Stover Removal Effects on Continuous Corn Yield and Nitrogen Use Efficiency Under Irrigation

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ABSTRACT

Corn (*Zea mays* L.) residue or stover is harvested as supplemental feed for livestock and is a primary feedstock for cellulosic biofuels. Limited information is available on corn residue removal effects on grain yield under different nitrogen (N) fertilizer rates, irrigation rates and amelioration practices to minimize soil carbon loss and soil erosion. A study on a silt loam in south, central Nebraska (2011-2016) evaluated potential interactions between stover removal (residue removal, no residue removal), irrigation rate (full, limited), fertilizer N management (112 lbs. N acre^{-1}, 180 lbs. N acre^{-1}), and amelioration practices (winter cover crop, manure, no amelioration practice) on continuous corn grain yield. Grain yields differed by N rate ($P < 0.0001$) and residue removal ($P = 0.0200$). System N efficiency (SNE; grain N uptake/N rate x 100) increased with amelioration treatments, increased under residue removal, and decreased with increased N rate (112 lbs. N acre^{-1} vs. 180 lbs. N acre^{-1}). Amelioration practices to maintain soil organic carbon (SOC) and reduce soil erosion also successfully maintained grain yield with stover harvest.

INTRODUCTION

Corn (*Zea mays* L.) stover is mechanically harvested on 0.81 million ha in the United States, primarily for livestock feed and bedding purposes and is also considered a primary feedstock for conversion to cellulosic biofuels (Mitchell et al., 2016; Schmer et al., 2017). Stover demand is expected to increase from national and regional requirements to produce low-carbon transportation fuels. Corn stover and other crop residues provide essential soil benefits such as wind and water erosion protection, soil carbon (C) cycling, and nutrient storage (Wilhelm et al., 2010). Excessive stover harvests, both for livestock or biofuels, may lead to soil C loss, yield declines, and increased erosion risk (Blanco-Canqui et al., 2014; Jin et al., 2015; Halvorson and Stewart, 2015; Wilhelm et al., 2010).

Irrigated, continuous corn systems are prevalent in the western Corn Belt Region (Grassini et al., 2011). However, a yield penalty is typically found for continuous corn compared with corn-soybean [*Glycine Max* L., (Merr.)] rotations in the western Corn Belt Region (Farmaha et al., 2016; Seifert et al., 2017; Varvel and Pederson, 1990). In addition, N fertilizer recommendations for continuous corn systems are higher than in corn-soybean systems (Varvel and Pederson, 1990).

Stover removal in continuous corn can increase plant productivity and N uptake (Sawyer et al., 2017). Stover removal may reduce the yield penalty associated with continuous corn systems compared with a corn-soybean rotation and reduce the need for additional N fertilizer requirements (Sims et al., 1998; Sindelar et al., 2013; Wortmann et al., 2016).

Limited studies have evaluated potential interactions between stover removal, irrigation rate, fertilizer N management, and amelioration practices on grain yield. Interactions between irrigation and N fertilizer rate indicated that N fertilizer increased crop water use efficiency and irrigation water use efficiency in no-till continuous corn (Rudnick et al., 2016). Previous research on stover removal in an irrigated system showed grain yield response was mixed (Blanco-Canqui et al., 2017; Halvorson and Stewart, 2015; Kenney et al., 2015; Schmer et al., 2014; Sims et al., 1998; Stalker et al., 2015; Wortmann et al., 2016). Carbon amendment or amelioration practices have been proposed to reduce negative impacts from stover removal related to changes in soil properties particularly in no-till systems (Ruis and Blanco-Canqui, 2017). Incorporating a winter cover crop is one amelioration practice to prevent SOC loss and limit erosion, but little information is available on yield effects within a continuous corn system (Blanco-Canqui et al., 2017). Applying manure as another possible amelioration practice provides valuable nutrients and C that were removed from corn stover harvest. Primary study objectives were to evaluate stover removal effects on grain yield and nitrogen use efficiency (NUE) under variable irrigation, nitrogen, and amelioration practices in a no-till, continuous corn system.

MATERIALS AND METHODS

The experimental site is located at the University of Nebraska-Lincoln's South Central Agricultural Laboratory (40.582° N; 98.144° W; 1811 ft (552 m) asl) located near Clay Center, NE with a climatic zone between subhumid and semiarid. Long-term mean annual temperature is 50.5° F (10.3° C) and mean annual precipitation (1983 to 2014) is 28.78 inches (731 mm) with 17.60 inches (447 mm) occurring during the growing season (April-October). Study site is on a Hastings silt loam (fine, smectitic, mesic Udic Argiustolls) with a 0-2% slope. Surface soil chemical and physical properties have previously been reported (Blanco-Canqui et al., 2014). The site was previously in a furrow-irrigated, ridge-tilled corn-soybean rotation system prior to study initiation. The site was disked in April 2010 to level the soil surface and has been in no-till since.

The experimental design is a randomized complete block and treatment design is s split-split-split factorial with four replications. The main plot is irrigation level (full or limited) with plot dimension 80-ft x 508-ft (24-m x 155-m). The field was irrigated using a variable-rate linear lateral move irrigation system (Valmont Ind., Valley, NE). Irrigation timing was managed to maintain between 45 to 90% of total available soil water within the 4 ft (1.2 m) soil profile to minimize plant water stress and drainage. Limited irrigation events were applied at the same time as full irrigation events and was 60% of the total applied compared to the full irrigation treatment. Available soil water was measured using Watermark Granular Matrix sensors (Irrometer Co. Inc., Riverside, CA) that measures soil matric potential. Soil matric potential sensors were installed at 1 ft (0.3-m) increments to a soil depth of 4 ft (1.2-m). Irrigation amounts are reported in **Table 1** for full irrigation and limited irrigation treatments.

The split-plot treatment was carbon amelioration treatments [winter cereal rye (*Secale cereale* L.), manure, or control] with plot dimension 80-ft x 170-ft (24-m x 52-m). Winter cereal rye was planted after stover harvest in the fall at a rate of 100 lbs acre^{-1} (112 kg ha^{-1}). Cereal rye was planted (late October) using a 1590 John Deere no-till drill (Deere & Co. Moline, Ill) with a 7.5 inch (19-cm) row spacing. The cereal rye cover crop was terminated two weeks prior to corn planting using glyphosate (*N*-(phosphonomethyl)glycine). Manure was applied in the fall every two years (2010, 2012, 2014, 2016) using a mechanical manure spreader after corn and stover harvests. Sheep manure was applied in 2010 and beef cattle manure was applied in 2012, 2014, and 2016. Manure was applied at rates that approximated P removal in irrigated corn (Blanco et al., 2014). Following manure application, N manure was credited to the amount of inorganic N applied at side-dress to meet experimental N treatment levels based on first (25%) and second (12%) year organic N mineralization (Koelsch and Shapiro, 2006; Wortmann and Shapiro, 2008).

Split-split plot dimensions are 40-ft x 170-ft (12-m x 52-m) and consist of stover removed or stover retained treatment plots. Stover was mechanically harvested to remove the maximum under field conditions. In 2010 and 2011, a flail shredder, a high-capacity hay rake, and round baler was used to remove corn stover while in 2012, 2013, 2014, 2015, and 2016 a self-propelled disk mower-conditioner and round baler was used. Corn stalks were cut at a height of 2 inches (5-cm) to maximize stover removal amounts. Stover removal was done in late October following grain harvest.

Split-split-split treatment plots consisted of N fertilizer rate (112 and 180 lbs. N $acre^{-1}$). Split-split-split plot dimension was 40-ft x 85-ft (12-m x 26-m). Nitrogen fertilization (urea ammonium nitrate; 32-0-0) was applied post corn emergence using a sidedress coulter injection system. Corn was planted in late April or May (**Table 1**) in 76-cm rows. Corn plant counts were taken in 2012-2016 from a 40 ft (12.1-m) length of row at approximately corn leaf stage V6. Aboveground dry matter samples from an area 30 inches (0.76 m) wide by 10 feet (3.04 m) long from all corn plots were hand collected every year soon after physiological maturity (September or early October). Ears were removed, dried, and weighed. Stalks were cut at ground level, chopped, and weighed, and a subsample was dried at 140°F (60°C) until constant mass was reached for calculation of stover dry matter production. Grain yields were determined from the dry mass of grain shelled from ears collected in the 10 foot (3.04-m) length of row. After shelling, cob weights were added to the calculated stover weight to obtain total non-grain dry matter (stover) production. Aboveground biomass parameters are reported on a dry-matter basis. Grain yields were obtained using a commercial-scale combine. A total of four rows were mechanically harvested (rows 5, 6, 12, and 13) for grain yield determination. Reported corn grain yields were adjusted to a moisture content of 155 g kg^{-1}. Total aboveground biomass is reported on a dry matter basis. Harvest index (HI) and nitrogen use efficiency (NUE) measures (equations one through five), calculated on a dry matter basis, were derived from Woli et al. (2016) and Sawyer et al. (2017).

Harvest index (HI) = grain biomass/total plant biomass [1]

Nitrogen harvest index (NHI) = grain N uptake/total plant N uptake [2]

Partial factor productivity (PFP) (kg kg-1) = grain yield/N rate [3]

Internal N efficiency (INE) (kg kg-1) = grain yield/total plant N uptake [4]

System N efficiency (SNE) (%) = (grain N uptake/N rate) x 100 [5]

Data Analysis

Grain yield, biomass yield, and grain harvest index was analyzed using the GLIMMIX procedure of SAS (v. 9.3) using a 0.05 probability level (SAS Institute, 2014). Experimental design was a randomized complete block with a split-split-split plot treatment arrangement. Analysis was performed across years. Treatments and interactions were considered fixed while years, replicates and subsequent interactions were considered random. The covariance structure that gave the smallest Akaike information criteria was used for each parameter. Differences between treatment least square means were determined using the LINES option as well as the SLICE and SLICEDIFF options when interaction effects were significant ($P \leq 0.05$).

Table 1. Hybrids, corn seeding information and irrigation rates for a continuous corn study near Clay Center, NE.

		Corn seeding		Irrigation rate	
Year	**Corn hybrid**	**Date**	**Rate**	**Full**	**Limited**
			# ac^{-1}	**--inches--**	
2010	Pioneer 1173HR	April 21	29,512	5.59	3.35
2011	Pioneer 541 AM-RR	April 29	29,512	5.31	3.19
2012	Pioneer P1498HR	April 24	34,014	7.72	4.76
2013	Pioneer P0876-CHR	May 16	34,000	3.97	2.40
2014	Pioneer P0876-CHR	May 2	34,320	3.97	2.40
2015	DeKalb 60-67	May 1	34,320	7.98	4.79
2016	DeKalb 60-67	May 13	34,000	9.31	5.59

RESULTS AND DISCUSSION

Grain yields increased with stover removal and N rate. Grain yield were similar between full and limited irrigation across years (**Table 2**). For the 180 lbs. N acre^{-1} rate, grain yields averaged 238 bu. acre^{-1} and averaged 202 bu. acre^{-1} for the 112 lbs. N acre^{-1} rate. Stover retention grain yields averaged 216 bu. acre^{-1}. Stover removal resulted in a 225 bu. acre^{-1} average. Corn population stands were similar for all treatments for this study (data not shown). Grain yield increases have been previously reported under no-till, irrigated continuous corn when stover was removed in eastern Nebraska (Schmer et al., 2014; Wortmann et al., 2016). Grain moisture values were lower for stover removal, limited irrigation, and lower N rate treatments. Lowest grain moisture values (15.9%) tended to be from stover removal and no amelioration treatment. Harvest index was greater with stover removal and increased N rate. Harvest index tends to increase with N rate but was not affected by stover removal in other studies (Sawyer et al., 2017; Sindelar et al., 2015).

As expected, nitrogen use efficiency measures that are related to plant biomass or grain yield decreased with increased N rate. Stover removal has been shown to have mixed effects on nitrogen use efficiency (Sawyer et al., 2017). In this study, system N efficiency, a comparison of grain N to applied N, was influenced by amelioration practice, residue removal, and N rate (**Table 2**). Manure application resulted in greater SNE (96%) compared with winter cereal rye ($P = 0.0363$) and no amelioration practice ($P = 0.0244$). Manure application, however, resulted in lower INE values (40.8 kg kg^{-1}) compared with winter cereal rye (43.3 kg kg^{-1}) or no amelioration practice (43.5 kg kg^{-1}). Stover removal had a higher SNE (96%) than stover retention (89%) while the 112 lbs. N acre^{-1} fertilizer rate resulted in a higher SNE (98%) compared with 180 lbs. N acre^{-1} rate (87%). Similar to Sawyer et al. (2017), INE was not influenced by stover removal (**Table 2**). A residue removal x amelioration interaction was found for PFP (**Table 2**). Manure with residual removal resulted in the greatest PFP (85.7 kg kg^{-1}) followed by winter cereal rye (83.0 kg kg^{-1}). Residue retention resulted in similar PFP values for each amelioration practices ranging from 77.6 to 78.9 kg kg^{-1}. Previous research in Minnesota showed no effect of stover removal or N rate on NHI (Sindelar et al., 2015). In this study, a three-way interaction of amelioration practice x residue x nitrogen rate was found for NHI (**Table 2**). Nitrogen harvest index was similar by residue treatments for the 180 lbs. N $acre^{-1}$ rate but NHI was greater for the 112 lbs. N $acre^{-1}$ rate when stover was removed. Stover removal at the 180 lbs. N $acre^{-1}$ rate resulted in a greater ($P = 0.0036$) NHI value for the no amelioration treatment.

Table 2. Significance of fixed sources of variation for grain yield, grain moisture, harvest index (HI), and nitrogen use efficiency (NUE†) by irrigation (I), carbon amendment (C), residue removal (R), and fertilizer nitrogen rate (N).

Sources of		--------Grain--------			------------NUE------------			
variation	df	Yield	Moisture	HI	PFP	NHI	INE	SNE
		-------------------*P*-values-------------------						
I	1	ns	0.0310	ns	ns	ns	ns	ns
C	2	ns	0.0086	0.0341	ns	ns	<.0001	0.0455
R	1	0.0200	<.0001	0.0066	<.0001	<.0001	ns	0.0002
N	1	<.0001	<.0001	0.0036	<.0001	ns	<.0001	<.0001
IxC	2	ns	ns	ns	ns	ns	ns	ns
IxR	1	ns	0.0221	ns	ns	ns	ns	ns
IxN	1	ns	ns	ns	ns	ns	ns	ns
CxR	2	ns	<.0001	ns	0.0024	ns	ns	ns
CxN	2	ns	ns	ns	ns	ns	ns	ns
RxN	1	ns	ns	0.0023	0.0005	0.0473	ns	ns
IxRxC	2	ns	ns	ns	ns	ns	ns	ns
IxCxN	2	ns	ns	ns	ns	ns	ns	ns
IxRxN	1	ns	ns	ns	ns	ns	ns	ns
CxRxN	2	ns	ns	ns	ns	0.0117	ns	ns
IxCxRxN	2	ns	ns	ns	ns	ns	ns	ns

†Nitrogen use efficiency includes partial factor productivity (PFP), nitrogen harvest index (NHI), internal nitrogen efficiency (INE), and system nitrogen efficiency (SNE).

SUMMARY

A grain yield increase can be expected for irrigated, no-till continuous corn by removal of stover. Exceptions would be in severe drought conditions as experienced in 2012. Stover removal rates and frequency would likely be less than in this current study. Amelioration practices to maintain SOC and reduce soil erosion resulted in increased INE and SNE while maintaining grain yields. Further information is required to ensure that stover harvest with or without amelioration practices is economically viable to producers.

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