NITROGEN AND CROP MANAGEMENT INFLUENCE IRRIGATED CORN YIELDS AND GREENHOUSE GAS EMISSIONS[1]

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ABSTRACT

The influence of tillage system and N fertility on corn grain yields, residue C inputs to the soil, soil organic carbon (SOC) sequestration, NO_3-N leaching potential, and greenhouse gas emissions under irrigated continuous corn production was evaluated. Corn was produced on a Fort Collins clay loam using no-till (NT) and conventional-till (CT) systems at several N fertility levels. Soil and plant data have been collected since the spring of 1999. Corn grain yields and residue C have increased with increasing N rate in both the CT and NT production systems. Residual soil NO_3-N levels have increased with increasing N rate in both tillage systems, but are lower in the NT system than in the CT system at the highest N rate. Averaged across N rates, no change in SOC has been observed in the CT system with time, but SOC has increased linearly in the NT system with each additional corn crop. SOC has not been significantly increased by N fertilization during the first 4 years, but trends are for SOC to be greater with N application than where no N fertilizer has been applied in the NT system. Several more cropping seasons will be needed to detect significant changes in SOC caused by N fertility management level. Nitrous oxide (N_2O) emissions increased similarly with increasing N rate in both tillage systems. Carbon dioxide (CO_2) emissions were greater with CT than with NT but did not vary with N rate. Methane (CH_4) emissions were low and not affected by tillage or N treatment. Therefore, the increase in SOC storage with NT is helping offset N_2O emissions from N fertilization needed to optimize crop yields compared with the CT system. Farmers need to apply N to optimize yields and economic returns, but should take care to use only that amount of N fertilizer needed for optimum yield in order to minimize NO_3-N leaching potential and N_2O emissions in irrigated systems.

INTRODUCTION

Cultivation of cropland has resulted in a significant decline in soil organic matter (SOM) and SOC with CT in the Great Plains (Haas et al., 1957; Peterson et al., 1998). Farming methods that utilize intensive mechanical tillage, such as moldboard plowing, for seedbed preparation or mechanical tillage for weed control, contribute to increased levels of CO_2 released to the atmosphere from the soil (Janzen et al., 1999; Lal et al., 1999). These cultivation practices have contributed to the increase in atmospheric CO_2 levels from 280 ppm (pre-industrial level) to about 370 ppm in

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2000. Cultivation and N fertilization also increase N_2O emissions and have contributed to the atmospheric increase in N_2O from 275 ppb in 1900 to 317 ppb in 2000. Cultivation of soil has also contributed to the increase in atmospheric methane (CH_4) from 700 ppm in 1900 to 1800 ppm in 2000 by decreasing the soil sink for CH_4 (IPCC, 1996, 2001). Based on a 100-year time frame, CH_4 has about 23 times and N_2O about 296 times the global warming potential (GWP) of CO_2. Increasing the level of SOC stored in the soil helps mitigate the effects of greenhouse gases (CO_2, N_2O, CH_4) emitted from agricultural systems which contribute to GWP.

Current farming technologies, such as NT systems, can help reduce the level of CO_2 released to the atmosphere by sequestering carbon (C) in the soil (Lal et al., 1998; Peterson et al., 1998). The value of SOC is more than improving water holding capacity and nutrient availability of the soil. Its hidden value comes in its ability to help mitigate the greenhouse effect on the environment. Thus we need to understand how crop management practices, such as N fertilization and tillage, affect SOC. Crop management practices that increase SOC contribute to improved soil quality and enhance environmental quality by reducing agricultural CO_2 emissions.

Under irrigated agriculture, crop residue levels (both above and below ground) may be sufficient to increase SOC storage in semi-arid lands of the central Great Plains. Corn grain yield potential is high in irrigated production systems, which also returns large quantities of crop residue to the soil surface at harvest. With a high level of residue returned to the soil surface under irrigation, one might expect SOC levels in irrigated fields to at least be maintained and possibly increased with time if NT systems are used (Allmaras et al., 2000). Lueking and Schepers (1985) showed that irrigated crop production using CT can maintain or build SOC when compared to adjacent native sod on sandy soils in northern Nebraska. Halvorson et al. (2000) showed that soil organic matter (SOM) decreased with time under an irrigated sugarbeet-wheat rotation at Sidney, Montana, but SOM concentration decreased the most with no N applied and the least at the highest N fertilizer rate.

Application of N fertilizer to optimize crop yield potential and economic returns is necessary to keep a quality food supply and farmers in business. Application of N fertilizer, however, results in increased emission of N_2O from the cropping system (Mosier et al., 1998). Development of sound N management practices for high yielding irrigated corn will depend on research that addresses the issues of residue management for SOC sequestration, NO_3-N leaching potential, and minimizing N_2O emissions.

Available information on the long-term effects of tillage and N fertilization on crop residue production and its subsequent effects on SOC and total soil nitrogen (TSN) in irrigated cropping systems in the Great Plains is limited. In this paper, we present data from an irrigated research site near Fort Collins, Colorado to document the influence of N fertility and tillage management on irrigated continuous-corn yields, corn residue production, greenhouse gas emissions, SOC sequestration, TSN, and soil NO_3-N leaching potential.

MATERIALS AND METHODS

Tillage (CT and NT) and N fertility treatments were established in 1999 on previously managed conventional plow tillage, continuous corn field located on a Fort Collins clay loam soil at the Agricultural Research, Development, and Education Center (ARDEC) north of Fort Collins, CO. The irrigated field had been in CT continuous corn for several years. The NT continuous corn rotation included six N rates (0, 30, 60, 90, 120, and 180 lb N/a) in a randomized complete block design with three replications with the same N rate being applied to the same plot each year. The highest N rate was 150 lb N/a in 2001. In 1999, a RT system with only three N rates was used to prepare the plot area for NT production starting in 2000. This was done to level out the furrows and ridges created with cultivation of the 1998 corn crop. The RT system consisted of one disk operation and one mulch-treader operation before planting in 1999. From 2000 to 2002, a NT continuous corn production system was used.

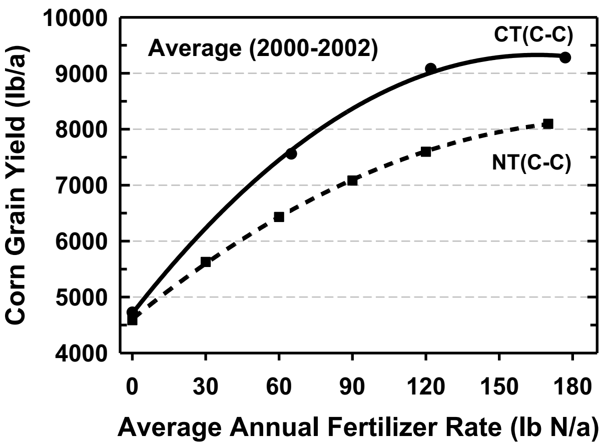

Fig. 1. Average corn grain yield as a function of N rate for the CT and NT systems.

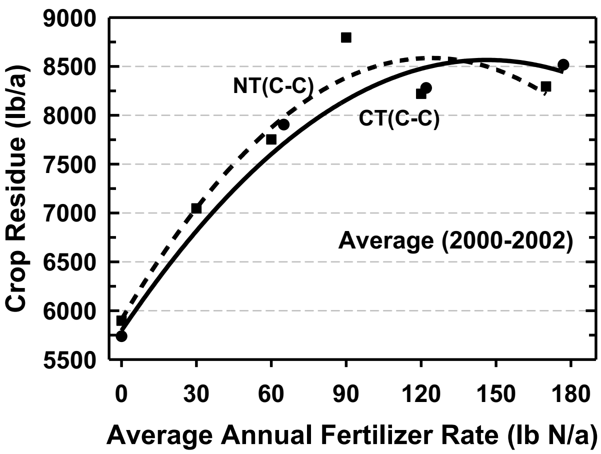

Fig. 2. Average corn residue production as a function of N rate for CT and NT systems.

The CT continuous corn rotation used mechanical tillage (stalk shredder, disk, moldboard plow, mulcher, land leveler, etc.) for seed bed preparation. Four fertilizer N rates (0, 60, 120, and 180 lb N/a) with four replications were included in the CT system in 2001 and 2002. The 2000 CT N rates varied slightly from the 2001 and 2002 treatments, but had an N fertility range similar to the NT system with four replications. An average N rate for each N treatment, including the control, will be used for comparison between tillage treatments in this paper.

Herbicides were used for weed control in both tillage systems. Nitrogen (UAN, 32%) was banded about two inches below the soil surface just prior to planting corn in the NT and CT systems, except UAN was banded over the seed row prior to planting and watered into the soil just after planting in the 2000 CT plots.

A subsurface band application of 0-46-0 was applied at a rate of 115 lb P_2O_5/a prior to planting the 1999 crops in both tillage systems. Liquid starter fertilizer containing P_2O_5 and K_2O with a very low concentration of N was applied to the seed row at planting in 2000 and 2002. Residual soil NO_3-N (0-6 ft soil depth) was determined prior to N application and after harvest each crop year.

Biomass samples were collected in mid to late September each year for determination of residue production. Grain yields were measured at physiological maturity in late October each year by collecting the ears from two 25 ft long rows per plot. The corn grain yields are expressed at 15.5 % water content. Soil samples were collected for SOC and NO_3-N analysis after grain harvest each year. Greenhouse gas fluxes were monitored one to three days/week from April 2002 to April 2003 in three of the N treatments (0, 120, and 180 lb N/a). A vented chamber technique was used to collect the gases in the field and a gas chromatograph used to analyze for gas concentration. Other details of the study are provided by Halvorson et al. (2002).

RESULTS

Grain and Residue Production. Average grain yields from 2000 to 2002 increased with increasing N rate for both tillage systems, with grain yields being slightly higher with CT than with NT (Fig. 1). The higher grain yields with CT probably resulted from earlier and faster plant development with CT compared with NT during May. Soil temperatures were warmer in the CT than in NT (data not shown) in late April and during May. This reduced ear size and kernel development in the NT system.

Residue returned to the soil also increased with increasing N rate, with residue levels being similar for both tillage treatments (Fig. 2), in contrast to grain yield. Residue production was near maximum at the 120 lb N/a rate. Residue C concentration averaged 44.6 % from 2000 to 2002 and did not vary with N rate. Therefore, residue C returned to the soil increased with increasing N rate and reflects the residue production level, since C concentration in the residue did not vary with N fertility treatment. Thus, over time one would expect a difference in SOC levels with N rate.

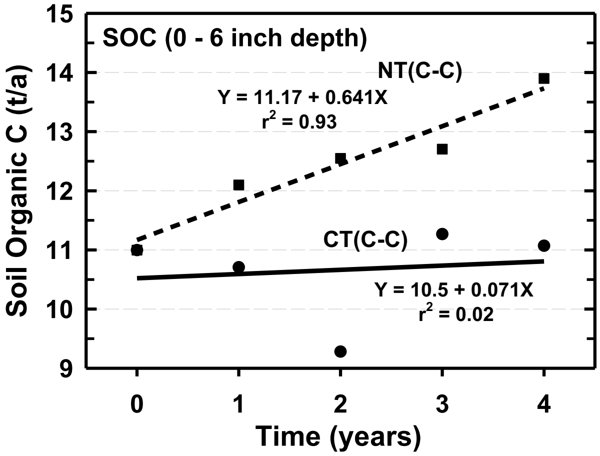

Fig. 3. Change in soil organic C in the 0 to 6 inch soil depth in NT and CT systems.

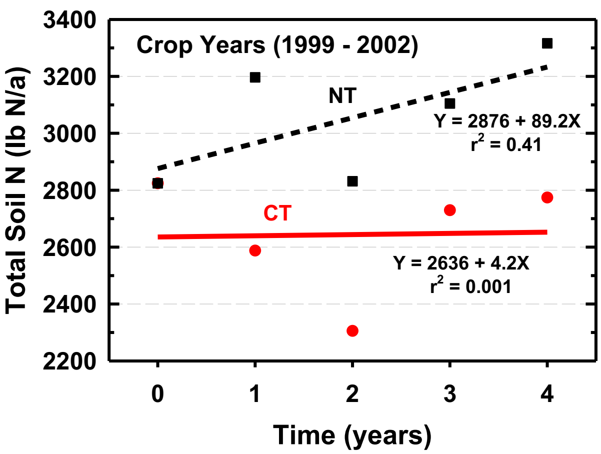

Fig. 4. Change in total soil N with each crop year in the CT and NT systems.

Soil Carbon and Nitrogen. SOC and TSN have been increasing linearly in the NT production system with each additional crop year (Fig. 3 and 4). In contrast, no significant change in SOC or TSN has been observed in the CT plow production system since study initiation in 1999.

Although residue C inputs to the soil surface at harvest increased with increasing N rate, a significant increase in SOC with increasing N rate has not been measured during the first 4 years of NT production. However, the trends (data not shown) are for the NT treatments receiving fertilizer N to have a slightly higher level of SOC than where no N fertilizer was applied.

Residual Soil NO_3-N Levels. The residual soil NO_3-N level in the 0-6 ft soil profile after harvest in 2002 increased slightly with increasing N rates up to 90 lb N/a, then increased rapidly at rates above 120 lb N/a (Fig. 5). At the highest N rate, the CT system had a higher level of residual soil NO_3-N than the NT system, with residual NO_3-N levels being similar at rates below 120 lb N/a. This reflects the sequestration of N in the SOM in the NT system and a much slower rate of release of the residue N to succeeding crops compared with the CT plow system of production.

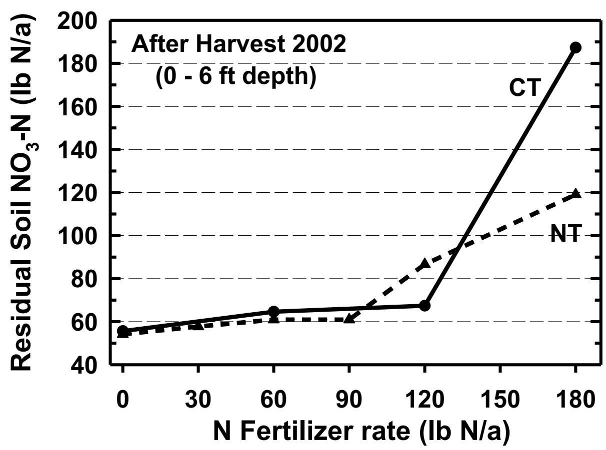

Fig. 5. Residual soil NO_3-N in 0 to 6 ft soil depth after 2002 corn harvest.

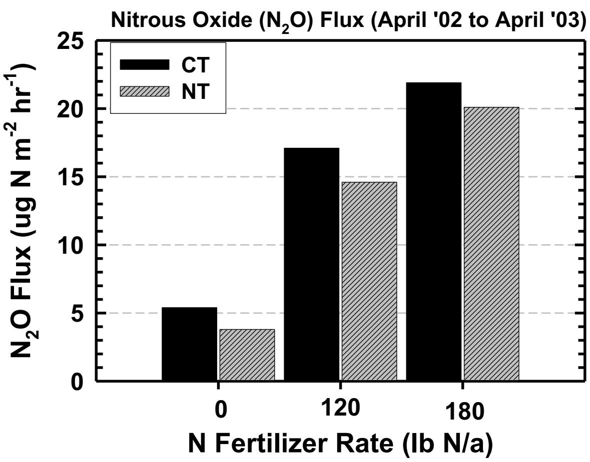

Fig. 6. Average nitrous oxide flux as a function of N and tillage treatment.

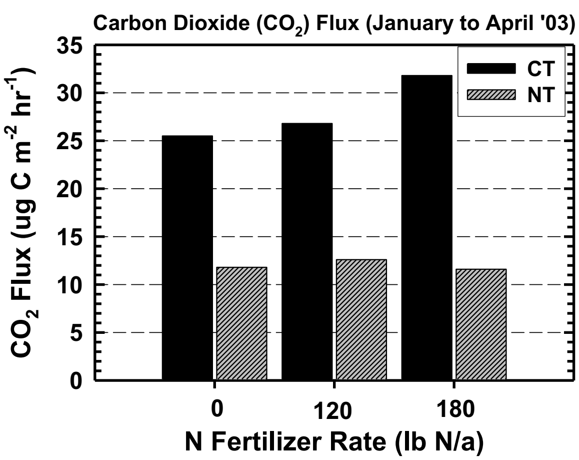

Fig. 7. Average carbon dioxide flux as a function of N and tillage treatment from January to April 2003.

Greenhouse Gas Fluxes. Nitrous oxide fluxes increased with increasing N rate in both the CT and NT systems (Fig. 6) for the April 2002 to April 2003 measurement period. Nitrous oxide fluxes were similar at a given N rate for both tillage systems. Carbon dioxide fluxes for the non-crop period, January to April 2003, were greater for the CT than NT system, but were not affected by N rate (Fig. 7). Methane fluxes were small, but positive for the total year from these irrigated corn systems with neither tillage nor N rate affecting the flux. These first year trace gas flux measurements suggest that converting from an irrigated CT system to a NT system will decrease CO_2 emissions without affecting N_2O and CH_4 emissions. Thus, the additional SOC sequestration with NT helps offset the global warming potential of these irrigated agricultural systems.

SUMMARY

Average grain yields were higher with CT than with NT during the first 3 years of this study, primarily due to slower development of the corn plant in the NT system due to colder soil temperatures in April and May. Residue production was similar for both tillage systems, increasing with increasing N rate.

Trends after 4 years show that SOC and TSN levels are increasing in the NT system but not in the CT system. Trends are for N fertilization to be increasing SOC when compared to plots with no N fertilizer applied in the NT system. SOC has not changed with time in the CT plowed system. Residual soil NO_3-N has increased with increasing rates of N fertilization, with CT having a higher level of residual soil NO_3-N than the NT system at the highest N rate.

Nitrous oxide emissions increased with increasing N rate, but were similar for both tillage systems. Carbon dioxide emissions were not affected by N fertilization, but were higher with the CT system than with the NT system. The soil was a small source of methane under irrigated conditions, but methane emissions did not vary with N fertilization or tillage system.

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