ASSESSMENT OF LONG-TERM EFFECTS OF TILLAGE AND NITROGEN MANAGEMENT PRACTICES ON IRRIGATED CORN YIELDS AND NITROGEN USE EFFICIENCIES

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ABSTRACT

Corn grain yields and crop nitrogen uptake are affected by management factors such as tillage intensity and nitrogen rates. Additional data about the long-term effects of tillage and nitrogen rates on yields and nitrogen use efficiencies of irrigated corn are needed. We are presenting preliminary results from a 17-year study about the effects of these management practices on irrigated corn yields and nitrogen uptake in a Fort Collins clay loam soil at Colorado State University's Agricultural Research, Development and Education Center (ARDEC) near Fort Collins, Colorado. We monitored the effects of different nitrogen rates on irrigated corn under no-till (NT), conventional tillage (CT) and strip-tillage (ST). Corn grain, cob, stalk and total aboveground biomass were measured at about 146 days after planting (DAP), harvest grain yields were measured at about 173 DAP, and nitrogen content was measured for all crop components. The effects of nitrogen rates on NT, ST and CT systems were fit with a linear-plus-plateau model, which is defined by a classic switching regression type of function. This long-term research suggests that ST and NT are recovering about 75% of the nitrogen fertilizer that is being applied to the system and that any nitrogen that is applied over a rate of 165 kg N/ha will be lost. However, the nitrogen losses could potentially be higher as the recovery of the nitrogen with the harvested grain component is much lower (close to 50%). Details of preliminary results on how tillage intensity has affected yields, nitrogen dynamics, and recovery use efficiencies will be presented.

INTRODUCTION

Corn is one of the most fertilized crops in the USA and there remains a need to continue improving nitrogen management practices to increase nitrogen use efficiencies (Ribaudo et al., 2011). The Northern Plains region ranks second-highest out of ten U.S. regions in total farmland area receiving nitrogen fertilizer applications, and third-highest in tonnage applying excess nitrogen fertilizer application (Ribaudo et al., 2011). Nehring and Mosheim (2019) reported that in farms in the United States, the nitrogen recovery efficiency for corn increased from 73% in 1996 to 81% in 2010. They assessed the corn nitrogen recovery efficiency as the ratio of the amount of nitrogen in the harvested crop to the amount of nitrogen applied. Several publications have reported on how nutrient losses from farm areas are impacting air and water quality and having potential negative impacts on human health (International Joint Commission, 2013; Monchamp et al., 2014; Smith et al., 2018; Temkin et al., 2019). Although crop nitrogen use efficiencies have been reported to be increasing, there remains a need to assess how management factors such as tillage and nitrogen rates impact nitrogen use efficiencies, and in particular there is a need to conduct long-term studies that can be used to conduct nitrogen budgets. Managing tillage and nitrogen application rates is a key strategy that can impact nitrogen use efficiencies and yield responses from corn. Long-term studies in drier areas of the Northern Plains have been conducted to assess nitrogen use efficiencies and budgets (Sindelar et al., 2016). Additional long-term studies that monitor the effects of tillage systems on irrigated corn yields, nitrogen uptake and nitrogen use efficiencies are needed. Our goal is to present preliminary results from our analysis of this long-term tillage study (2001 to 2017) that we have been conducting.

MATERIALS AND METHODS

Site and Experimental Design

The field study was conducted at Colorado State University's Agricultural Research, Development and Education Center (ARDEC) near Fort Collins, Colorado. A field that was cultivated in corn for seven years prior to 2000 was used. In 2000, part of the field was converted to no-till and monitoring of the no-till and cultivated area began. In 2006, the no-till plots were split into east and west plots, and strip till was added and monitored until 2012, when it was converted back to no-till. The no-till yields and nitrogen uptake were monitored in the area that has continuously been no-till since the establishment of the study. The cultivated plots were monitored until 2008, and in 2009 the cultivated field was converted to strip till. Data from 2001 to 2017 were used from all tillage systems. The 2008 data were not used because the field had received heavy hail damage and the data were dropped from the study.

Tillage and Cultivation Operations

For the cultivated site (2001-2008): A flail chopper was used to chop up corn stalks to make them easier to incorporate pre-planting, then a disc plow was used to incorporate surface residue prior to moldboard plowing and sometimes again after moldboard plowing to break up soil aggregates. A moldboard plow was used to invert the top 30 cm of soil. A roller harrow was then used to help break up the furrows and large soil aggregates, typically twice. Finally, a land plane was used in multiple passes to level the finely tilled soil surface (2001-2008). In 2003 only, a spring-tooth harrow was used pre-planting to loosen up soil from hard rains prior to leveling. Also in 2003 only, a 3 m rotary hoe was used pre-emergence to break up a hard crusted soil surface and aid crop emergence. In 2004 only, we ripped after plowing to fracture the compaction layer to a depth of 61 cm using a 6-shank parabolic plow. This operation was then followed by the typical rolling and leveling operations. In 2005 only, pre-planting, we used a drag to level the field after fertilizer application had left deep ruts in the tilled seedbed.

For the no-till (2001-2017): The flail chopper was used on corn stalks pre-planting in 2001 only. From 2002-2012, the stalks were left standing and from 2013 to 2017 the corn stalks were roll-chopped post-harvest to increase their contact with the soil to aid in residue decomposition. After a decade of NT in an arid climate the buildup of desiccated residue was beginning to cause planting issues, resulting in less-than-ideal germination and inconsistent crop emergence.

For the strip tillage (2006-2017): From 2012-2017, a stalk roller/chopper was used on corn stalks post-harvest for consistency. From 2006-2017, the plots were strip tilled pre-planting at a tillage depth of 23 cm.

Biomass Harvesting Operations, Nitrogen Analysis and Statistical Analysis

Fifteen corn plants were collected at about 146 days after planting (DAP) to determine corn grain, cob, stalk and total aboveground biomass. Harvested grain yields were determined by harvesting 15 m of row at about 173 DAP. Nitrogen analyses were conducted using a dry combustion method with an Elementar Vario Macro C-N analyzer (Elementar Americas Inc.). Initially in 2000 the nitrogen rates ranged from 0 to 202 kg N/ha, but due to minimal grain yields in 2000 (Halvorson et al., 2006), the rates were reduced to a range from 0 to 168 kg N/ha in 2001, and increased again to a range from 0 to 202 kg N/ha in 2002 (Halvorson et al., 2006). The nitrogen fertilizer rates were increased to a range from 0 to 224 kg N/ha in 2003. The rates were increased again in 2005 to a range from 0 to 246 kg N/ha and maintained at that range.

Additional information about the experimental study can be found in Halvorson et al. (2006) and Stewart et al. (2017). The effects of nitrogen rates on NT, ST and CT systems were studied with a linear-plus-plateau model, which is defined by a classic switching regression type of function. We used R nls to solve the nonlinear fixed-effects regression model and checked results with MATLAB fitnlm for robustness. Additionally, we used the likelihood ratio (LR) test (Greene, 2008) to determine if the estimated parameters were statistically different for the no-tillage, conventional tillage, and strip tillage treatments.

RESULTS AND DISCUSSION

Yields

A detailed discussion of these results will be presented at the conference. In agreement with Halvorson et al. (2006) we found that by converting a cultivated and irrigated continuous corn system into a no-till system, the yields will be reduced. The average yields for no-till from 2001 to 2007 (9.45 Mg/ha) were lower than the yields observed with the cultivated system (9.85 Mg/ha; $P<0.01$). However, the average yields for no-till from 2006 to 2007 (9.41 Mg/ha) were significantly higher than the conventional tillage grain yields (9.27 Mg/ha; $P<0.01$). The higher average corn yields in the cultivated system for 2001 to 2007 were achieved with a significantly lower amount of nitrogen (88.4 kg N/ha) than it took for no-till (160.5 kg N/ha) to achieve its highest yields ($P<.01$). Even when the no-till had higher yields during the 2006 to 2007 years, it also required a higher amount of fertilizer nitrogen (112.4 kg N/ha) to achieve those yields than the fertilizer nitrogen (75.0 kg N/ha; $P<0.01$) for the cultivated yields.

The strip tillage yields during 2006 to 2007 (9.90 Mg/ha) were the highest ($P<0.05$) of all tillage treatments in each of those years. Although strip tillage needed more nitrogen (113.3 kg N/ha) than the conventional tillage (75.0 kg N/ha), the strip tillage and no-till nitrogen fertilizer requirements to achieve their maximum yields were not significantly different. No-till (10.2 Mg/ha) and strip tillage (10.3 Mg/ha) yields from 2006 to 2017 were not significantly different.

Nitrogen

No-till had significantly lower grain N uptake (114.8 kg N/ha) than conventional tillage (130.1 kg N/ha) during the 2001 to 2007 period ($P<0.01$). The lower grain N uptake with the no-till was achieved at a higher nitrogen rate (168.5 kg N/ha; $P<0.05$) than the nitrogen rate required to achieve the maximum grain N uptake with the conventional tillage (149.5 kg N/ha). Although during the 2006 to 2007 period no-till still had significantly lower grain nitrogen uptake (97.9 kg N/ha) than the nitrogen uptake with the conventional tillage (125.1 kg N/ha; $P<0.01$), there were no significant differences between the nitrogen fertilizer rate of the no-till (100.8 kg N/ha) and the nitrogen fertilizer rate of the conventional tillage (114.2 kg N/ha) needed to achieve the maximum nitrogen uptake in the corn grain, suggesting that more nitrogen is cycling through the system after a few years of the no-till system. No-till also had significantly lower grain N uptake (120.8 kg N/ha) than strip tillage (129.9 kg N/ha; $P<0.10$) during 2006 to 2017, but the rates of N fertilizer where the maximum grain N uptake was obtained for no-till (155.2 kg N/ha) and strip till (158.7 kg N/ha) were not significantly different.

Preliminary Summary

These long-term research results suggest that even with NT there are significant losses of N to the environment. The data suggest tilled systems lose a greater fraction of applied N than do no-till systems for continuous corn. We are currently working on several N balance assessments and papers to verify this current hypothesis. The results from 2006 to 2017 suggest that NT and ST both recover over 100% (195.0 kg N/ha) of the total N fertilizer applied if we just consider the total aboveground N uptake versus the N fertilizer applied. However, since the non-fertilized control plots assess the background N sources and they averaged a total uptake of 77.6 kg N/ha, then the fertilizer N uptake for NT and ST is estimated to be about 117.4 kg N/ha (195.0 – 77.6 kg N/ha). This suggests that we are losing at least about 47.3 kg N/ha of the applied N fertilizer (NUE of 71.3%). It also supports the conclusion that any N fertilizer applied over 165.0 kg N/ha will be lost. The losses from the system could be much higher since a significant amount of the N uptake is also returned to the soil with the crop residue. The percentage of recovery of the N fertilizer with the grain component is lower (125.3 kg N/ha – 47.8 kg N/ha = 77.5 kg N/ha removed/157.0 kg N/ha = NUE of 49.4%). A detailed analysis will be presented.

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