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Research Letter

Ten-Year Assessment Encourages No-Till for Corn Grain and Stover Harvest

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Core Ideas

- No-till with 35% stover removal met corn grain yield, income, and soil protection goals.
- Profitability for no-till and chisel plow systems were equal due to lower machinery costs.
- Cost-efficient stover harvest is essential for bio-economy development.

Abstract: Developing a bio-economy by harvesting crop residues from highly productive corn (*Zea mays* L.) cropping systems requires science-based management decisions to maintain or enhance grain yield and soil, water, and air resources. Which tillage and stover harvest practices are best for accomplishing these goals? Continuous corn grain yield response to either no-till or chisel plowing with two stover harvest rates (3.4 or 5.1 Mg ha^{-1} yr^{-1}) was evaluated for 10 yr in central Iowa. Each tillage and stover removal combination was replicated four times. Year-to-year variation affected grain yield more than tillage practice (0.2 Mg ha^{-1}) or stover removal (0.1 Mg ha^{-1}). Grain yields were not statistically different (p = 0.33) between tillage systems. Including machinery costs made return on investment for chisel plow and no-till equivalent even though no-till yields were numerically lower. Net stover income per megagram was US$2 to $4 greater at the 3.4 versus 5.1 Mg ha^{-1} harvest rate because of more efficient harvesting. Among the four practices, no-till with 3.4 Mg ha^{-1} stover harvest met multiple goals, including providing acceptable corn grain yields, positive net income per megagram stover, and sufficient residues to protect the soil.

Increasing corn (*Zea mays* L.) grain yields, residue management challenges, and slowly emerging bioenergy and bioproduct markets for cellulosic feedstock have created many questions regarding which tillage and stover removal practices will best meet agronomic, bio-feedstock, and producer goals. Grain yields, especially under humid, rainfed conditions, such as those in Iowa, are often affected by tillage with no-till yields being 5 to 10% lower than with conventional tillage (DeFelice et al., 2006; Pittelkow et al., 2015; Toliver et al., 2012). One reason for lower no-till yields is that greater amounts of surface residue with excess C relative to N can result in greater N immobilization and decreased N availability for future crops as the stalks degrade (Pittelkow et al., 2015). Harvesting some corn stover can potentially increase no-till yields by addressing these C/N issues (Karlen et al., 2014) and reduce the need for higher N fertilizer rates (Coulter and Nafziger, 2008). However, to protect against soil erosion and build soil organic matter, up to 60% of the aboveground biomass (stover) may need to be kept in the field (Wilhelm et al., 2010). Continued excessive stover removal, such as removing all aboveground biomass, can reduce C inputs to the soil, leading to lower soil organic matter and less N mineralization over time (Johnson et al., 2010).

Yield has been the traditional metric for crop production, but adopting no-till practices may be financially better because production costs can be reduced by 5 to 10% compared with conventional tillage. Al Kaisi et al. (2015) summarized a 10-yr continuous corn study in Iowa and showed a return on investment (ROI) of US$469 ha^{-1} for no-till compared with $434 ha^{-1} for chisel plow. Adoption of no-till practices can also protect soils from erosion, reduce potential soil organic matter decline, and provide more efficient nutrient recycling through residue decomposition (Wilhelm et al., 2004). In this study, we evaluated the effects of two tillage and stover harvest rates on corn grain and stover yield from a 10-yr study in central Iowa.

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Abbreviations: ROI, return on investment.

Methods

The research site was established in 2008 at the Iowa State University Agricultural Engineering and Agronomy Research Farm (42.017584°, –93.76448° WGS84). The primary soil types were Webster silty clay loam (fine-loamy, mixed, superactive, mesic Typic Endoaquolls) on 0 to 2% slopes and Clarion loam (fine-loamy, mixed, superactive, mesic Typic Hapludolls) on 2 to 5% slopes. Four treatments evaluated two tillage systems (no-till and chisel plow with spring disking) and two corn grain stover removal rates (moderate [10-yr average 3.4 Mg ha^{-1}] and high [10-yr average 5.1 Mg ha^{-1}]) in continuous corn. Each treatment was replicated in four plots. Individual plots were 85.3 m long and 12.2 m wide (0.104 ha). Residues were harvested using a single pass collection, and removal rates were measured using a weigh-wagon. Annual stover tissue samples were analyzed for nutrient content at a commercial testing laboratory. These plots were part of a larger research effort evaluating multiple crop systems (Karlen et al., 2014). Additional studies have focused on several aspects of corn stover bioenergy systems, including nutrient removals and costs (Johnson et al., 2010; Karlen et al., 2015).

Corn was planted 5 cm deep at approximately 79,000 kernels ha^{-1} (32,000 kernels ac^{-1}) with a 0.76-m (30-in) row spacing. Average fertilizers (kg N, P, or K ha^{-1}) applied per calendar year at high versus moderate stover removal rates were similar for N (219 vs. 218 kg), P (38 vs. 45 kg) and K (185 vs. 170 kg) and applied on plot-specific nutrient needs. Grain and stover were harvested using John Deere 9600 series combines equipped with eight-row heads. Corn grain and stover yields are reported on a 0 kg^{-1} moisture (dry mass) basis.

Calendar-year average temperature and precipitation data were collected for Iowa region 5 (NOAA, 2018). Growing conditions between 2008 and 2017 included near record highs and lows (Fig. 1). Given this range, these 10 years provide valuable yield data for how these management systems operate over the range of weather conditions that occur in central Iowa.

Preharvest machinery costs were calculated for each year from 2008 to 2017 using estimated Iowa production costs (Plastina, 2018). Marketing year statewide Iowa corn prices were used from USDA National Agricultural Statistics Service (2018). Stover harvest costs were estimated from previously calculated biomass harvesting costs reported by Archer et al. (2014) for the same treatments used in this study. Iowa cornstalk biomass price estimates were obtained from the USDA Agricultural Marketing Service National Biomass Energy Report (NW-GR310) (USDA Agricultural Marketing Service, 2018). High and low available biomass price data were averaged by week and mean and median values were generated. Statistical analysis was conducted using R (R Core Team, 2017). All field data and management records are available (Supplemental Table S1).

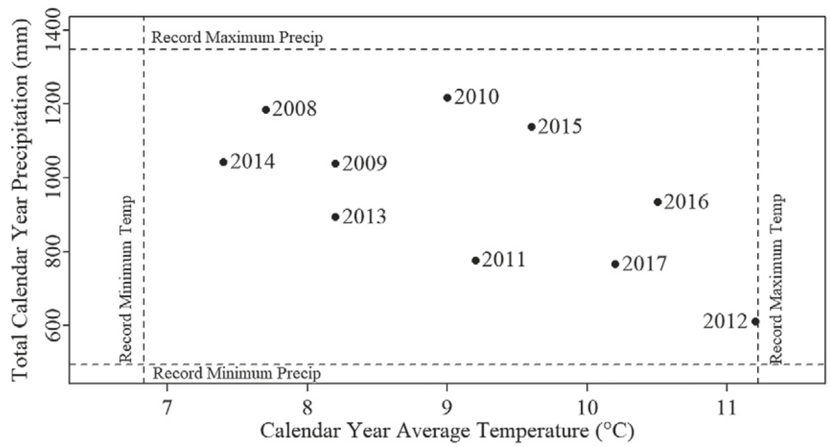

Fig. 1. Calendar year total precipitation and average temperature for central Iowa from 2008 to 2017 with record year minimum and maximum values from 1895 to 2017 noted.

Results and Discussion

Average grain yields had a greater range among years (Fig. 2A; 7.7–10.8 Mg ha^{-1}) than differences between tillage practices (Fig. 2B; 9.7 and 9.5 Mg ha^{-1}) or stover harvest rates (Fig. 2C; 9.6 and 9.7 Mg ha^{-1}).

While year-to-year variability is expected but generally uncontrollable under rainfed conditions, producers do have direct control over tillage and stover harvest practices. Comparing Fig. 2A with Fig. 1 suggests above-average yields with less across-treatment variability, indicated by narrower boxplots, occurred during years with rainfall greater than ~900 mm. For years 2010, 2015, and 2016, higher rainfalls combined with warmer temperatures likely created more favorable growing conditions. Our focus, however, was on yearly rainfall and temperature data and not on weather variability within the growing season. Grain yields were not statistically different for the two tillage practices using $P < 0.1$

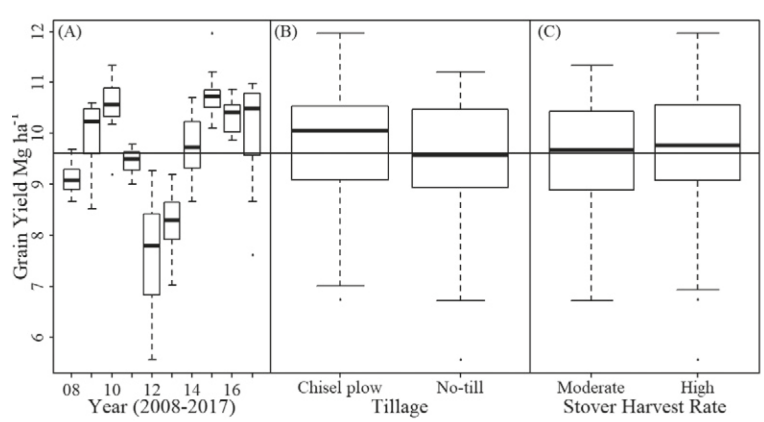

Fig. 2. Boxplots showing grain yield (Mg ha^{-1}, 0% moisture content) by (A) year, (B) tillage, and (C) stover harvest, with the overall average yield (9.6 Mg ha^{-1}) shown as a horizontal line.

for a two-sample t test ($p = 0.33$). However, p values are not the only decision criteria producers use to select tillage practices, particularly since the trend suggests chisel plow had a 0.2 Mg ha^{-1} (3 bu ac^{-1}) higher average yield.

This slight yield difference was less important if machinery costs along with average corn prices were included in a ROI analysis. Producers using chisel plow would need to produce approximately 0.23 Mg ha^{-1} yr^{-1} (0.20 Mg ha^{-1} 0% moisture) more than no-till producers to compensate for higher preharvest machinery costs (Table 1).

This gap covers the average 0.2 Mg ha^{-1} yield difference between chisel plow and no-till at this site from 2008 to 2017 (Fig. 2B). We recognize that a producer transitioning from a chisel plow to a no-till system would incur additional economic and opportunity costs, such as selling and purchasing new equipment or learning a new crop management approach, but we are convinced long-term ROI is a more sustainable basis for making agronomic evaluations than focusing only on yield.

No-tillage practices may be even more desirable for producers who are interested in harvesting corn stover to generate additional income from animal feed and/or bedding or cellulosic feedstock (Karlen et al., 2014). At this site, the high removal rate (5.1 Mg ha^{-1}) was above the recommended upper limit (i.e., leaving 60% residue in the field) suggested by Wilhelm et al. (2010). Based on the 9.6 Mg ha^{-1} corn grain yield average (Fig. 2) and assuming a 1:1 grain-to-stover ratio (Wilhelm et al., 2011), the upper limit would be 3.8 Mg ha^{-1} of stover harvest. Pushing the sustainability limits is not necessary since the results also suggest there was no potential economic benefit associated with removing higher amounts of stover due to higher harvest costs. Stover harvesting costs will depend on the method of collection, which for this study was a single-pass operation. The moderate removal rate (3.4 Mg ha^{-1}) with either no-till or chisel plow practices was calculated to net \$2 to \$4 Mg^{-1} more than the high removal rate based on either mean or median weekly cornstalk prices (Table 2). As expected, the high stover removal treatment increased gross returns by \$40 to \$50 ha^{-1} compared with moderate removal, but due to higher harvest cost the unit cost per megagram of stover was lower. Since individual producers may be interested in maximizing gross returns or maximizing returns per unit cost, this 10-yr study confirms that long-term research focused on the entire bioenergy production system is needed to adequately characterize grain and stover harvest, soil resource, and ecosystem service effects.

Conclusion

A 10-yr corn grain yield comparison between no-till and chisel plow treatments showed similar yields and ROI when estimated preharvest machinery costs were included. No-till can thus be a viable option for stover removal systems. The

Table 1. Preharvest machinery costs between chisel plow and no-till continuous corn treatments using Iowa State University Extension cost of production estimates.

Year	Preharvest machinery costs†		Cost difference	Average corn price‡	Yield needed to cover cost difference
	Chisel plow	No-till			
	———— \$ ha^{-1} ————			\$ Mg^{-1} (× 10^{-3})	Mg ha^{-1}
2008	99.8	58.8	41.0	0.161	0.253
2009	92.6	55.8	36.8	0.141	0.260
2010	92.1	54.1	38.0	0.206	0.185
2011	105.2	69.9	35.3	0.244	0.145
2012	114.3	76.5	37.8	0.272	0.139
2013	114.3	76.5	37.8	0.177	0.214
2014	122.5	83.0	39.5	0.146	0.270
2015	115.3	78.5	36.8	0.139	0.265
2016	109.6	75.3	34.3	0.130	0.264
2017	109.6	71.4	38.3	0.128	0.299
Average	107.5	70.0	37.6	0.174	0.230

† Includes fixed and variable preharvest machinery costs for continuous corn and low-till corn and soybean using the corn data (Plastina, 2018).

‡ Iowa marketing year average corn price (USDA National Agricultural Statistics Service, 2018).

Table 2. Estimated corn grain stover harvesting costs and income for tillage and stover removal treatments.

System	Harvesting cost†	Biomass 10-yr average	Total harvesting cost	Gross income‡ mean/median	Net income mean/median	
	\$ Mg^{-1}	Mg ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ Mg^{-1}
Moderate						
Chisel plow	11	3.336	46	185/175	138/129	33/31
No-till	11	3.450	49	191/181	142/132	32/29
High						
Chisel plow	14	5.029	89	279/263	190/174	30/27
No-till	13	5.104	87	283/267	196/180	29/27

† Calculated from Archer et al. (2014), Table 1.

‡ Biomass average Mg ha^{-1} multiplied by USDA Agricultural Marketing Service weekly average price for Iowa cornstalks of \$55.40 Mg^{-1} and the weekly median price of \$52.36 Mg^{-1} (USDA Agricultural Marketing Service, 2018).

moderate removal rate (3.4 Mg ha^{-1}) provided the most cost effective stover harvest return (\$32 Mg^{-1}). Keeping additional residue in the field may be accruing soil health benefits that will be evaluated in future soil sampling. Overall, using no-till practices with moderate stover removal appears to be a production system that provides short-term sustainable corn grain and stover yields while also protecting soil resources over the wide range of weather conditions that can occur in central Iowa. A significant research challenge remains to ensure research results from bioenergy production systems quantitatively address long-term agronomic, economic, and soil resource impacts over multiple decades.

Supplemental Material

Supplemental Table S1 includes plot grain and stover yield information, along with harvest dates, cultivars, and nutrients applied.

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