IRRIGATED CROP MANAGEMENT EFFECTS ON PRODUCTIVITY, SOIL NITROGEN, AND SOIL CARBON

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ABSTRACT: Crop management practices that optimize crop yields and reduce soil erosion tend to have positive effects on soil organic carbon (SOC) sequestration, but may also affect residual soil nitrate-N (NO_3-N) levels and nitrous oxide (N_2O) emissions. The influence of N fertility on corn grain yields, residue C inputs to the soil, SOC sequestration, NO_3-N leaching potential, and N_2O emissions under irrigated continuous corn production in two states is discussed. Two N fertility levels were established on separate halves of center-pivot irrigation systems located near Dalhart (Dallam fine sandy loam) and Texline, TX (Conlen and Dumas clay loam soils) employing reduced-till (RT), continuous corn production systems. The normal fertility program (N1) at the Texas sites had corn yield goals of 250+ bu/A. The higher N fertility treatment (N2) received the same fertilizer rate as the N1 treatment plus an additional application of liquid N fertilizer to the corn residue after harvest and prior to fall tillage to aid the decomposition of the corn residues. Grain yields and residue C inputs to the soil have been similar for both N treatments. SOC levels (1999-2002) are increasing linearly with each crop year and are now greater than native sod SOC levels. Addition of liquid N to the corn residue after harvest (N2) has not significantly influenced SOC levels after 4 years at either site. Root zone soil NO_3-N levels have increased in the cropped area compared to native grass at both sites and have increased more with the N2 than the N1 treatment. At the Colorado site (Fort Collins clay loam), corn was produced in 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 changes in SOC caused by N fertility management level at all sites. At the Colorado site, N_2O emissions increased similarly with increasing N rate in both tillage systems. 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.

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PROBLEM: Conversion of native grasslands to cultivated cropland has generally resulted in a significant decline in soil organic matter (SOM) and SOC with CT under dryland conditions (Haas et al., 1957; Peterson et al., 1998). Halvorson et al. (2000) showed that after 27 years of NT intensive cropping management, SOM levels under NT were 85% of native sod levels whereas the CT, crop-fallow production system was 40% of native sod levels at a Nebraska site.

Farming methods that utilize intensive mechanical tillage, such as moldboard plowing, for seedbed preparation or disking for weed control, contribute to increased levels of carbon dioxide (CO_2) released to the atmosphere (Janzen et al., 1999; Lal et al., 1999). Atmospheric CO_2 levels have increased from 280 ppm (pre-industrial level) to about 370 ppm in 2000, N_2O increased from 275 to 317 ppb, and methane (CH_4) increased from 700 to 1800 ppm, with agriculture contributing to this increase (IPCC, 1996, 2001). Based on a 100-year time frame, CH_4 has 23 times and N_2O has 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 RT and 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 management practices, such as N fertilization, 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 and southern Great Plains. With irrigated corn production, high levels of plant nutrients are often applied to maximize grain yield potential, which returns large quantities of crop residue to the soil surface. For example, assuming a 230 bu/a corn crop with a grain to stover ratio of 1:1, potentially 12,880 lb/a of corn residue containing 45 % C could be returned to the soil each crop year. With this level of residue input to the soil, liquid N fertilizer applied to the residue after harvest may aid in residue decomposition and enhance the SOC sequestration process. However, additional N fertilizer may also increase the amount of N available for leaching.

Based on the potential residue levels returned to the soil surface under irrigation, one might expect the level of SOC in these irrigated fields to at least be maintained and possibly increased with time if RT 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 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 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 irrigated research sites, two in Texas and one in Colorado, to document the influence of N fertility and tillage management on irrigated continuous-corn yields, corn residue production, SOC sequestration, and soil NO_3-N leaching potential. Greenhouse gas emissions data from the Colorado site are also discussed.

MATERIALS AND METHODS:

Texas Sites. The two sites in the northwest Texas Panhandle located near Dalhart and Texline were initiated in April 1999. Following the 1998 cropping season, two N fertility management levels were established at each location on center-pivot irrigated fields that were being continuously cropped to corn by Jim Poole and business associates. Half of each pivot received a normal fertility program (N1). The other half (N2) received additional liquid N fertilizer (Fig. 1), which was applied to the corn stalks prior to fall tillage operations to aid in residue decomposition.

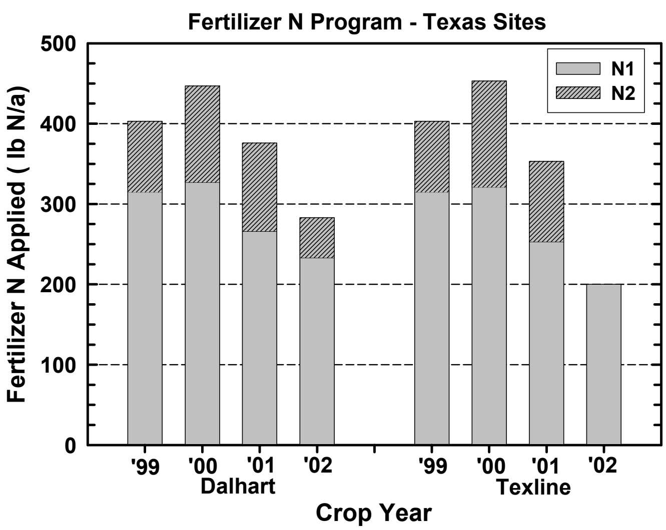

Fig. 1. Nitrogen fertilizer application rates each year for N1 and N2 treatments at Dalhart and Texline, TX sites.

A heavy duty combination disk/chisel plow/ripper implement with a tillage depth of about 12 to 14 inches was used in the fall after harvest. A disk type implement was used in the spring for seedbed preparation. When the corn was about 2 ft tall, an interrow ripper-dammer/diker machine was used to control weeds between the rows and create small dams between corn rows to reduce water runoff from the field. Herbicides were applied for weed control. The corn was planted with a JD MaxEmerge planter with a coulter and trash whipper in front of the seed opener.

Initial soil samples were collected in April 1999 from these two irrigated corn fields and from the native sod areas adjacent to the center-pivot to estimate the initial native sod SOC levels prior to conversion to corn production. The study areas have been monitored since 1999 to determine changes in SOC in the 0 to 3, 3 to 6, 6 to 12, and 12 to 24 inch soil depths. Changes in soil NO_3-N levels (0 to 6 ft depth) have also been monitored since 1999 to determine if fall N application to the residue with the N2 treatment would influence the soil NO_3-N levels in the root zone. Soil samples were collected each fall immediately after corn harvest and before fall tillage.

At both sites, corn stand counts were determined and corn biomass samples collected in September each year from about the same location as the initial April 1999 preplant soil samples by using GPS to relocate the sampling sites. Grain yields were estimated by hand harvesting corn ears from two rows, 25 feet long, at the soil sampling locations when collecting plant biomass samples. Combine yields for each half of a pivot were determined by Mr. Poole using grain yield monitors. The biomass and grain samples were analyzed for C and N content. Other details of the Texas sites are presented by Halvorson et al. (2003). The Texas studies were initiated at the request of the Fluid

Fertilizer Foundation and Mr. Poole to evaluate the impacts of maximum soil productivity on SOC sequestration.

Dalhart Site. The site is located about 9 miles northwest of Dalhart, Texas on a 500-acre field with center-pivot irrigation on a Dallam fine sandy loam soil. This site was broken from native grass in 1995, with 1999 being the fifth corn crop.

Texline Site. The site is located about 11 miles north of Texline, Texas at the corner of Oklahoma, New Mexico, and Texas. The cropped area was broken from native grass in the fall of 1995, planted to winter wheat that was grazed until April 1996, then planted to corn, with 1999 being the fourth corn crop. This is a 400-acre field located on a gently sloping Conlen clay loam (N2 fertility level) and rolling Dumas clay loam (N1 fertility level). No fall N was applied to the residue after the 2001 corn harvest in the N2 treatment area because of a large amount of residual soil NO_3-N. After harvest, cattle grazed the corn stalks at this site in the fall of 2001 and 2002. The 2002 corn crop was badly damaged by hail in early May and early August.

Colorado Site. The tillage and N fertility treatments were established in 1999 on an irrigated, 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, Colorado. The 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.

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 CT 2000 N rates varied slightly from the 2001 and 2002 treatments, but had N fertility ranges similar to the NT plots with four replications. An average N rate for each N treatment, including the control, will be used for comparison between tillage treatments in this presentation.

Herbicides were used for weed control in both tillage systems. Nitrogen (UAN, 32%) was banded 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 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 rows 25 ft long 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 weekly (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. At Dalhart, hand harvest corn grain yields averaged 206 and 172 bu/a for the N1 and N2 treatments, respectively, from 1999-2002. Combine yields averaged over each half of the pivot were 217 bu/a for the N1 and 210 bu/a for the N2 fertility levels (Fig. 2). The plant sampling locations were on the western part of the field, where water stress in the corn was the greatest during 2000, 2001, and 2002 growing seasons. The lower grain yields for N2 sampling sites, located in the southwest corner of the field, probably resulted from hot-dry winds from the southwest during the growing season and below average growing season precipitation in 2001 and 2002. Therefore, the overall combine grain yields for each half of the pivot are higher than our hand sample yields because the whole half of the field was represented. Because the field sampling sites at Dalhart were selected to allow a soil sample comparison with native sod sites on the outside edge of the pivot, the N2 fertility treatment sampling area tends to be on slightly more rolling terrain than the N1 fertility treatment. This may also explain the slightly lower grain yields with hand sampling on the N2 fertility sampling sites compared to the N1 fertility sites.

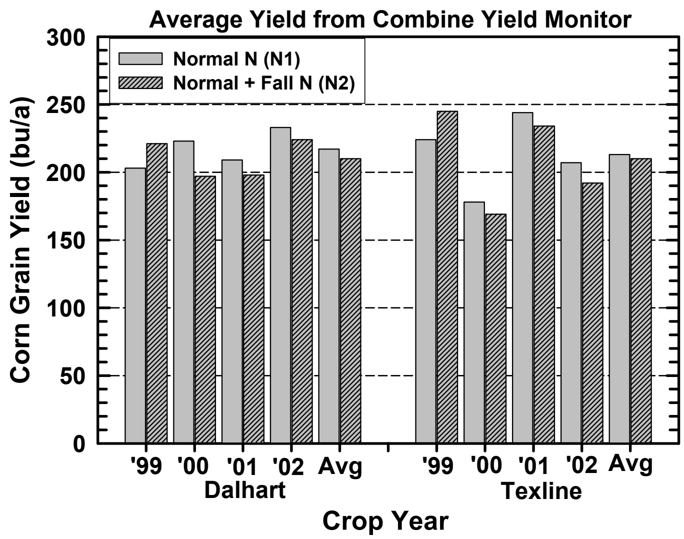

Fig. 2. Average combine grain yield for each N treatment at the Dalhart and Texline, TX sites.

The average (4-year) amount of corn residue returned to the soil for the N1 and N2 treatments at Dalhart was 10,184 and 9,469 lb/a, respectively (Fig. 3). Residue C concentration averaged 44.9% (range 44 to 47%) with a 4-year average above-ground residue C input to the soil of about 4,588 and 4,271 lb C/a per year for the N1 and N2 treatments, respectively. The N concentration of the residue averaged 0.92%. Yearly differences in residue production reflect differences in growing seasons and corn hybrids

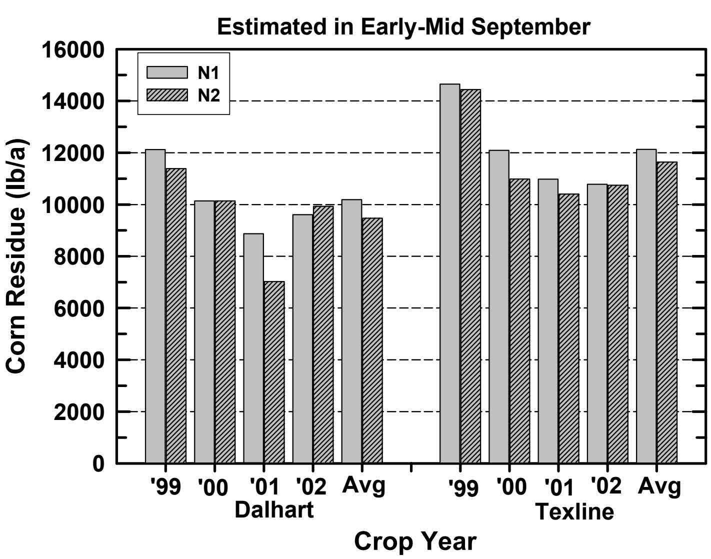

Fig. 3. Corn residue levels each year for the N treatments at Dalhart and Texline, TX sites.

grown. A large quantity of residue C was being incorporated into the soil each year in this irrigated, RT continuous corn production system at Dalhart.

At Texline, hand harvest corn grain yields averaged 204 and 185 bu/a for the N1 and N2 treatments, respectively, from 1999-2002. Combine yields for each half of the pivot averaged 213 and 210 bu/a for the N1 and N2 treatments, respectively (Fig. 2). Because the plant and soil sampling sites were selected to allow a comparison of soil samples with native sod sites on the outside edge of the pivot, the N2 fertility treatment sampling area is on a steeper sloping area than the N1 fertility treatment at this site. This may be causing the slightly lower grain yields on the N2 fertility sampling sites compared to the N1 fertility site. The topography difference between N1 and N2 treatments is true of the whole field area occupied by each treatment, which may also explain the slightly higher combine yields for the N1 compared to N2 treatment. Hand harvest grain samples were generally collected several weeks prior to black layer formation in the kernel. Thus the combine grain yields obtained at maturity were expected to be greater than the hand sample yields.

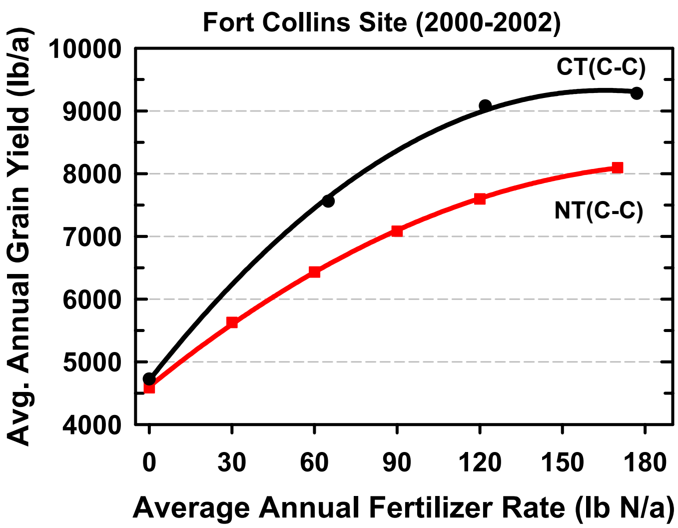

Fig. 4. Average corn grain yield as a function of N rate for the CT and NT at Colorado site.

Estimated corn residue amounts returned to the soil at Texline averaged 12,126 and 11,643 lb/a for the N1 and N2 fertility areas, respectively, from 1999-2002 (Fig. 3) with an average C concentration range of 43 to 46 %. The estimated amount of residue C returned to the soil surface has averaged 5,365 and 5,260 lb C/a, respectively, for the N1 and N2 treatments. The residue averaged about 44.7 % C and 0.93% N over the 4-yr period.

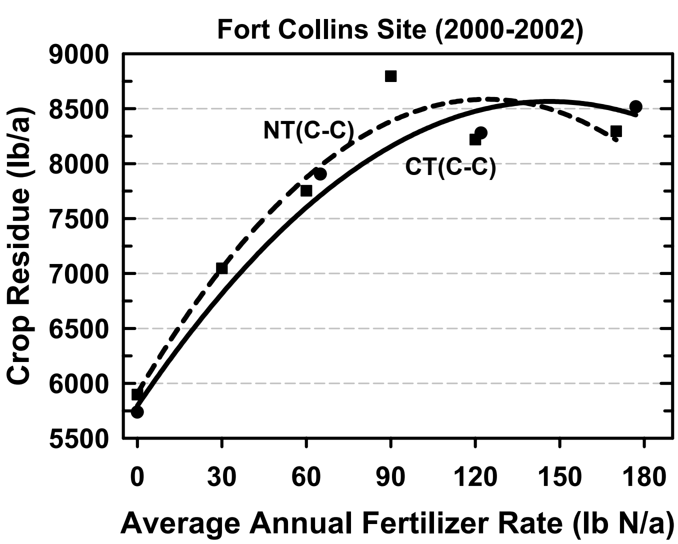

Fig. 5. Average corn residue production as a function of N rate for CT and NT systems at Colorado site.

Colorado Site. 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. 4). 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. 5), 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, with an average residue C concentration range of 43.6 to 45.9 %. These C concentrations are very similar to those observed at the Texas sites. Residue C returned to the soil increased with increasing N rate (Fig. 6) and reflects the residue production levels, 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.

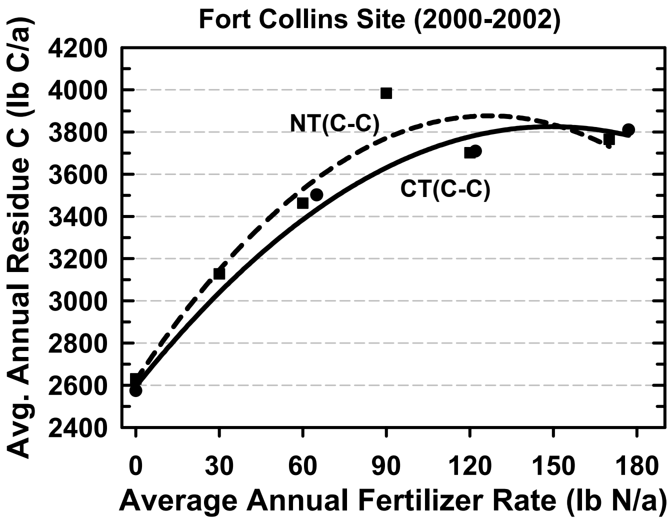

Fig. 6. Average residue C returned to soil as a function of N and tillage treatments at Colorado site.

Soil Carbon and Nitrogen. At the Texas sites, based on the residue levels returned to the soil surface and the fact that the fields were not moldboard plowed, one might expect the level of SOC in these irrigated fields to at least be maintained and possibly increased with time. The current continuous corn production system appears to be increasing the SOC each year in the 0-6 inch soil depth (Fig. 7). Increases were also observed in the 0-12 and 0-24 inch soil depths (Halvorson et al., 2003). Because the C inputs to the soil have been similar for both N fertility treatments, difference in SOC accumulation between the N1 and N2 treatments are not yet detectable. Total soil N (TSN) has also been increasing with each crop year in the 0-6 inch soil depth at both sites (Fig. 8). This supports the observation of increasing SOC with time.

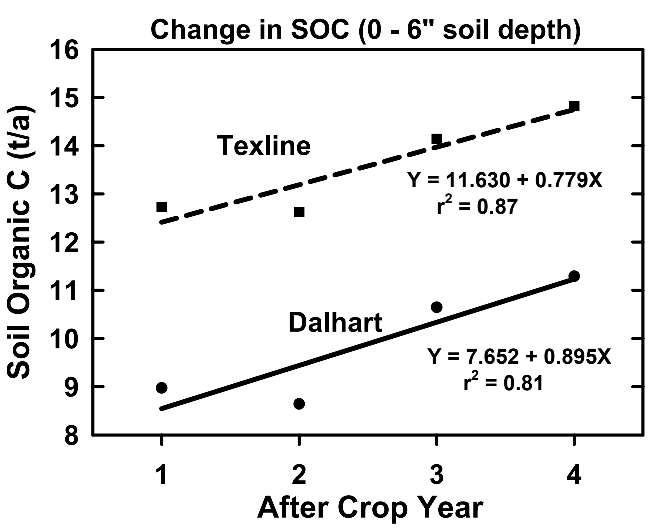

Fig. 7. Change in soil organic C with time at Dalhart and Texline, TX sites in the 0 to 6 inch soil depth.

At Dalhart and Texline, the cropped area SOC level in 2001 exceeded the level present in the native sod area in 1999 (data not shown, Halvorson et al., 2003). Total soil N levels followed the same trends as for SOC. The increase in SOC level within the irrigated continuous corn system at Dalhart indicates that Mr. Poole is building SOC in this fine sandy loam soil when averaged over both N fertility treatments. The change in soil profile SOC levels at the clay loam Texline site show the same trends as the Dalhart site of increasing SOC and TSN in the cropped area.

Since yield levels are high for both N fertility levels at the Texas sites, differences in SOC between the N1 and N2 treatments are small.

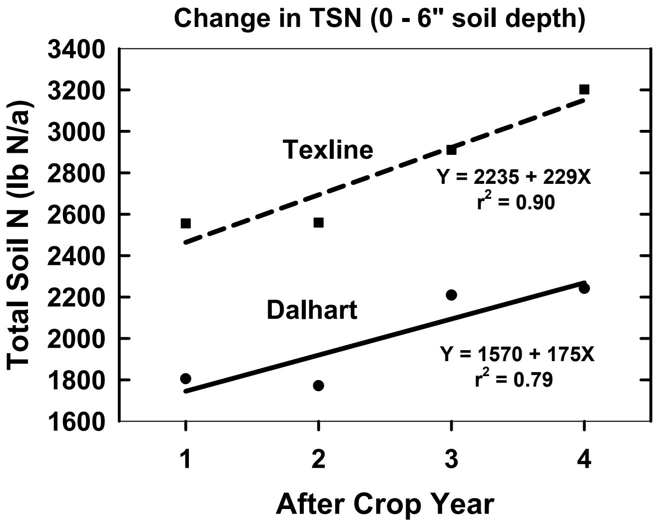

Fig. 8. Change in total soil N in the 0 to 6 inch soil depth with time at Dalhart and Texline, TX.

Several more years of data from the irrigated cropped fields are needed to determine if differences can be detected in SOC changes between the N1 and N2 fertility management treatments. Soil sample analyses show no definite trends in SOC changes after 4 years of differential N treatments at either Texas site.

At the Colorado site, SOC has been increasing linearly in the NT production system with each additional crop year (Fig. 9). In contrast, no significant change in SOC has been observed in the CT plow production system since study initiation in 1999.

The rate of increase in SOC sequestration at the Colorado site under NT production is slightly less than with the RT production systems in Texas. This may reflect the fact that less biomass residue C was being cycled to the soil at the Colorado site that at the Texas sites. Although residue C inputs to the soil surface at harvest increased with increasing N rate at the Colorado site, 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 was applied.

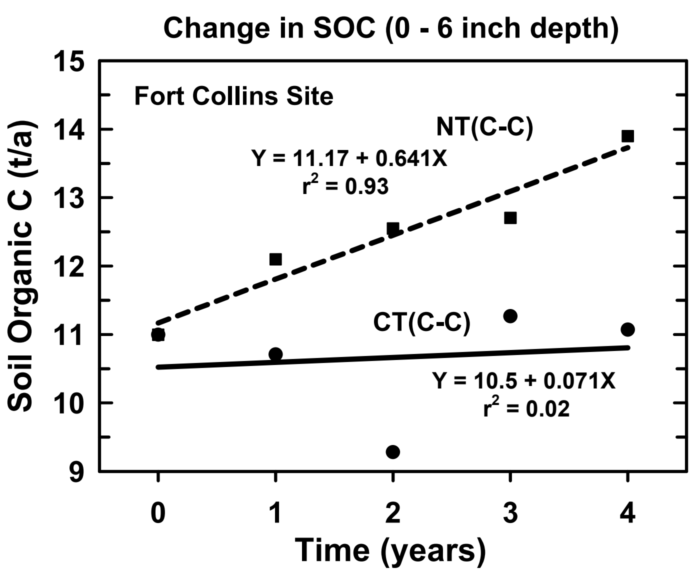

Fig. 9. Change in soil organic C in the 0 to 6 inch soil depth in NT and CT systems at Fort Collins, CO site.

Texas Residual Soil NO_3-N Levels. At Dalhart, soil NO_3-N levels under native sod area were very low compared to the residual soil NO_3-N in the cropped areas (Fig. 10). Residual soil NO_3-N following corn harvest has been greater for the N2 treatment than for the N1 treatment since 1999. This indicates that the addition of extra liquid N to the corn residue after harvest with the N2 treatment is contributing to a higher residual soil NO_3-N level than with the normal N1 fertilizer program. For this reason, Mr. Poole reduced the after-harvest N application to the residue in 2001 to 50 lb N/A (Fig. 1).

At Texline, the residual soil profile NO_3-N levels were higher in the cropped area than in the native sod area (Fig. 10). The level of residual soil NO_3-N for both N treatments appears to be increasing in this

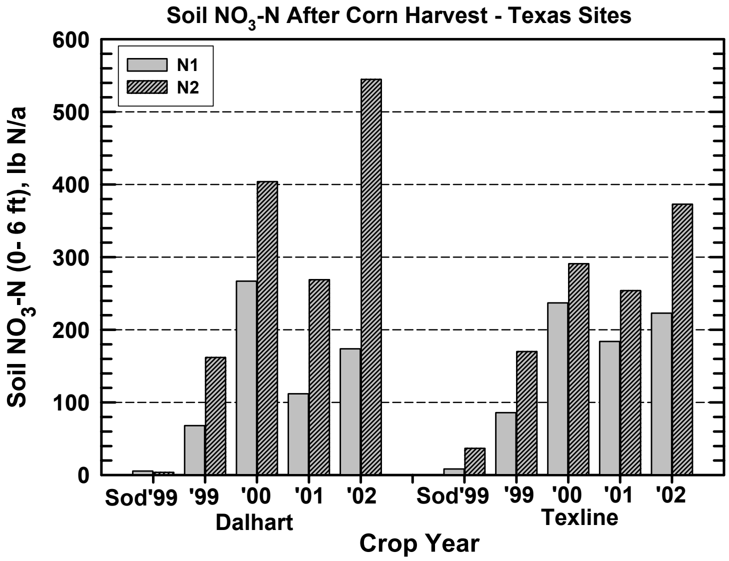

Fig. 10. Soil NO_3-N levels in native sod in 1999 and after corn harvest each year at Dalhart and Texline,TX sites.

irrigated continuous corn production system. High yields in 2001 resulted in more N removal than in 2000 and a reduced residual soil NO_3-N after the 2001 corn harvest for both N treatments, but higher residual soil NO_3-N levels were observed in 2002. However, residual soil NO_3-N levels remained higher in the N2 treatment, indicating the extra fall-applied N to the corn residue was increasing the residual soil NO_3-N level.

Because the Texas fields have been continuously cropped to corn since conversion from native sod to cropland seven to eight years ago, it will be interesting to observe the change in SOC with time and to assess the effects of maximum soil productivity on SOC sequestration and NO_3-N leaching potential. Residual soil NO_3-N levels have increased at both Texas sites with the N1 treatment. This probably reflects the result of fertilizing for a 250+ bu/a corn crop but not achieving this yield potential, which leaves residual N fertilizer in the soil and available for leaching below the root zone. The soils at both sites have a dense caliche layer at 4 to 6 ft which may reduce the loss of NO_3-N by leaching. Corn roots have been visually observed in the soil cores collected to 4 ft at the Texas sites.

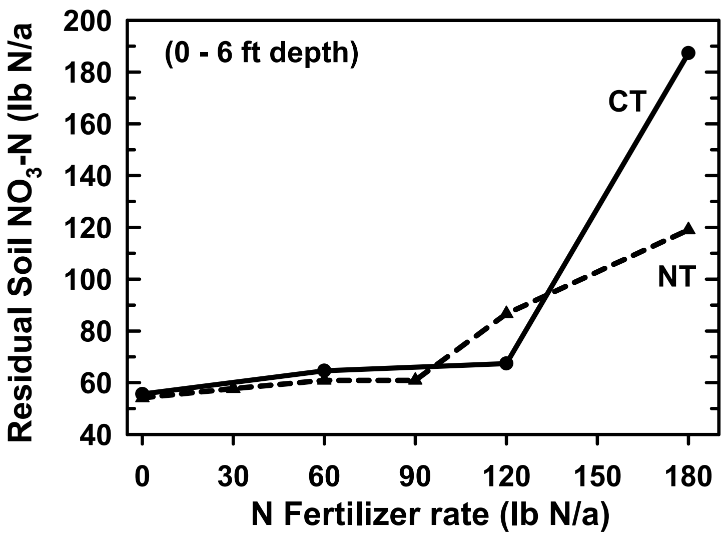

Fig. 11. Residual soil NO_3-N in 0 to 6 ft soil depth after 2002 corn harvest at Colorado site.

Colorado Residual Soil NO_3-N Levels. The residual soil NO_3-N level in the 0-6 ft soil profile after harvest in 2002 at the Fort Collins site increased slightly with increasing N rates up to 90 lb N/a, then increased rapidly at rates above 120 lb N/a (Fig. 11). 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.

Greenhouse Gas Fluxes at the Colorado Site. Nitrous oxide fluxes increased with increasing N rate in both the CT and NT systems (Fig. 12) for the April 2002 to April 2003 measurement period. Nitrous oxide fluxes were similar at a given N rate for both tillage systems. Methane fluxes were small (7.6 ug C m^{-2} hr^{-1}), but positive for the total year from these irrigated corn systems with neither tillage nor N rate affecting the flux. Carbon dioxide fluxes measured from January 2003 to April 2003 with no plant growth present were greater for the CT (28 mg C m^{-2} hr^{-1}) than the NT (12 mg C m^{-2} hr^{-1}) system, but were not affected by N rate. 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 RT and NT helps offset the global warming potential of these irrigated agricultural systems.

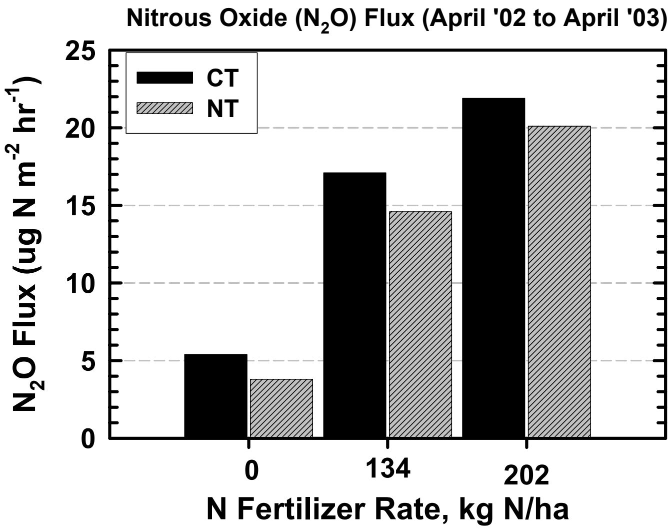

Fig. 12. Average nitrous oxide flux as a function of N and tillage treatment at Colorado site.

SUMMARY: This paper presents information on the effects of N and tillage management on corn grain yields, residue biomass, residue C and residue N returned to the soil, and changes in SOM, TSN, and NO_3-N levels in the soil under irrigated crop production in northwest Texas and northern Colorado. Grain yields varied due to climatic variation between years and site differences. Total residue biomass and residue C returned to the soil has been greater at the Texline, Texas site (clay loam soil) than at the Dalhart, Texas site (fine sandy loam). Both Texas sites have had higher grain yields and residue C amounts returned to the soil than at the Colorado site.

Four-year trends in SOC and TSN changes show that SOC and TSN levels are increasing at both Texas sites and only in the NT system at the Colorado site. The SOC and TSN levels of the cropped fields in Texas have equaled or exceeded those of the native sod. Several more years of data collection will be needed to ascertain whether the addition of liquid N fertilizer in the fall to the corn residue before tillage will benefit SOM or SOC sequestration at the Texas sites. At the Colorado site, the 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 levels were very low under native sod at both Texas sites compared with the cropped areas. Residual soil NO_3-N levels at both Texas cropped sites have increased since 1999. Residual soil NO_3-N was greater under the N2 management treatment (N applied to corn residue after harvest) than with the N1 management treatment at both Texas sites. Residual soil NO_3-N has increased with increasing rates of N fertilization at the Colorado site, with CT having a higher level of residual soil NO_3-N than the NT system at the highest N rate.

Greenhouse gas emissions at the Colorado site were influenced by N and tillage management. 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, continuous corn production, but methane emissions did not vary with N fertilization or tillage system.

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