N mineralized, a separate set of replicated samples for each treatment per management zone was sacrificed after 0, 5, 10, 15, 30, 45, 60, 90 and 120 days of laboratory incubation. Soil samples of 50 g were extracted with 250 ml 2 M KCl after 30 minutes of shaking time. Extracts were filtered through Whatman® 40 filter papers and stored in a freezer to prevent further microbial processes until use for analyses. After all extractions were completed, samples were thawed, and concentrations of NH_4-N and

NO_3-N in the extract were determined by continuous flow injection colorimetry using an AutoAnalyzer. All inorganic N concentrations were expressed on an oven-dry basis.

Mineralization rates in the incubated soils were determined as discussed by Kaboneka et al. 1997 and Jezile (2006). Net N mineralization was calculated as the difference between soil inorganic N (NH_4-N + NO_3-N) in amended and unamended soils.

(a) $\text{Net } N_m = N_{m \text{ amended soil}} - N_{m \text{ unamended soil}}$ (1)

where N_m = N mineralization (mg N kg^{-1} soil)

(b) The percent N mineralization was calculated as follows:

$\% \text{ N mineralization} = [(X\text{-}Y) / Z] \times 100$ (2)

where: X = mg of N mineralized from amended soil, Y= mg of N mineralized from unamended soil and Z = mg of N added in animal manure amendments.

Experimental design and data analysis

The incubation experiment was designed as a two factor (management zones and animal manure) factorial. Four manure treatments of 22, 44, 67, and 134 Mg ha^{-1} were replicated three times on each management zone of low, medium and high productivity. The statistical data analysis was performed using PROG GLM procedure in SAS (SAS Institute, 2005). Treatment means were compared using least significant difference ($P \leq 0.05$) (Steel et al., 1997), and curve fitting was performed with Microsoft Excel 2003 (Redmond, WA).

RESULTS AND DISCUSSION

Nitrogen mineralization and management zones

A significant difference ($P \leq 0.05$) in mineralized N across MZs was found across manure rates. (Table 3.3). The regression curves of the net inorganic N (NO_3-N + NH_4-N) shows that N mineralization increase with manure rate and incubation time (Fig. 3.1). The fundamental significance of Fig. 3.1 is that, as incubation time increased, the total inorganic N mineralization increased significantly across low, medium and high MZs.

The high, medium and low MZ N mineralization rates were compared and there was no significant difference in cumulative N mineralized between MZs over time (Fig 3.2). (Table 3.1). The lack of statistical difference in mineralized inorganic N between MZs is hypothesized to have been influenced by the lack of substantial difference in soil particle sizes (only 6% clay difference between MZs) and pH (Table 3.1). Watts et al. (2007) studied the difference in N mineralization rate of dairy manure amended soils collected from an on-going precision agriculture project. The study revealed no significant difference on soils that had similar amounts of clay content and pH, but a wide difference in sand content. Our study findings agree with the results reported by Watts et al. (2007). Based on the results of this study it is sufficient to say that there was no difference in N mineralized between low, medium, and high management zones (Fig. 3.2). Verberne et al. (1990) and Jastrow (1996) reported that in soils with high amounts of aggregates, the clay-sized particles are bound around organic material, thereby, protecting organic matter from decomposing. Watts (2007) added that it is only when soil aggregates are destroyed that the organic matter is exposed to microbial attack. However, these observations do not apply to our study since the addition of manure followed by immediate incubation would not influence aggregate stability or organic binding with clay.

While the aim of this study was not to compare percentage N mineralized with that of previous studies (Waskom, 1997), the percentage N mineralized for dairy animal manure was lower for northeastern Colorado soils (Marx, 2008) (Table 3.4). The reason for lower mineralized inorganic N on across zones on all treatments (Table 3.4) was thought to be due to the high respiration rate as measured through CO_2 evolution (Fig 3.3). Franzluebbers (1999) reported that substantial N immobilization is likely to occur due to very high respiration rates during mineralization. Mineralized inorganic N was lower at initial mineralization stage followed by a gradual increase in mineralized N after day 15 (Fig 3.2). Koelsch (2005) reported that when applied to soils, manure increases the energy or food supply available to the soil microbial population. This energy supply stimulates soil microbial activity, which consumes more available N than the mineralization processes release. Thus, high microbial activity during initial manure mineralization from day 1 to 15 could have caused a reduced rate of release of available inorganic N. When the microbial populations reached a steady state (after 15 days as indicated by leveling off of CO_2 production, Fig. 3.3) the available inorganic N slowly increases (Fig. 3.2). The mineralized N can be a useful parameter for determining the potential impact of applied animal manure across and within MZs, and for estimating the N-supplying capacities of soils.

Carbon dioxide evolution and N mineralization

The dairy animal manure used in the incubation study had a water content of 604.2 mg kg^{-1} (Table 3.2), pH of 7.25, NH_4-N content of 1171 mg kg^{-1}, NO_3-N content was 22.3 mg kg^{-1}, and a total N content of 9.8 g kg^{-1}. The C/N ratio of the dairy animal manure was 21:1, suggesting that rapid mineralization of added organic N would be expected (Bitzer and Sims, 1988). Carbon dioxide evolution in manure amended soils increased more rapidly from time 0 to 14 and decreased steadily after peaking at 21 days (Fig 3.4), depending on manure rate.

The CO_2 evolution of all dairy manure treatments reached a peak at day 14 on low zone, and day 21 on high and medium zones. Only the 22 and 44 Mg ha^{-1} treatments reached a peak CO_2 evolution at day 14 while manure treatments of 66 and 134 Mg ha^{-1} reached a peak at day 21. After reaching the peak, CO_2 evolution started to decrease (Fig. 3.3; 3.4). The decrease in CO_2 evolution denotes dying of microbes and as the microbes die, the level of inorganic N increases. Fig 3.1 and 3.2 shows clearly that after day 14, the inorganic N accumulation curve increased nonlinearly.

The high rate of microbial activity is shown by the rate of CO_2 evolution during a 120 day laboratory incubation study (Fig. 3.5). At the end of the study, cumulative CO_2 evolution on our study reported low levels of accumulated inorganic N per weight of added manure treatments. Calderon et al. (2004) proposed measuring the N (N_2 and N_2O) lost through denitrification, which was not possible in our study. Despite the fact that NH_4-N was the dominant form of inorganic N in the dairy manure used in the study (Table 3.2), NO_3-N was the dominant form of N in the soil when inorganic N was measured throughout the incubation period. The results of NO_3-N as a dominating form of inorganic N suggest that NH_4-N was nitrified and some NO_3-N was also released from dying microbes.

CONCLUSIONS

The objective of this study was to evaluate and compare the N mineralization of variable rates of dairy cattle manure applied on soils collected from low, medium, and high MZs, in a controlled environment. The lack of clearly pronounced differences in soil pH and particles size between MZs is hypothesized to be the main factor that resulted in no statistical difference of mineralized inorganic N over time between MZs. That being the case, a study involving spatially variable soils with significantly different soil particle size between MZs may result in a different conclusion based on our original hypothesis. Our major concern with higher manure rates such as 67 and 134 Mg ha^{-1} on the low productivity management zone at a field level is the potential environmental pollution associated with such high rates of manure application. An agronomically and environmentally sound compromise must be made when determining manure application rates. Our rates may not supply the needed N to the plant while high rates can result in buildup of NO_3-N that will be subjected to leaching. The key is determining proper manure rates. This can be done by using accepted manure and soil testing procedures. The results of the study support the hypothesis that variable rates of manure mineralize differently within MZs, however, the results do not support the hypothesis that variable rates of manure in soil may mineralize differently across MZs.

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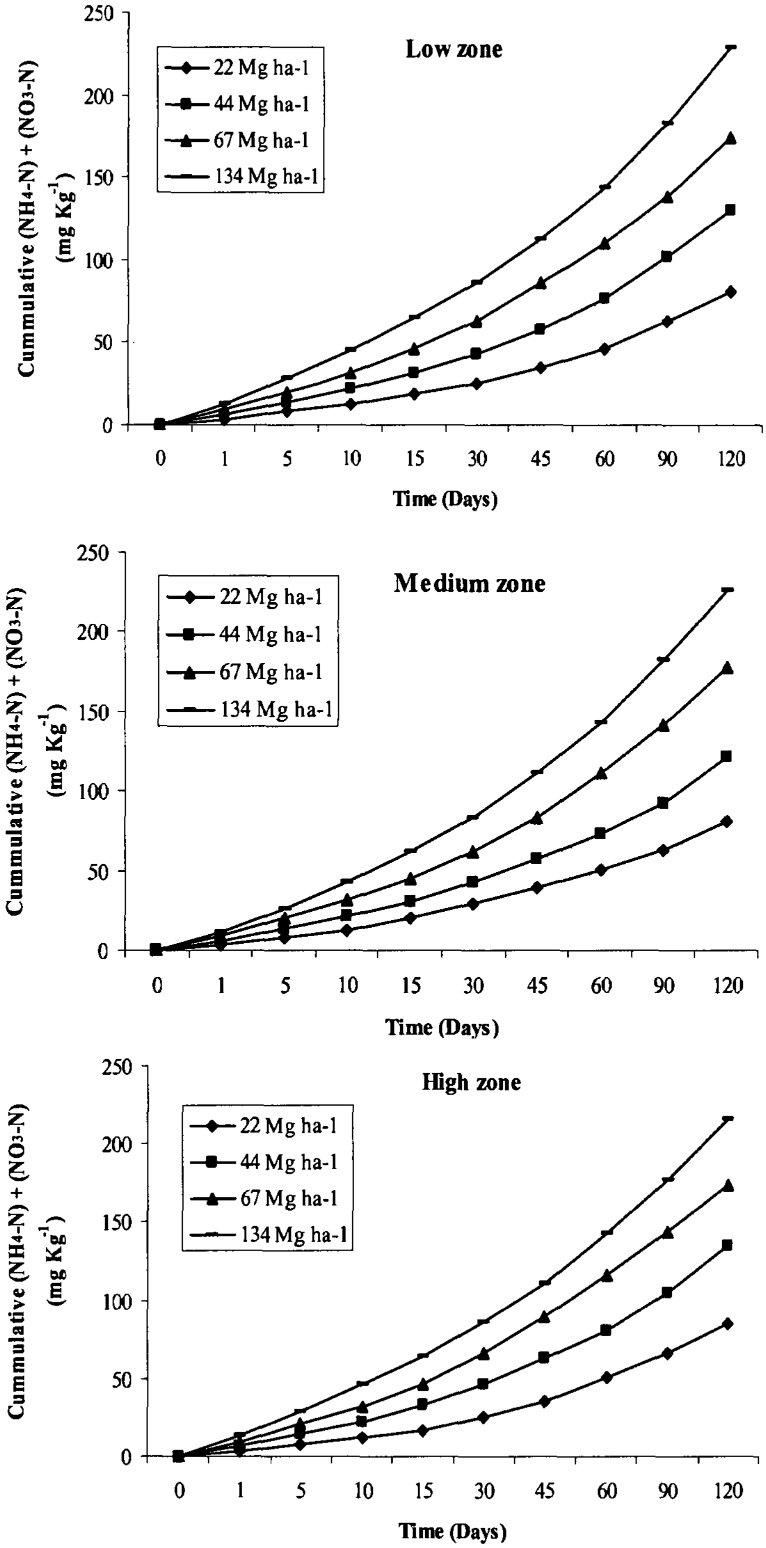

Fig. 3.1. Regression cumulative inorganic nitrogen (NH_4-N + NO_3-N) mineralized during a 120 days laboratory incubation study on low, medium, and high management zones manured with 22, 44, 67 and 134 Mg ha^{-1} of dairy animal manure.

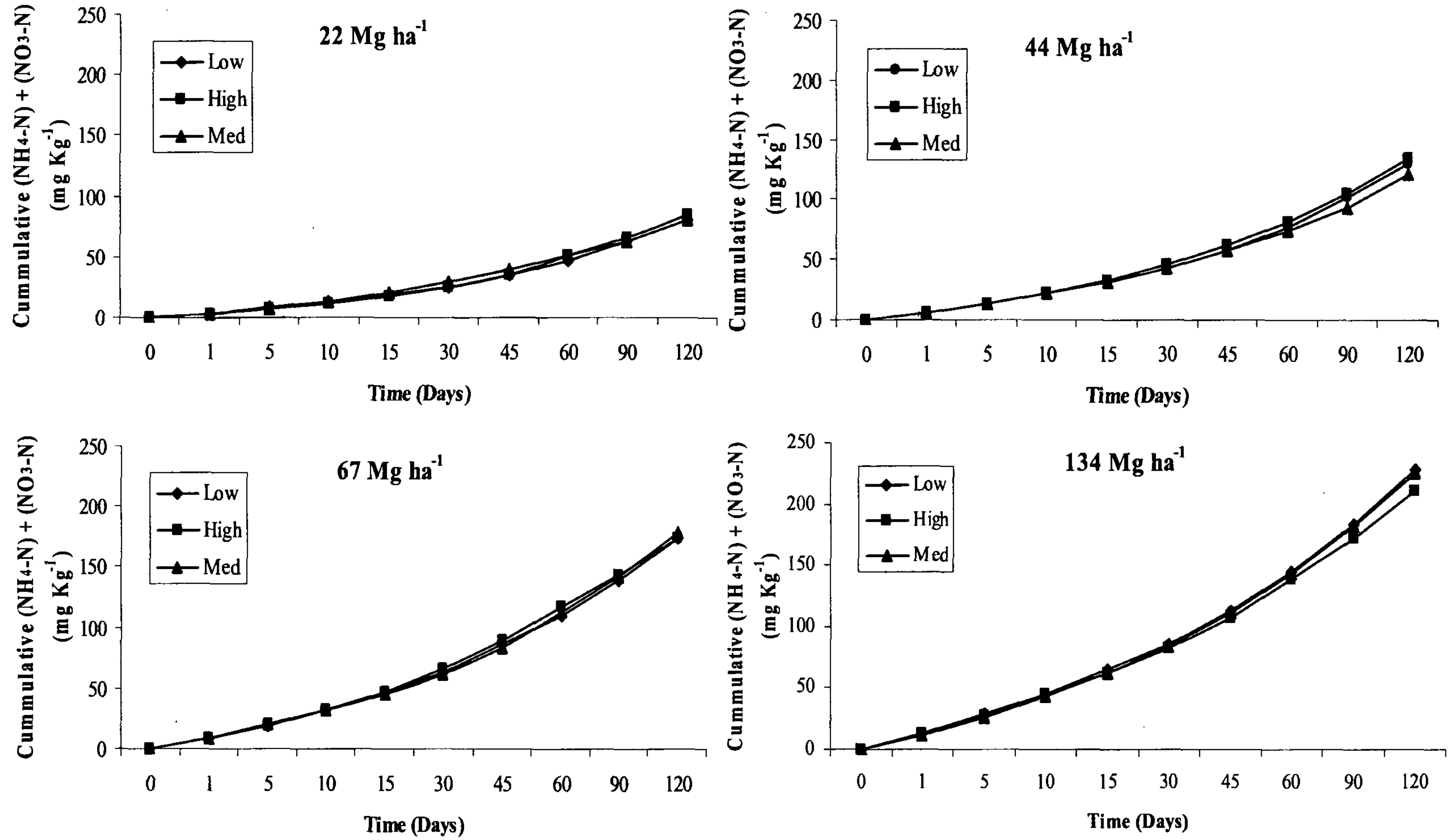

Fig. 3.2. Regression curve of cumulative inorganic N (NH_4-N + NO_3-N) mineralized during a 120 days laboratory incubation study on low and high management zones manured with 22, 44, 67 and 134 Mg ha^{-1} of dairy manure.

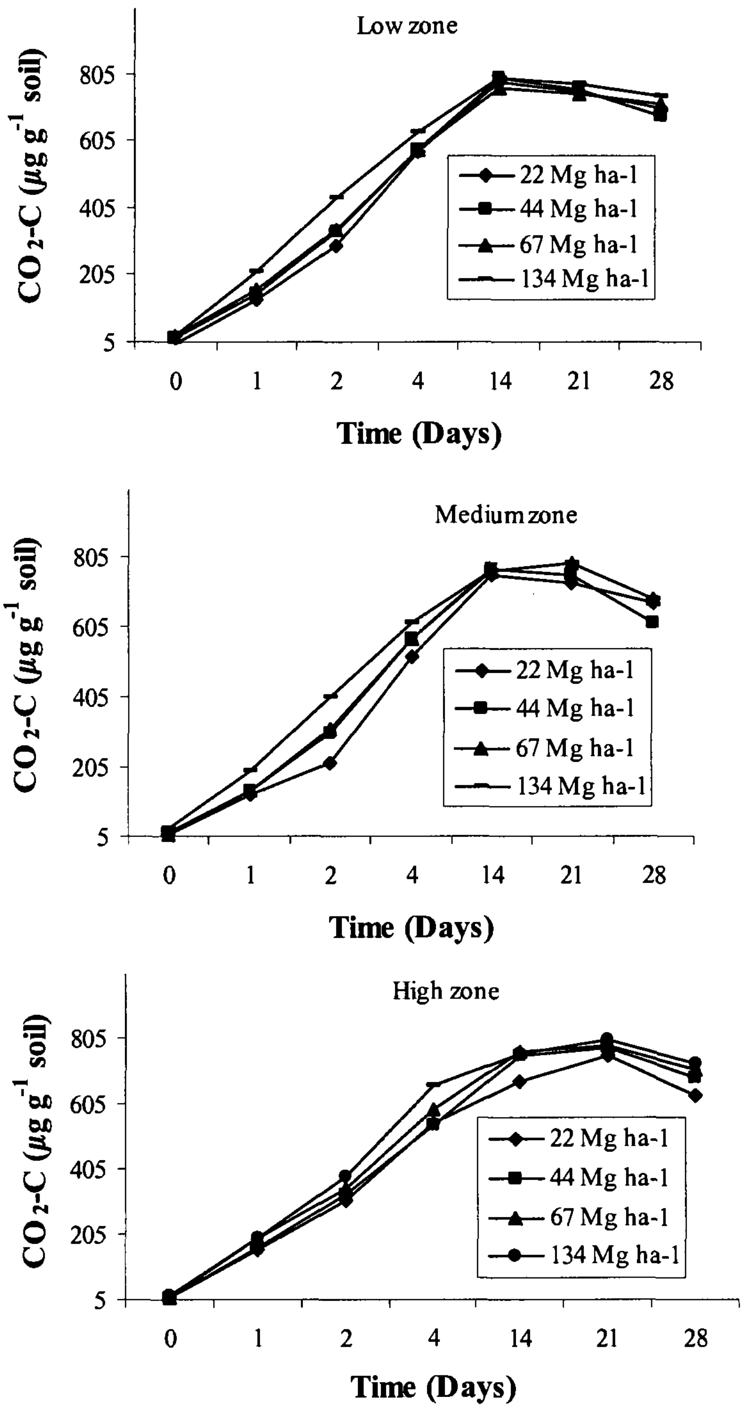

Fig. 3.3. A 28 day snapshot of carbon dioxide (CO_2) evolved from 22, 44, 67, and 134 Mg ha^{-1} of dairy manure on low, medium and high management zones respectively during a 120 days laboratory incubation study.

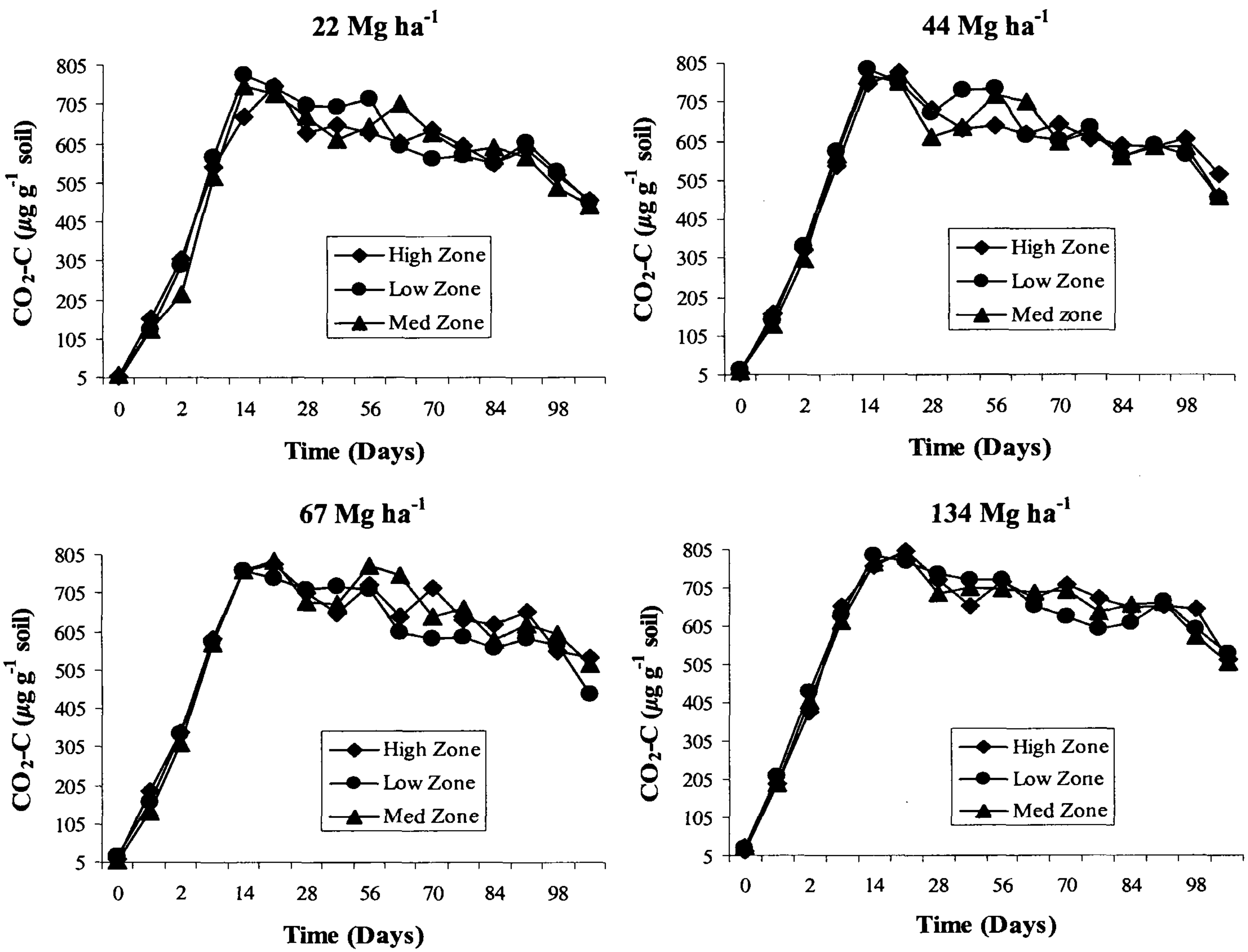

Fig. 3.4. Carbon dioxide evolved during a 120 days laboratory incubation study on low, medium and high management zones manured with 22, 44, 67 and 134 Mg ha^{-1} of dairy manure.

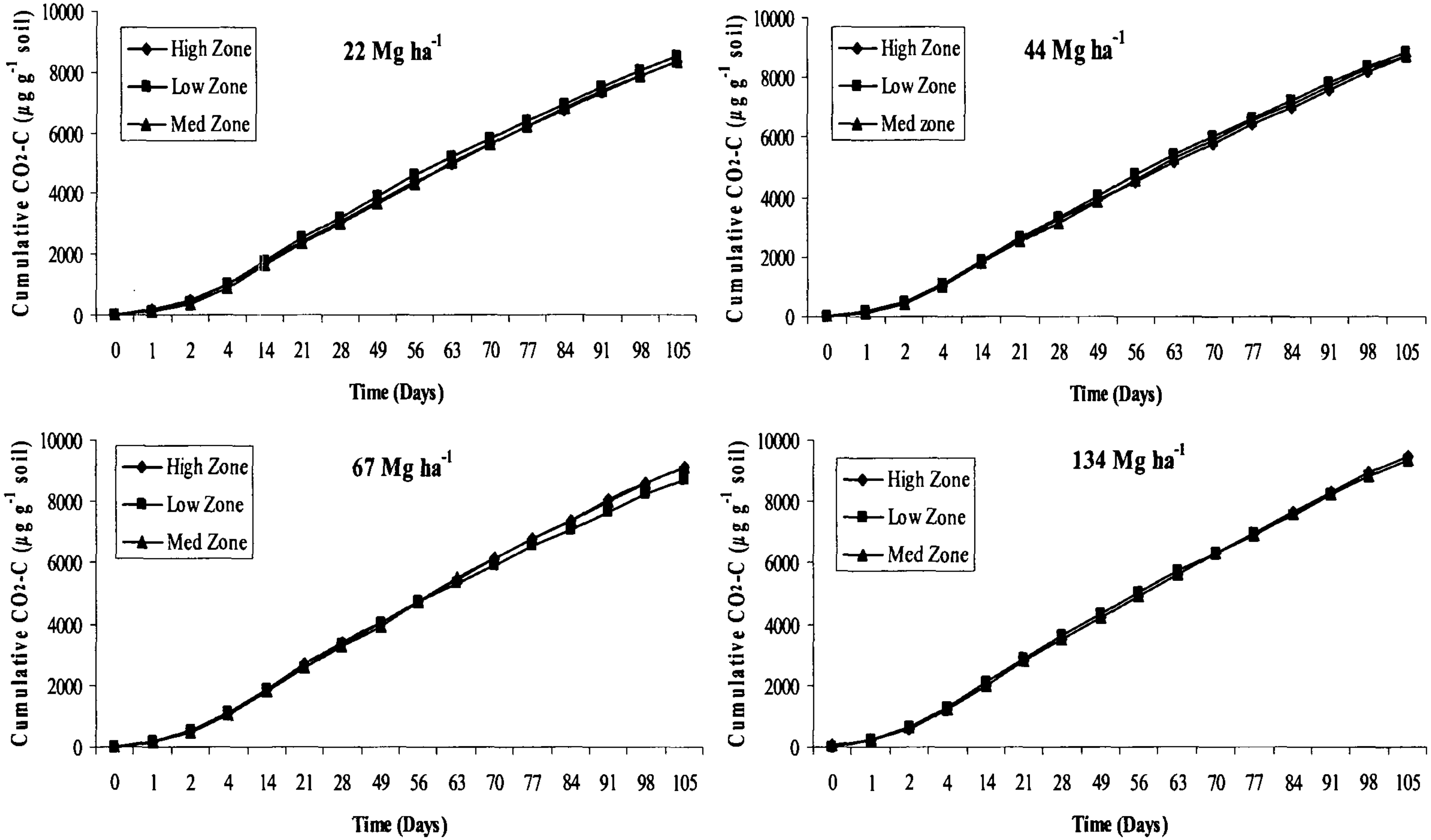

Fig 3.5. Regression curve of cumulative carbon dioxide (CO_2) evolved during a 120 days laboratory incubation study on low, medium and high management zones manured with 22, 44, 67 and 134 Mg ha^{-1} of dairy manure.

Table 3.1. Selected pre-study topsoil properties sampled on management zones at 0-15 cm sampling depths

Management	Sand	Clay	Soil textural Class	OM†	EC‡	pH	Total C	Total N	NH_4-N	NO_3-N
Zones	— g kg^{-1} —			g kg^{-1}	dS m^{-1}		—— g kg^{-1} ——		—— mg kg^{-1} ——	
High	472	364	Clay Loam	18	0.8	7.8	15.6	1.12	7.6	27.5
Medium	532	304	Sandy Clay Loam	16	0.9	7.8	18.2	0.54	5.3	15.1
Low	452	304	Sandy Clay Loam	15	1.0	7.8	19.6	0.78	4.7	15.2

†OM=Soil organic matter, ‡ EC = Electrical Conductivity

Table 3.2. Selected characteristics of dairy cattle manure (DCM) used in for laboratory incubation study. Nutrients, organic matter and ash contents are on a dry weight basis.

Year and Source	Total N	Total P	Organic Matter	Ash	Water Content	NO_3-N	NH_4-N	EC†	pH†	C/N ratio
	g kg^{-1}					mg kg^{-1}		d S m^{-1}		
DCM	9.80	2.47	392.0	608.0	604.2	22.3	1171	4.75	7.25	21

†Electrical conductivity (EC) and pH were determined on 5:1 water to dry manure ratio.

Table 3.3. Least square mean comparisons of N mineralized on 22, 44, 67 and 134 Mg ha^{-1} of dairy manure treatments on low, medium and high management zones ($P \leq 0.05$).

		Low Zone		
Treatments	22 Mg ha^{-1}	44 Mg ha^{-1}	67 Mg ha^{-1}	134 Mg ha^{-1}
22 Mg ha^{-1}	NS	0.0043	<.0001	<.0001
44 Mg ha^{-1}	–	NS	0.0144	<.0001
67 Mg ha^{-1}	–	–	NS	0.0018
134 Mg ha^{-1}	–	–	–	NS
		Medium Zone		
Treatments	22 Mg ha^{-1}	44 Mg ha^{-1}	67 Mg ha^{-1}	134 Mg ha^{-1}
22 Mg ha^{-1}	NS	0.0399	<.0001	<.0001
44 Mg ha^{-1}	–	NS	0.0020	<.0001
67 Mg ha^{-1}	–	–	NS	0.0114
134 Mg ha^{-1}	–	–	–	NS
		High Zone		
Treatments	22 Mg ha^{-1}	44 Mg ha^{-1}	67 Mg ha^{-1}	134 Mg ha^{-1}
22 Mg ha^{-1}	NS	<.0001	<.0001	<.0001
44 Mg ha^{-1}	–	NS	0.0006	<.0001
67 Mg ha^{-1}	–	–	NS	0.0003
134 Mg ha^{-1}	–	–	–	NS

Table 3.4. Total and percentage mineralized nitrogen (N) in laboratory incubation study on low, medium and high management zones manured with 22, 44, 67 and 134 Mg ha^{-1} of dairy manure.

	Low zone		Medium		High zone	
Treatment	Total min. N	N mineralized	Total min. N	%N mineralized	Total min. N	%N mineralized
–Mg ha^{-1}–	mg kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	%
22	80.4a	24.2	80.96a	24.3	85.3a	21.7
44	130.5b	26.2	121.23b	24.2	134.6b	24.9
67	174.3c	25.5	178.43c	24.8	173.0c	23.5
134	228.8d	26.7	226.23d	22.9	211.2d	22.5

APPENDIX

CO_2 Analysis by IRGA (infrared Gas Analyzer)

1. Change Magnesium percholrate, Mg $(CLO_4)_2$ on back of IRGA after every 300 samples.
   - Pull off part of right tube containing Mg $(CLO_4)_2$, pour it into the hazardous waste container.
   - repack: piece of glass wool in 1 end (roll up), add Mg $(CLO_4)_2$ with funnel, and put another piece of glass wool in other end, put back into machine.
2. Septa on IRGA and standard gas tank need to be changed every day before sampling
   - septa (blue) throw it away; put in new one with pen cap (flat end)
   - stop screwing piece back in when septa starts to flex
3. Open air valve on IRGA
4. Prep standard gas tank
   - Open valve on the top of the tank and the one on the front LEFT
   - Plug needle in and let gas out for 20 – 30 seconds (only needle, no tube)
5. Press 2 on IRGA to bring up the figure on the screen (takes about 10 minutes)
6. Turn on computer and type "comm."
7. Press F3 on computer (local echo)
8. Set values of $\Delta C2$ μm/m value around 0.3/0.4 by using zero dial on left of IRGA
9. Press Alt-U on computer
10. Press L, then Enter

    repeat step 9 and 10 for every sample

    **INT value should be 400/ml, so 2ml ≈ 800, and 4ml ≈ 1600

Standard Curve

1. take about 2 ml of gas from tank (1040 CO_2) into syringe and flush out
2. Take out about 4 ml of gas, close stopcock b/f pulling needle out
3. Compress gas to 2 ml and inject into IRGA QUICKLY
4. Read INT value on IRGA and record
5. Repeat ALT-U and enter after top number is below one
6. Pump air in and out of syringe after each sample to flush
7. Repeat step 1 – 6, injecting 4, 6, 8 and 10 ml of standard gas

Sample Analysis:

1. Use 60 ml syringe and pump up and down 5 times to mix inside of jars b/f sampling
2. Take gas samples from jars using steps as for standard sample above

   **make sure to flush syringe with lab air 4/5 times before inserting into next sample

   **close top-cock on syringe b/f removing needle from jar septa

Exit:

1. Press Alt-X
2. Turn of monitor of computer and IRGA off
3. Close air valve

Sample #	Milliliters of GAS	Liters of GAS	Moles of GAS	μmoles of CO_2 injected	IRGA readings	Correlations	Slope	Intercept	μmoles CO2/jar	μg CO_2-C/jar	ppm CO_2	Soil (g)	μg CO_2-C/g OD soil
A	B	C	D	E	F	G	H	I	J	K	L	M	N
A	Standards 2,4,6,8,10 Samples Vary	B/1000	PV = nRT	**Standards** D*1040 **Samples** Slope*F* intercept	F	x-values (F) y-values (E) **Standards**	x-values (E) y-values (F) **Standards**	x-values (E) y-values (F)	$\frac{E*0.93\ell}{C}$	J*12	E/D	100	K/M

R = Universal gas constant (0.0831 ℓ□bar□K^{-1}□mol^{-1})
T = Temperature (293 K = 25°C)
V = Volume of gas (ℓ)
P = Pressure (0.843 bar)
n = No. of moles
1040 ppm (gas concentration for standards