Cover Crops and Strip Tillage had no Effect on Yield in Production-scale Sugarbeet Fields

Anna M. Cates[2], Jodi DeJong-Hughes[1], Dorian Gatchell[3], Mark Bloomquist[4]

[1]University of Minnesota Extension, Wilmar, MN, USA. [2]University of Minnesota, Department of Soil, Water, and Climate, St. Paul, MN, USA. [3]Minnesota Ag Services, Granite Falls, MN, USA. [4]Southern Minnesota Beet Sugar Cooperative, Renville, MN, USA.

Abstract

Sugarbeet production, including pre-season tillage and late-season soil inversion to lift beets, leaves soil vulnerable to wind erosion by removing all residue cover from soil. The integration of cover crops and strip tillage can provide protection of soils from wind erosion in sugarbeet fields, while also potentially improving soil health, decreasing water erosion, and nutrient losses. However, it's critical to show that these practices do not carry risk of lowering profits by diminishing yield and quality. Here, we evaluated the effect of strip-tillage with and without cover crops prior to sugarbeet on sugarbeet yield and quality parameters. We performed replicated strip trials on three growers' fields in Western Minnesota, using production-scale equipment and grower best management practices, and found no effect of strip-tillage with or without cover crops in yield, sucrose %, sucrose purity, or extractable sucrose (P>0.10 for all variables). This indicates that adopting strip-till and cover crops practices poses little risk to on-farm profit.

Introduction

Sugarbeet production in Minnesota is concentrated on flat, fine-textured soils in the Western and Northwestern part of the state, where wind erosion rates are estimated at between 10 and 11.6 Mg/ha/yr (Soil Survey Staff, NRCS, 2015, USDA National Agricultural Statistics Service, 2018, Erosion by State NRI 2017). Standard sugarbeet management practices in Western Minnesota include full-width fall tillage, which can exacerbate erosivity by reducing soil structure and reducing plant residue cover (den Biggelaar et al., 2003). However, many growers use spring-planted cover crops, which provide a small amount of living residue to slow soil movement and protect sugarbeet seedlings (Wilson et al., 2001).

Growers may be able to increase protection by planting fall-seeded cover crops, which produce more biomass and more effectively slow wind erosion during vulnerable early spring periods (de Baets et al., 2001), and by switching to strip-tillage, cultivating only the strips where crops will be planted. Strip tillage is known to reduce water erosion (Ryken et al, 2018). This effect is presumably due to both changes in surface roughness (Wagner & Fox, 2013) and increases in

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soil organic matter (Fernández et al., 2015) and biological activity (Jaskulska et al., 2020), although aggregate stability is not always increased in strip-till systems (Al-Kaisi et al., 2014, Fernández et al., 2015). While rates of wind erosion in strip-till systems had not been studied in the field, the Wind Erosion Prediction model (WEPS) predicted that the erosion rate decreased 94% in strip till relative to conventional till (Ruffin & Tallman, 2017), as tilled strips break up the surface and slow the movement of dislodged particles.

In order for environmental benefits to be realized on agricultural lands, they must fit into a profitable farm system, and evidence is mixed on how fall-seeded cover crops and strip-tillage may affect sugarbeet yield, quality, and profit. Winter camelina and winter wheat cover crops decreased sugarbeet stand establishment and root yield in four site-years of a North Dakota study, coincident with lower soil water content under winter cover crops (Cabello-Leiva, 2022). In Germany, a winter-hardy cover crop decreased beet emergence due to increased residue, but researchers thought that better planting equipment could overcome the challenges of planting through residue, and yield was comparable as long as weeds were controlled (Peterson & Rover, 2005). Living mulch terminated at sugarbeet stage V2 had no impact on beet yield in a 4-year Montana field experiment (Keshavarz Afshar et al., 2018). These mixed results show that cover crops must be applied carefully, in the context of a complete growing system, in order to mitigate potential yield losses (Marcillo & Miguez, 2017).

Strip-till has been used in sugarbeet in relatively few locations (Evans et al., 2009; Overstreet, 2009), so few growers are willing to risk high-value crop yield to experiment with new practices. Satellite data suggests that no more than 32% of acres in MN and ND beet-growing regions along the Red River of the North used conservation tillage between 2005 and 2020 (OpTIS, 2020). In recent years, Vice President of Agriculture and Research with Minn-Dak Farmers' Cooperative, Mike Metzger, reported sugar content was similar with strip till and conventional tillage plots with and without cover crops. However, root yield was 5.1 Mg/ha less with strip till than with conventional tillage (Metzger, 2019, personal communication). In contrast, Overstreet (2009) found the sugar content was lower with strip till than with conventional tillage but had similar tonnage when the berm was leveled and the planter could plant the seed at the proper depth.

A large-field study in Montana investigated the economics of strip till versus conventional tillage at 6 locations (Ruffin & Tallman, 2017). The researchers reported that, overall, farmers saved 40% per acre when using strip till in sugarbeet. This is due to using less fuel, less wear and tear on equipment, less irrigation, and fewer passes across the field. Farmers also saved an average of one hour of labor per acre. Cover crops and strip-till can be a risk *mitigation* strategy as they help the soil be more resilient to the effects of wheel traffic by reducing wheel rutting and soil compaction during periods of excess moisture. Cover crop residue also conserves moisture later in the growing season, which has been shown to reduce yield variability in maize (Leuthold et al., 2021). The soil resilience to wheel traffic may also allow sugarbeet producers to be more precise in critically timed pesticide applications allowing for a healthier crop and potentially higher yields due to more field working days (Fletcher and Featherstone 1987).

Strip till and cover crops could potentially reduce environmental impacts, and strip-tillage can increase efficiency by combining field passes to till and fertilize, as well as use less fuel. However, the systems need to be tested in the upper Midwest climate and soils. Here, we tested the effects of strip till and fall-seeded cover crops on sugarbeet yield and quality in farmers' fields, using field-scale equipment.

Materials and Methods:

This field experiment was conducted at three fields near Winthrop (Field 1), Danvers (Field 2), and Granite Falls (Field 3), Minnesota (Figure 1). Treatments included: strip-till (ST), strip-till with cover crops interseeded early in the corn growing season (ST + Early CC), strip-till with cover crops seeded late in the corn growing season (ST + Late CC), and chisel plow (CP). The field experiment was a randomized complete block design with three replications, although different treatments were present in different locations (Table 1). The timeline of crop management and data collection is given in Table 2.

This area is characterized by cold winters and hot, dry, summers, with mean annual precipitation of 1,817 mm (515 mm May-Oct) and mean annual temperature of 6 °C (16°C May-Oct, -4.4°C in Nov-April) (Minnesota DNR, no date). Both growing seasons were drier than normal, with 372 mm of precipitation May-Oct in 2020, and 447 mm May-Oct in 2021, which mostly fell late in the growing season (Minnesota DNR, no date). We observed that the cover crop establishment in 2020 was not very successful: there was minimal emergence of clover and annual ryegrass in the ST + Early CC treatment, which soon died back as corn canopy closed. Late-planted cereal rye in the ST + Late CC also produced small amounts biomass. Based on these field conditions, cover crop treatments were relatively minimal.

Table 1: Tillage and cover crop treatment descriptions applied at three Minnesota farm locations between 2020 and 2021.

Treatment	Tillage	Cover crop	Fields
ST	Fall strip till (Field 3 had a second additional pass in the spring on the strip till treatments)	None	1,2,3
ST + Early CC	Fall strip till	Crimson clover (5.6 kg/ha) & annual rye (14.5 kg/ha) interseeded at V2-V4 corn	1
ST + Late CC	Fall strip till	Cereal rye (67 kg/ha) applied aerially by drone as corn was reaching maturity	1, 2, 3
CP	Fall chisel plow, spring field cultivation	None	2, 3

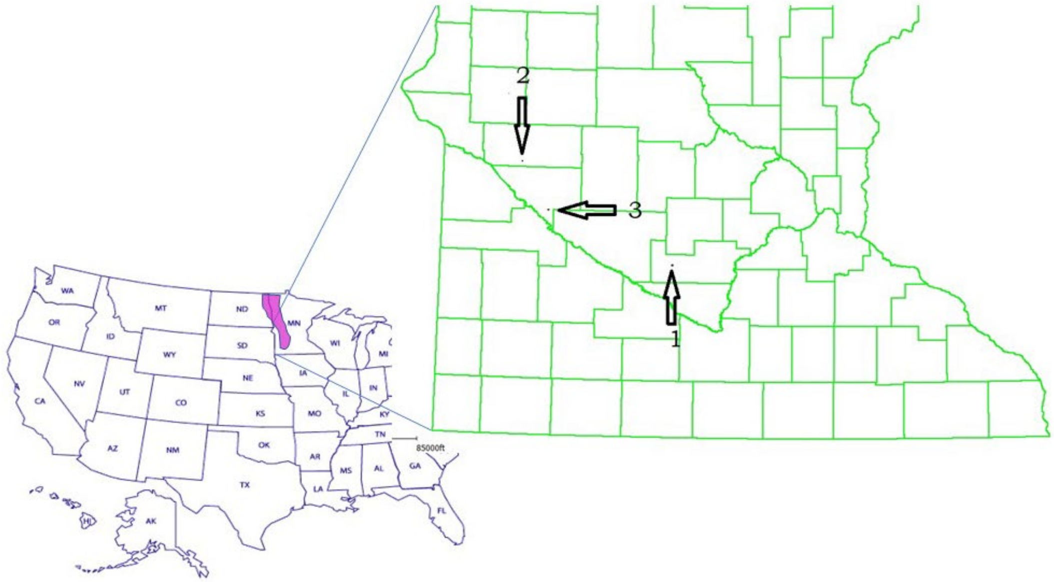


Figure 1: Field locations in Minnesota. The pink shaded area on the US map represents approximate range of beet production in the region.

Figure 2: Representative image of poor growth of cereal rye cover crops at Field 3 in ST+ Late CC (Table 1), planted Sept 9 2020 and pictured here April 26 2021.

Table 2: Timeline of field activities

Year	Month	Activity
2020	May 10-20	Soil sampling for fertility, corn planting (all treatments)
	June 5-10	Cover crop treatments drilled (ST+ Early CC)
	September 9-10	Cover crop treatments aerially planted (ST+ Late CC)
	October 15-21	Harvest corn
	Oct 21-Nov 6	Fall strip till and chisel plow tillage treatments
2021	April 30	Field cultivation (CP)
	April 22- April 30	Plant sugarbeets (Field 1: Crystal M837; Field 2: SESVanderHave 862; Field 3: SESVanderHave 863)
	June 9	Assess beet stands
	September 28 and October 4	Hand-harvest beets

All tillage and planting equipment used was field scale. Corn and sugarbeets were planted in 0.56-m rows, in 13.6-m wide plots. Plots were the length of the fields, 0.8 km. Sugarbeet stand count was assessed by counting seedlings in .914 m sections at eight randomly distributed locations per plot (avoiding wheel-trafficked areas). At harvest three meters of row were hand-harvested at six locations per plot (three evenly distributed transects at each long end of the plot) and weighed for Mg per hectare yield calculation.

Each sample was analyzed for percent sucrose, percent extractable sucrose, and percent purity by the Southern Minnesota Beet Sugar Cooperative (SMBSC). The SMBSC used a near-infrared (NIR) system to assess % sucrose (DA 7250 NIR Analyzer, Perten Instruments, Springfield IL) based on a calibration curve comparing NIR to the GS6-4 ICUMSA (ICUMSA Method GS6-3, 1994). Percent purity was also assessed using NIR, based on the quantity of sucrose relative to the total dissolved solids in the beet, reported as a percent. Percent extractable sucrose was calculated using a SMBSC proprietary formula estimating the percent of the sucrose in the beet that the factory will be able to extract and granulate, based on percent sugar, percent purity, factory operation assumptions and constants.

Statistical Methods

Since treatments were unbalanced among fields, we used two separate models to assess 1) the effect of late-planted cover crops in strip till at all three sites (ST vs ST + Late CC at Fields 1, 2, and 3) and 2) the effect of three tillage/cover crop treatments at two sites (ST vs ST+ Late CC vs CP at Fields 2 and 3). The same models were used to evaluate the response variables of stand counts, yield, % sucrose, % purity, and % extractable sucrose. We used a linear mixed model with treatment, field and field x treatment as fixed effects, and replicate as a random effect (*lmer*, R package *lmerTest* (Kuznetsova et al., 2020), analyses conducted in R v 4.0.4 (R Core Team, 2016)). Pairwise contrasts between treatments or fields were assessed using estimated marginal means (*emmeans* R package) (Searle et al. 2022).

Results

We evaluated beet response to cover crop and tillage treatments, and overall, we found that fields varied from each other in beet yield and quality, but there was no effect of tillage and cover crop treatment. Comparing ST and ST + Late CC at all three fields, we found no treatment differences in stand counts, yield, % sucrose, % extractable sucrose, or % purity (Table 3). We did find a significant main effect of field in all metrics except stand count (Table 4). The yield (Figure 1) was significantly lower at Field 1 than at Field 3. Field 1 had lower % sucrose (Figure 2) and % extractable sucrose (13.3% compared to Field 2, 14.0% and Field 3, 14.1%). Percent purity was greater at Field 2 (91.0%) than at Fields 1 (90.3%) and 3 (90.3%).

Evaluating three treatments (CP, ST, ST + Late CC) at Fields 2 and 3, we also found no treatment effects, and similar trends by field as the assessment across three locations (Table 3). Fields 2 and 3 differed in stand counts, yield and extractable sucrose. Yield and extractable sucrose were greater in Field 3, while stand count was higher in Field 2.

Table 3: Analysis of variance results for beet yield and quality, based on the three treatments present in two fields or two treatments present in three fields (see Tables 1 and 2) for treatment details).

	Sum Squares	Mean Squared Error	Numerator degrees of freedom	Denominator degrees of freedom	F value	Pr(>F)
			2 treatments, 3 fields			
Stand Counts						
Treatment	3.0E+08	3.0E+08	1	186	2.37	0.125
Field	2.7E+08	1.4E+08	2	186	1.09	0.339
Field x Treatment	3.1E+08	1.5E+08	2	186	1.25	0.288
Yield						
Treatment	0.05	0.05	1	102	0.0283	0.867
Field	16.89	8.44	2	102	5.15	<0.01
Field x Treatment	0.73	0.37	2	102	0.223	0.800
Percent Sucrose						
Treatment	0.17	0.17	1	100	0.301	0.584
Field	16.28	8.14	2	100	14.4	<0.0001
Field x Treatment	0.14	0.07	2	100	0.125	0.882
Percent Extractable Sucrose						
Treatment	1.7E+05	1.7E+05	1	102	0.175	0.676
Field	5.0E+07	2.5E+07	2	102	24.9	<0.0001
Field x Treatment	6.8E+05	3.4E+05	2	102	0.342	0.711

Purity						
Treatment	0.0085	0.0085	1	102	0.0217	0.883
Field	13.05	6.52	2	102	16.6	<0.0001
Field x Treatment	0.49	0.24	2	102	0.616	0.542
			3 treatments, 2 fields			
Stand Counts						
Treatment	3.2E+07	1.6E+07	2	210	0.144	0.866
Field	6.1E+08	6.1E+08	1	210	5.43	0.021
Field x Treatment	1.7E+08	8.6E+07	2	210	0.762	0.468
Yield						
Treatment	3.08	1.54	2	101	0.926	0.399
Field	11.88	11.88	1	101	7.150	<0.01
Field x Treatment	1.14	0.57	2	101	0.343	0.710
Percent Sucrose						
Treatment	1.238	0.619	2	101	0.983	0.378
Field	0.043	0.043	1	101	0.068	0.795
Field x Treatment	0.336	0.168	2	101	0.267	0.766
Percent Extractable Sucrose						
Treatment	7.9E+05	3.9E+05	2	101	0.449	0.639
Field	2.6E+07	2.6E+07	1	101	29.957	<0.0001
Field x Treatment	2.3E+06	1.1E+06	2	101	1.304	0.276
Purity						
Treatment	0.0139	0.0070	2	99	0.015	0.985
Field	1.080	1.080	1	99	2.358	0.128
Field x Treatment	0.472	0.236	2	99	0.515	0.599

Table 4: Stand count (plants per hectare).

Treatment	Field 1	Field 2	Field 3
ST	102,666	107,963	98,592
ST + Late CC	116,519	107,148	104,296
CP	NA	112,037	97,778
ST + Early CC	101,116	NA	NA

Figure 3: 2021 sugarbeet yields by strip-till and cover crop treatments at 3 locations in Minnesota. In the box-and-whisker plots, the colored portion represents data between the 25th and 75th percentile, the horizontal line in the middle represents the median, and the vertical lines extend to the maximum and minimum of the data. See Table 3 for statistical analysis, and Tables 1 and 2 for full treatment details. CP = chisel plow, ST = strip-till, CC = cover crop.

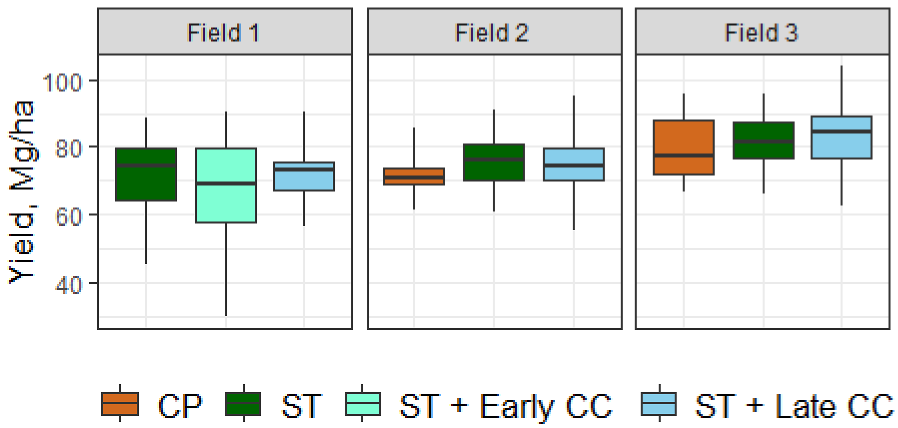
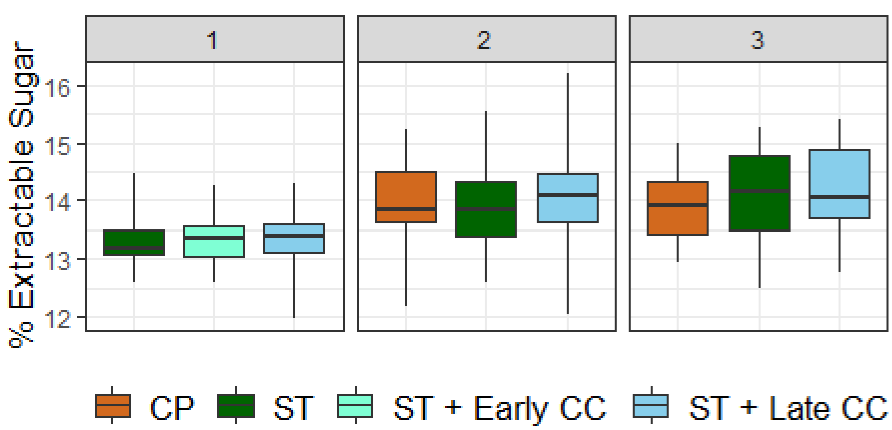


Figure 4: Sugarbeet 2021 extractable sucrose yield (%) by strip-till and cover crop treatments at 3 locations in Minnesota. In the box-and-whisker plots, the colored portion represents data between the 25th and 75th percentile, the horizontal line in the middle represents the median, and the vertical lines extend to the maximum and minimum of the data. See Table 3 for statistical analysis, and Tables 1 and 2 for full treatment details. CP = chisel plow, ST = strip-till, CC = cover crop.



Discussion

We found that beets grown with strip-tillage, with or without cover crops, yielded similar to beets grown using conventional tillage at two field locations (P=0.866). The sugarbeet quality measured in our study was similar to SMBSC 2021 averages: 16.37% sucrose, 13.79% extractable sucrose, and 90.6% purity (Mark Bloomquist, SMBSC, personal communication). Our beet yields are also in the range of other recent research in Minnesota (Chaterjee et al. 2019, Lystad et al. 2020), and average yield for SMBSC in 2021 were 82 Mg/ha (Mark Bloomquist, SMBSC, personal communication), so we are confident that the treatments imposed here are relevant for competitive regional beet production. This is similar to regional data showing competitive yields in corn and soybean with strip-till (Daigh et al. 2019). Beet yields in strip till in were similar to conventional till Montana (Keshavarz et al. 2019), lower in Germany (Laufer and Koch, 2017), and greater in Poland (Gorski et al. 2022). Others have found variation by site-year in strip-till (Wenninger et al. 2019, Overstreet 2009) and Evans et al. (2009) suggests that clay soils may require fall strip-tillage while sandier soils may do better with a spring pass, so the technology will need to be tailored to individual conditions. Another consideration will be the interaction of tillage system with disease severity, especially for *Cercospora beticola.* This has not been studied specifically in strip-till systems. Tillage is recommended after harvest to speed leaf decay in Montana (Jacobsen et al. 2010), and whether tillage in the strip would be sufficient for this purpose has not been studied.

Cover crop growth in this study was minimal and had a correspondingly nil effect on the beet yield and quality. In Idaho, oilseed radish planted before beets was found to increase mesopores in the soil, leading to increased soil saturation (Wenninger et al. 2019). This could be a concern in the beet growing areas of North Dakota and Minnesota, where spring water saturation can delay planting or cause a need for replanting, which usually reduces yields (Bloomquist et al., 2019). However, under wet conditions, Cabello-Leiva (2022) found no difference in soil water content, beet yield or quality with a large number of cover crop treatments in North Dakota. We need more studies on effects of cover crops on soil moisture under different conditions, to better predict whether the increased soil water retention due to residue or water use of growing cover crops dominates the annual water balance.

Conclusions

We found no response in beet yield or quality to tillage or cover crop treatments at three site-years in Western Minnesota. There is a need to test these technologies in more locations and conditions, and future research should explore cover crop treatments with more robust growth, as that could change the cover crop's effect on beet outcomes. Farmer adoption of strip-till technology can be hampered by high equipment costs and pressure to conform to production norms in their area (Grover and Gruver, 2017) as well as fear of risk to production, so addressing these other barriers will be critical to increase adoption of strip-till from current low levels (<32% between 2005 and 2020 in Western Minnesota (OpTIS, Conservation Technology Information Center)). In addition, future work should more precisely quantify the expected environmental benefits of reduced till and cover crop systems in sugarbeets.

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