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Introduction

With human population projection estimates pointing to nine billion by year 2050, the importance of maintaining Earth's basic ecosystem services has quickly become increasingly important. Supporting this expanding population with enough food, fiber, and fuel has intensified demands on agricultural land and other natural resources (Haile-Mariam et al., 2008). Intensive agriculture, coupled with an increase in nitrogen (N) fertilizer use, has contributed significantly to the elevation of atmospheric greenhouse gases (GHGs), including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)(Haile-Mariam et al., 2008). These three GHGs differ noticeably in their atmospheric concentrations, residence time in the atmosphere, and global warming potential (GWP) (Leibig et al., 2012). Of the three GHGs, N_2O is present in the lowest atmospheric concentrations but has the greatest GWP, at 298 times that of CO_2 (IPCC, 2007; NOAA, 2011).

The objective of this research is to characterize soil N_2O emissions following one irrigation event at full irrigation or deficit irrigation rates in a continuous corn, no-tillage (till) system under different N fertilization treatments (commercial N, cattle manure). Full irrigation is defined as the amount of water needed to meet 100% of a plant's water needs, and the deficit irrigation rate used here represents 60% of full irrigation. Employing best management practices (BMPs), as it pertains to agricultural irrigation levels, is important in assisting in the mitigation of the GHGs listed.

Importance of Conservation Tillage

Conservation tillage is tillage that reduces loss of soil or water relative to conventional tillage (Brady and Weil, 201). There are several types of conservation tillage methods, including minimum till, mulch till, ridge till, strip till, and no-till. The system being studied for this research is under a no-till management practice. This means that next years' corn crop is planted directly into a seedbed not tilled since harvest of the previous crop. The primary advantage that no-till has over conventional tillage is that it does not disturb the soil habitat and leaves anywhere from 50 to 100% of the soil surface covered with non-grain crop residues (Brady and Weil, 2010). Reduced soil disturbance results in far lower GHG emissions in comparison to conventional tillage. Due to the increasing awareness of the benefits that a no-till system provides, the amount of acres being managed as no-till, have expanded to nearly all regions of the United States and are now implemented in some form on almost half of all conservation tillage acres (Brady and Weil, 2010).

In contrast, conventional tillage is usually thought of as a tillage practice that encourages the turning of soil completely in order to prepare the seedbed, as well as a means for weed control (Brady and Weil, 2010). Conventional tillage disrupts the soil habitat by exposing previously protected soil organic matter to the atmosphere. This disturbance stimulates soil microbial activity (i.e. respiration) by increasing the availabilities of both oxygen and soil organic matter for microbial decomposition. Turning the soil also moves non-grain crop residue from the soil surface to underground, leaving the soil less protected from wind and water erosion. The increase in respiration by the soil microbes correlates to a direct increase in the amount of GHG's being emitted by that system.

Continuous Corn Systems

These study plots are also continuous corn systems, which in this region of the United States, holds high importance because of its embedded cultural traditions, as well as its impact on our local economy. Corn, here, is more than simply a crop to be grown, it is a way of life. The U.S. corn crop has recently been hovering around 13 billion bushels. The portion of this corn crop that is exported accounts for 55% of the world's corn exports, and is worth about $60 billion (Paasche, 2012). Out of the top ranking corn producers in the U.S., Nebraska ranks 3rd, at 11.5% of total production, behind only Illinois and Iowa (Moss, et al, 2011).

Corn is part of an integrated agricultural system that provides food, fiber, and fuel to all of the world's inhabitants. In fact, most corn goes to livestock for feed or is turned into ethanol (Paasche, 2012). The 2012 ethanol mandate, which set the benchmark for fuel production, is 13.2 billion gallons; this translates into about 4.5 billion bushels of corn (Paasche, 2012). In 2011, more corn went to ethanol than to feed (Rapp, 2012). Additionally, the rise in corn prices is a product of more than demand alone. Drought, brought on by the very climate change we wish to lessen, along with increasing foreign oil prices that affect fertilizer costs, have both contributed significantly to corn's rise in value (Jin, 2013).

Water's Role

Water is the most important factor affecting agricultural activities on the Great Plains. Most of the water used in the Great Plains comes from the High Plains Aquifer (sometimes referred to by the name of its largest formation, the Ogallala Aquifer), which stretches from South Dakota to Texas. This water is used by all people, for all reasons, in this region; it is the source of irrigation water for farmers and growers, drinking water for urban residents, and used for factory and mechanical processes. The aquifer holds both current recharge from precipitation and so-called “ancient” water, which is water trapped by silt and soil washed down from the Rocky Mountains during the last ice age.

As population increased in the Great Plains and irrigation became widespread, annual water withdrawals began to outpace natural recharge. Today, an average of 19 billion gallons of groundwater is pumped from the aquifer each day (Collins, 2008). This water irrigates 13 million acres of land and provides drinking water to over 80 percent of the region’s population. Since 1950, aquifer water levels have dropped an average of 13 feet in Nebraska, equivalent to a 9 percent decrease in aquifer storage. In heavily irrigated parts of Texas, Oklahoma, and Kansas, reductions are much larger, from 100 feet to over 250 feet (Collins, 2008).

The link between water and agriculture is strong-- one reason that irrigation levels are being studied as a part of this study. While most people recognize that the world is facing a future of water scarcity, not everyone has connected the dots and realized that this also means a future of food and grain shortages (Brown, 2008). Because of the world’s rapid population expansion, farmers are increasingly losing water rights to urban areas. Water is already so scarce in the southwest U.S. that huge and long-term water sales are already being conducted, shifting incomprehensible amounts of water from agriculture to cities. In 2003, San Diego bought annual rights to 200,000 acre-feet (over 65 billion gallons) of water from farmers in nearby Imperial Valley (Brown, 2008). This is the largest farm to city water transfer in U.S. history and covers the next 75 years. For context, one acre-foot of water supplies a family of 5 for one year, and irrigates about a half-acre of corn in most areas of Nebraska (UNL water center, 2011).

Agriculture's Link to Climate

This research is important because there is vast potential for soils to mitigate some greenhouse gas emissions by agriculture. Agricultural management can decrease soil emissions as well as maximize the storage of atmospheric CO_2 in crop biomass and eventually in soil organic matter (Johnson, et al, 2007). Climate change is a quantifiable certainty without diminished GHG emissions. Because of agriculture's significant role in GHG emissions, due to its immense worldwide land occupancy, implementing BMPs on agriculture has the potential to prevent thousands of tons of GHGs from ever entering the atmosphere (Johnson, et al, 2007). This is significant if we wish to alleviate future ills concerning human habitats and living conditions.

The agricultural sector is the largest anthropogenic source of N_2O in the U.S., accounting for 69% of the total N_2O emitted, and 92% of agricultural N_2O emissions is derived from soil management practices (Liebig, et al., 2012).

The American Society of Agriculture, Crop Science Society of America, and Soil Science Society of America's (ASA-CSSA-SSSA) Greenhouse Gas Working Group has provided five wide-ranging strategies for mitigating agricultural GHG emissions (Greenhouse Gas Working Group, 2010). Of the five, the improvement of N fertilizer use-efficiency was listed as one of the primary modes in which to reduce GHG emissions from a known source (Liebig, et al., 2012). This improvement of efficiency involves making N available to plants in the amount needed at the correct time to meet plant demand. This will successfully result in less reactive N available for potential conversion to N_2O.

In addition to the Greenhouse Gas Working Group's mitigation strategies, adaptation approaches were also offered. Of four vital recommendations, soil management and the implementation of efficient irrigation methods were two (Greenhouse Gas Working Group, 2010). The ability to deliver water to crops in space and time in precise doses with minimal loss is one way to increase water- and nutrient-use efficiency (Delgado et al., 2011).

The major N losses often occur during the first week after applying N fertilizer, and additional N losses can continue over the following three weeks (Inselbacher et al, 2011). Both nitrification and denitrification contribute to N_2O losses, with nitrification supplying NO_3^- to the soil, and denitrification, converting that same NO_3^- into N_2O (Inselbacher et al, 2011). Soil ammonium (NH_4^+) and nitrate (NO_3^-) are the products of mineralization and nitrification respectively, and both have been shown to influence nitrification and denitrification rates and N_2O emissions (Baggs and Blum, 2004).

Nitrous oxide emissions in agricultural settings vary widely across the landscape. Nitrification and denitrification are regulated by many soil factors, including soil texture, water content, soil temperature, aeration, the amount of soluble organic carbon (C), soil pH, and the communities of soil microbes present (Granli and Bockman, 1994). In some cases, N_2O fluxes may be more closely related to soil properties than to the N fertilizer sources applied (Haile-Mariam et al., 2008).

Though N_2O emissions are influenced by many variables, the soil microbial community controls an immense stake in the processes of soil N_2O emissions. According to

Inselbacher et al. (2011), soil microbes cannot be treated as a uniform pool in the soil. While N fertilization may influence all soil microbes, effects can vary between different groups of micro-organisms (Cavagnaro et al., 2008). Because of this, fertilizer induced changes in soil processes and GHG emissions are dependent on the activities of the soil microbial community (Inselbacher et al., 2011).

The objective of this research is to characterize soil N_2O emissions in relation to differing irrigation events. Because denitrification, the process responsible for converting NO_3^- into N_2O, is an anaerobic one, it is hypothesized that the treatments receiving 100% irrigation will exhibit greater N_2O emissions than the plots receiving 60% irrigation. It is also hypothesized that the test anchors receiving the recent manure application will have greater N_2O emission levels than the test anchors that received neither a fresh manure addition nor any manure at all.

Materials and Methods

Site Description and Experimental Design

The study site is located at the University of Nebraska-Lincoln's South Central Agricultural Laboratory (SCAL; Clay Center, NE). The site is managed as an irrigated, continuous corn production system, under no-till management. Experimental treatments include four different management practices: two irrigation levels (full or deficit); two N rates (125 or 200 kg N/ha); two crop residue removal treatments (no removal or maximum removal); and three practices for ameliorating residue removal (non-ameliorated control, winter cover crop, or manure addition) (Table 1). There were four replicates of these treatment combinations across the study site. Manure was applied as

23.8 metric tons/hectare (ha) of beef manure in October, 2012 (*personal communication,* V. Jin, 2013). This translated into roughly 300 kg/ha of total N, of which 25% was credited to the field as first-year mineralizable organic N (~75 kg/ha; Table 2). Only 25% is credited because this is the estimated amount of total applied organic N that soil microbes will break down into inorganic N, which is then plant-available.

This study focuses on a subset of the full experimental design and involves only the non-ameliorated control (n=16) and manure-amended plots (n=32) under the maximum residue removal treatment. Nitrous oxide measurements were taken from maximum residue removal plots in treatments fertilized at the two N rates. Within manure-amended plots, paired measurements were taken on soil areas newly applied with manure or on soil areas where manure had been applied two years prior to sampling.

Greenhouse Gas Sampling and Analysis

Nitrous oxide fluxes were measured and calculated using sampling designs and protocols standardized by the USDA-ARS's Greenhouse Reduction through Agricultural Carbon Enhancement Network (GRACEnet) (Parkin and Venterea, 2010). Gas measurements were taken with static vented chambers. These chambers consist of steam pans, approximately 18 inches x 13 inches, in two parts: a bottom and top half. The bottom half has the bottom cut out of it so that it can be inserted into the ground to define a uniform soil area for measuring soil N_2O emissions.. The top half is fashioned into a vented and insulated sampling lid, with a gasket lining the perimeter, and a sampling port for syringe collection of the gases emanating from the soil. The lid is clamped onto the anchor during sampling to ensure an airtight seal. Gas samples are collected using a stratified sampling design in which gases are sampled at 0, 10, 20, and 30 minutes following lid closure. Samples were collected on October 8, 9, 10, 12, 15 and 22nd of 2012. Concentrations of N_2O were measured using gas chromatography within 4 days of sample collection. Gas flux rates were calculated as concentration change over time within the closed chamber volume. Cumulative GHG emissions were estimated by linear interpolation of flux rates between sampling dates. This data was then entered into SAS, a statistical analysis program, to make multiple pairwise comparisons.

Results

Differences in irrigation levels did not significantly alter the amount of N_2O being released from the study site (Figure 1). Cumulative nitrous oxide emissions, however, tended to be higher under 100% irrigation levels compared to deficit irrigation levels. Though strong data was not found in the cumulative amount of N_2O being released between the two irrigation levels, the timing of the peak of flux varied between irrigation treatments. In both the 125 kg N/ha and 200 kg N/ha manure-amended treatments, which received manure on day one, N2O emissions at the 60% irrigation level peaked on day four, while the plots at the 100% irrigation level peaked on day five(see figures 2,3,4, and 5).

Discussion

The lack of significant differences between the two irrigation levels was unexpected. It was hypothesized that the increased irrigation level would translate into an increase in N_2O emissions, due to denitrification being an anoxic process. While there were slight trends showing that the increased irrigation did emit more N_2O, the strongest differences were seen between amelioration treatments. In the plots where manure was applied two years prior, there are still greater N_2O emissions than in the plots where manure was never applied (non-ameliorated controls). This suggests that the manure is still present and is continuing to mineralize, adding to the soil's total N pool.

The reasons for not finding significant differences between treatments could be many. One reason could be because we did not take gas samples on day three of the study. Perhaps fluxes were greatest on day three, but were simply missed, due to not being able to take samples that day. Another plausible reason for not finding differences is that statistics were not run on N-rates. Because we know that rates of N_2O are directly influenced by the amount of total N in the system, this is certainly something that could have been helpful to have data on. N_2O fluxes are very minute, compared to the CO_2 being emitted from the soil, so an additional reason significant findings might have been hard to find, is for the simple reason that differences between treatments are difficult to identify.

Future studies would be wise to look at N_2O rates over an entire year, to see if any long term trend differences between treatments begin to emerge.

The important thing to remember is that we have the technologies and intelligence needed to raise water use efficiency, and thusly, nitrogen use-efficiency. Combined, the effectiveness of more precise management practices concerning water and nitrogen, has the potential to prevent negative effects on water quality, soil health, and climate health.

Conclusion

More research is needed in order to make definitive conclusions about the differences in N_2O emissions observed between 100% irrigation levels and the 60% irrigation levels, in continuous corn, no till systems. Test plots receiving manure additions showed a delayed peak of N_2O emissions in the 100% irrigation plots, exhibiting both an irrigation level difference and a nitrogen rate treatment difference.

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Figure 1: Cumulative N_2O-N flux in g/ha/d in 60% and 100% irrigation levels, in plots under three different management programs and two different N treatment levels.

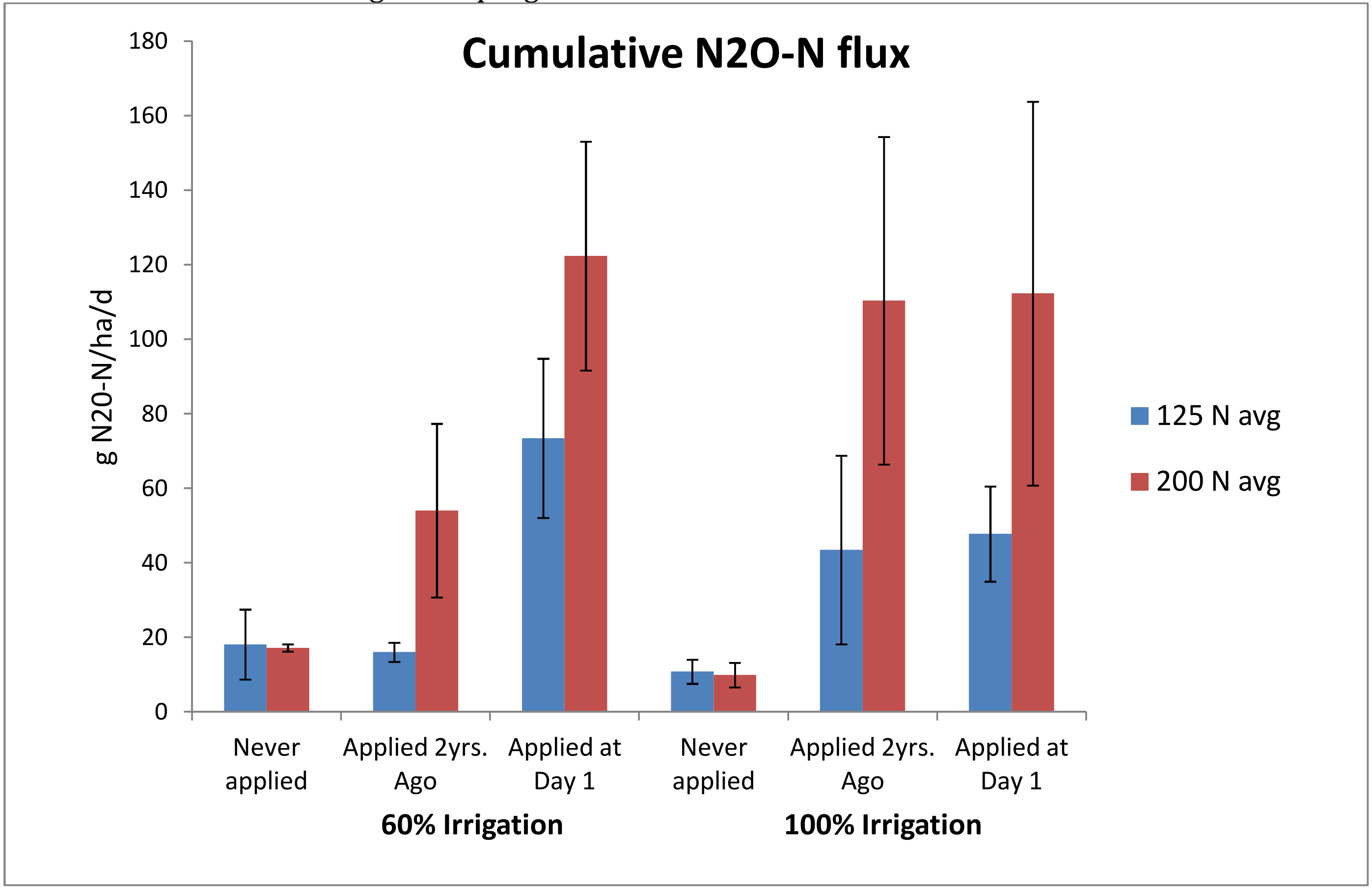

Figure 2: Daily Flux Rates N_2O, 60% Irrigation, 125 kg N/ha

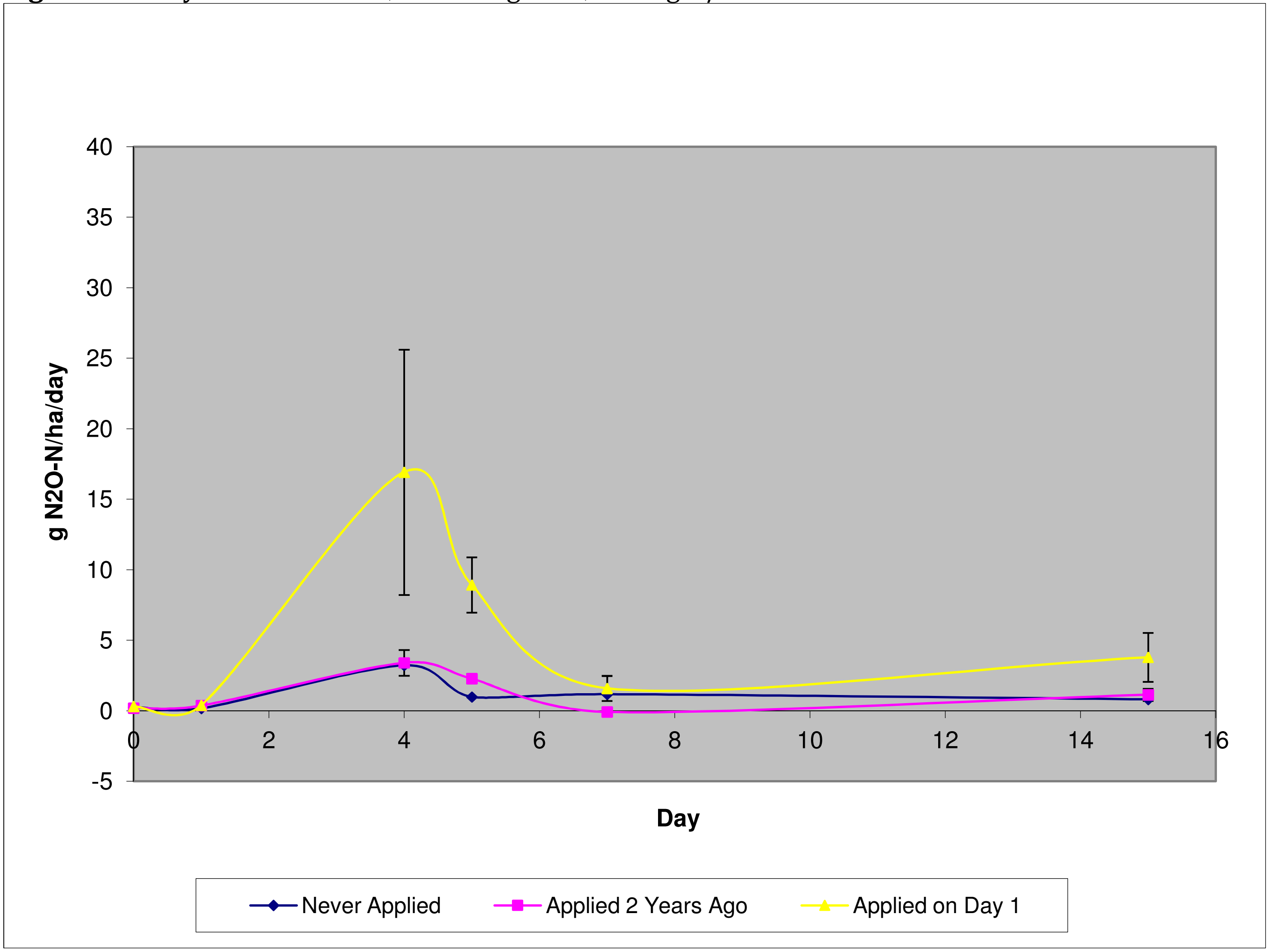

Figure 3: Daily Flux Rates N_2O, 100% Irrigation, 125 kg/N

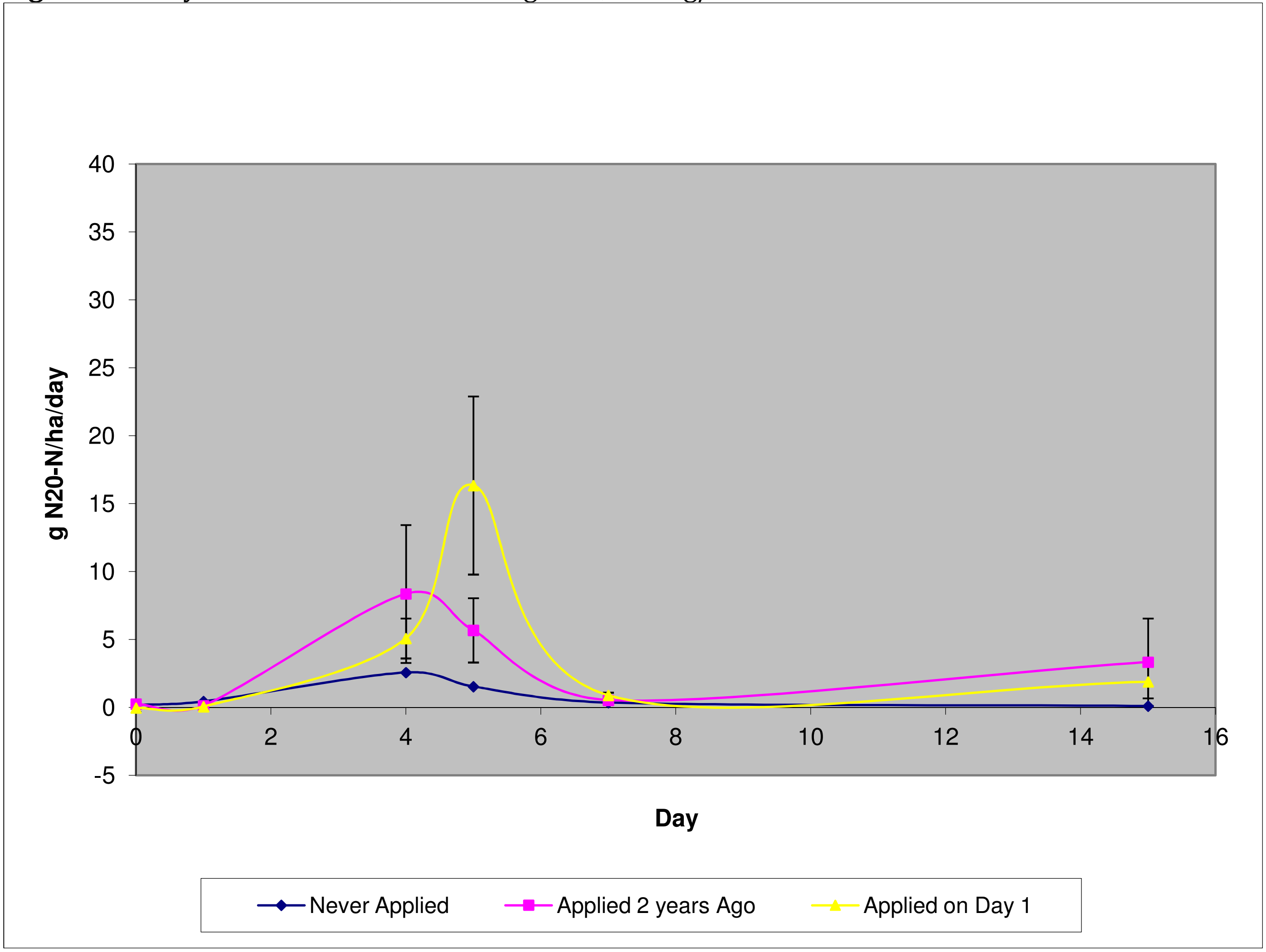

Figure 4: Daily Flux Rates N2O, 60% Irrigation, 200 kg N/ha

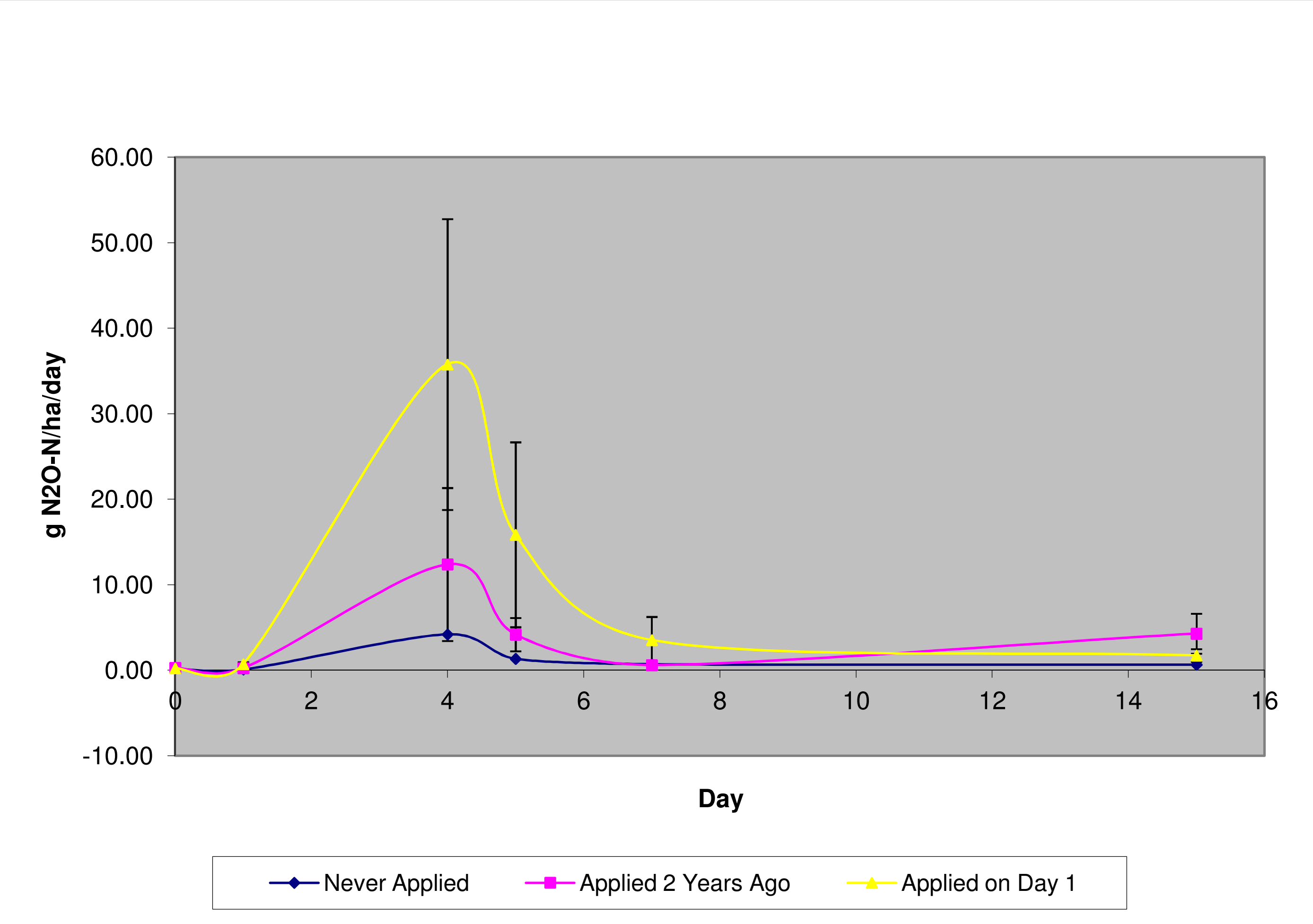

Figure 5: Daily Flux Rates N2O, 100% Irrigation, 200 kg N/ha

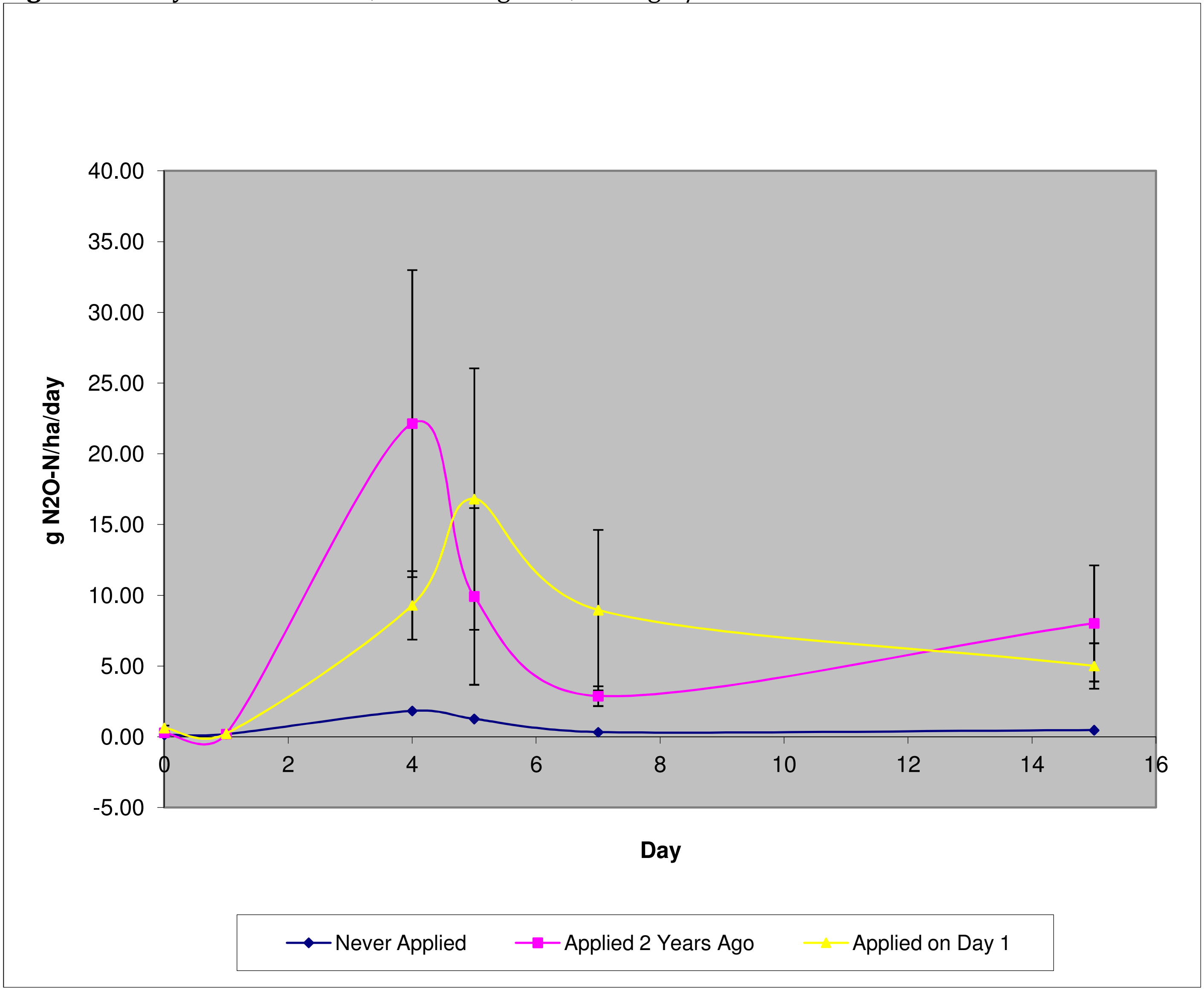

Table 1: Experimental treatment managements for test plots.

N rate:	60%Irrigation	100% Irrigation
125 kg/N/ha	Manure Never applied	Manure Never applied
	Manure Applied 2 years ago	Manure Applied 2 years ago
	Manure Applied on day 1	Manure Applied on day 1
200 kg/N/ha	Manure Never applied	Manure Never applied
	Manure Applied 2 years ago	Manure Applied 2 years ago
	Manure Applied on day 1	Manure Applied on day 1

Table 2: Beef Manure - Selected Properties

Beef manure applied Oct 2012 (metric tons/ha)	23.8		
pH	6.9		
Moisture %	20.1		
Dry matter %	79.9		
Nutrients	**kg/ metric ton**	**metric tons/ha**	**kg/ha**
Total C	127.1	3.0250	3025.0
Total N	12.5	0.2975	297.5
P_2O_5	16.8	0.3998	399.8
K_2O	19.4	0.4617	461.7
S	4.7	0.1119	111.9
Ca	26.5	0.6307	630.7
Mg	7.3	0.1737	173.7
Na	3.0	0.0714	71.4
Zn	0.14	0.0035	3.5
Fe	8.5	0.2015	201.5
Mn	0.27	0.0065	6.5
Cu	0.03	0.0008	0.8

Figure 6: Study site location, by county. Red star is Clay County, Nebraska, where the SCAL site is located.