Spring-seeded Green Manures Continue to Demonstrate Variable Benefits on Sandy Soil

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Abstract. Spring-planted green manure cover crops may provide a nitrogen (N) benefit to a subsequent sweet corn (*Zea mays* L.) crop, but spring growth and lack of consistent benefits documented in previous studies provide limitations to adoption. Berseem clover (BC; *Trifolium alexandrinum*) and chickling vetch (CV; *Lathyrus sativus* L.) are two legumes that could be beneficial when spring-seeded, but they have not been well studied in this context. The objectives of this study were to measure spring-seeded cover crop biomass and N yield, and the subsequent effects on sweet corn yield and response to N fertilizer. The study was conducted in 2014 and 2015, and the experimental design was a randomized complete block split-plot design with cover crop as whole-plot treatments [CV, BC, berseem clover and oat (*Avena sativa*) mixture (BC + O), oats, and no cover crop] and N rate as split-plot treatments. Cover crop growth and effects on sweet corn production varied greatly between years, with both cover crop and sweet corn biomass greater in 2015, although BC produced very little biomass ($<0.7 \text{ Mg}\cdot\text{ha}^{-1}$) and thus is not recommended for spring seeding. In 2014, CV resulted in the lowest agronomically optimum N rates (AONRs) compared with no cover crop, suggesting a potential N credit when only having an N yield of $11.6 \text{ kg}\cdot\text{ha}^{-1}$, but this effect was not seen in 2015. There was also no evidence that oat would supply N to the subsequent crop. Overall, evidence is lacking that any spring-seeded cover crop will provide a consistent N benefit on sandy soil, and limitations to spring growth may preclude widespread adoption.

Spring seeding of green manure cover crops expands the opportunity for their use in northern climates where there are limited opportunities to plant covers in the fall before snowfall. In regions characterized by cooler climates, cash crops typically occupy fields for the majority of the growing season, which limits the ability to plant cover crops in the fall, particularly as options for overwintering grasses and legumes are minimal. Spring seeding allows for greater choice in the types of cover crops that could be used, expanding the ability to integrate species that are not winter-hardy. For certain cool-season cover crops, spring planting (March–April) allows adequate time for cover crops to establish and serve as a supplemental N source, resulting from either sequestration of existing soil N resources or fixation of atmospheric N by

legumes. The potential performance of cover crops within these windows may be limited to soils with high sand content (which will allow for more rapid drying and warming in the spring) and crop rotations that allow for a later planting date of the main crop (e.g., crops that are harvested within 90 d of planting).

The Central Sand Plains of Wisconsin is a landscape in which spring-seeded green manures could be used to provide benefits to irrigated cropping systems. This region has high nitrate concentrations in groundwater (Bero et al., 2014; Kraft et al., 1999), resulting, in part, from high-value, high-N-demand crops grown under pivot irrigation. Sweet corn is a common crop in this region and is typically harvested 90 d after planting (DAP), allowing for a range of planting dates in the spring and summer months. Current fertilizer guidelines for sweet corn are $168 \text{ kg}\cdot\text{ha}^{-1}$ N, but significant amounts of N leaching can occur if crop uptake is not synchronized with plant-available N in irrigated sandy soils (Yuan et al., 2017).

On sandy soils, cover crops can be used both to reduce N leaching (Snapp et al., 2005) and to supply N to the following cash crop (Andraski and Bundy, 2005). Past research on spring-planted legume and grass cover

crops in the Central Sand Plains has shown varying N benefits for sweet corn grown after cover crop integration (Johnson et al., 2012; West et al., 2016). Investigating the potential benefits of field pea (*Pisum sativum*) as a spring-seeded cover crop preceding sweet corn in the Central Sands, West et al. (2016) and Johnson et al. (2012) determined no N benefit from field pea in this system. Beyond field pea, other legume cover crops have not been tested in this region for potential spring biomass production or N contribution to the cash crop production season. Grass green manures such as oat may also supply N to subsequent crops; Andraski and Bundy (2005) showed that oat supplied N to field corn in two of three growing seasons.

Beyond the degree of spring growth, other management factors may impact the N contribution of the cover crop. Cover crop termination methods and subsequent effects on N uptake by the cash crop have not been well studied. West et al. (2016) and Johnson et al. (2012) ended field pea cover crop through mechanical tillage. This aggressive termination technique, which incorporates the cover crop residue into the soil, may have increased decomposition of the plant material and mineralization of N, leading to asynchronous N availability, with N uptake and potential leaching losses. It is likely that chemical termination, without mechanical incorporation, would be more beneficial on sandy soil as a result of the more extended decomposition of the residue and subsequent N mineralization.

Outside of the Central Sands, other cover crops such as CV and BC have provided promising benefits of increased cash crop yields resulting from supplied N credits. When grown as a full-season crop, CV has been shown to increase wheat yields compared with red clover (Bullied et al., 2002). On a sandy loam soil in Winnipeg, Canada, Thiessen Martens et al. (2005) measured an N credit of 29 to $45 \text{ kg}\cdot\text{ha}^{-1}$ after spring-planted CV. Ross et al. (2009) measured 84 to $110 \text{ kg}\cdot\text{ha}^{-1}$ N in their spring-planted BC after 14 to 16 weeks of growth, resulting in an increase in subsequent barley yield. For studies that have evaluated the benefit of cover crops on sweet corn yields, results have been quite variable, showing no effect (Isse et al., 1999) and neutral to positive effects (Bhardwaj, 2006; O'Reilly et al., 2012). In the case of O'Reilly et al. (2012), total sweet corn aboveground biomass (AGB) was greater with oat and oat and oilseed radish cover crops compared to no cover crop; however, this biomass increase did not translate to an increase in marketable sweet corn yield.

Evaluation of other legume cover crops is warranted, as is their effect on crop yield and N fertilizer equivalent. The goal of the study was to determine the N credit of spring-planted grass and legume cover crops (oat, oat + BC, CV, and BC) for sweet corn on irrigated sand, as measured by differences in agronomically optimum N rates determined

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by nonlinear regression. Specific study objectives were 1) to measure spring-planted cover crop growth and N content, and 2) to determine the impact of spring planted cover crops on sweet corn yield.

Materials and Methods

Site description and experimental design.

A 2-year study was conducted in 2014 and 2015 at the University of Wisconsin, Hancock Agricultural Research Station (HARS) (lat. 44°8'23" N, long. 89°31'123" W; elevation, 328 m) on an overhead-irrigated Plainfield loamy sand soil (mixed, mesic Typic Udipsamments). The 2012 fall soil test for the 2014 field indicated 6.5 pH, 0.9% organic matter (OM) (measured as loss on ignition), 89 mg·kg⁻¹ phosphorus (P) Bray 1 extractable P, and 66 mg·kg⁻¹ potassium (K) Bray 1 extractable K. The 2013 fall soil test for the 2015 field indicated 6.5 pH, 0.9% OM, 121 mg·kg⁻¹ P, and 85 mg·kg⁻¹ K. The experimental design was a randomized complete block split-plot, replicated four times. Whole-plot treatments (7.3 × 27.4 m) were spring-planted oat, CV, BC, BC + O, and no cover crop. Split-plot treatments (4.6 × 7.3 m, six corn rows wide) consisted of urea-N fertilizer applications: 0, 56, 112, 168, 224, and 280 kg·ha⁻¹ N.

The experiment in 2014 followed 2 years of field corn and, in Fall 2013, the field received a single tillage pass with a Turbo-Till® (Great Plains Manufacturing, Inc., Salina, KS) field cultivator at a 20-cm depth. In Spring 2014, the field received seedbed preparation with three passes of the Turbo-Till® field cultivator followed by one pass with a 20-cm Brillion (Landoll Corporation, Marysville, KS) soil finisher. In 2015, the experiment followed a soybean–potato rotation, with no tillage in Fall 2014. Cover crop seedbed preparation in 2015 consisted of one pass with the Turbo-Till® field cultivator at a 20-cm depth and 112 kg·ha⁻¹ potash (0–0–60).

The cover crops were drill seeded with the Oliver-Superior No. 64® Grain Drill (Oliver Corporation, Chicago, IL) on 21 Apr. 2014 and on 16 Apr. 2015. Seeding rates were 134 kg·ha⁻¹ for oat (variety not stated in 2014, 'Saber' in 2015), 67 kg·ha⁻¹ for CV ('AC Greenfix'), 13 kg·ha⁻¹ for BC (variety not stated in 2014; 'Balady 1' in 2015), and the combined treatment of BC + O was 67 kg·ha⁻¹ for oat and 11 kg·ha⁻¹ BC (drilled separately). CV was inoculated with 'N-Dure' (Verdesian, Cary, NC) and BC with Nitragin® Gold (Novozymes, River Falls, WI). Cover crop seeds were obtained from Albert Lea Seed (Albert Lea, MN) for both years of the study.

The cover crops were ended on 10 June 2014 with 2.8 L·ha⁻¹ Credit Extra® (Nufarm Americas Inc., Alsip, IL; a.i. 2.3% glyphosate, mixed with nonionic 80/20 surfactant, and ammonium sulfate (AMS; 21–0–0–24S). CV plots were also treated with 0.7 L·ha⁻¹ 2,4 D Amine 4, (Loveland Products Inc.; Greeley, CO, a.i. 46.5% dimethylamine

salt of 2,4-dichloro-phenoxyacetic acid) and 1.9 L·ha⁻¹ Parallel® Plus Herbicide [Makhteshim Agan of North America, Inc., Raleigh, NC; a.i. atrazine 2-chloro-4-ethylamino-6-isopropylamino-s-triazine and metolachlor 2-chloro-N-(2-ethyl-6-mehtylphenyl)N-(2-methoxy-1-methylethyl) acetamide] on 16 June 2014. CV plots received their last herbicide treatment of 211.6 mL·ha⁻¹ Laudis® {Bayer CropScience LP, Research Triangle Park, NC; a.i. 34.5% tembotrione 2-[2-chloro-4-(methylsulfonyl)-3-[(2,2,2-trifluoroethoxy)methyl]benzoyl]-1,3-cyclohexanedione mixed with AMS and methylated seed oil} on 31 July 2014. In the 2015 season, all cover crops were ended 12 June 2015 with an application of 2.1 L·ha⁻¹ Mad Dog Plus® [Loveland Products Inc.; a.i. 41% glyphosate N-(phosphonomethyl) glycine mixed with nonionic 80/20 surfactant and AMS]. The oat cover crop stand required surface cultivation with an M&W® 10' Dyna-Drive® (Alamo Group Inc., Seguin, TX) on 16 June 2015 and a second herbicide application [Parallel® (Atrazine), 1.6 L·ha⁻¹] on 19 June 2015 for complete cover crop termination. Other than the mechanical incorporation of oat in 2015, no tillage was conducted before sweet corn planting.

Sweet corn ('DMC 21-84'; Del Monte Foods Hybrid Yellow Sweet Corn Seed; Del Monte Foods, Walnut Creek, CA) was planted on 13 June 2014 and 19 June 2015 with a John Deere MaxEmerge (Deere & Company, Olathe, KS) 2 four-row planter at a seeding density of 60,500 plants/ha. Six rows were planted per plot at a 76-cm row spacing, and starter fertilizer (10–20–20–4S–2Ca + micronutrients) was applied at planting (224 kg·ha⁻¹). Urea was hand applied at 56 kg·ha⁻¹ N at the V4 sweet corn growth stage and at 56, 112, 168, or 224 kg·ha⁻¹ N at the V8 growth stage. Fertilizer was irrigated within 24 h of application. Irrigation, insecticide, and herbicide were applied by the staff at the HARS as needed.

Sample collection and analysis. Precipitation and daily air temperatures (maximum and minimum) measurements were recorded at HARS–UW Extension AG Weather and were used to calculate growing degree day (GDD) accumulation for both the cover crop and sweet corn growing seasons and were calculated as

$$\text{GDD (}^{\circ}\text{C)} = \left[\frac{T(^{\circ}\text{C})_{(\text{daily max})} + T(^{\circ}\text{C})_{(\text{daily min})}}{2} \right] - T_{\text{base}},$$

where the daily maximum temperature was 30 °C and the daily minimum temperature was 10 °C. T_{base} is the base temperature for each plant, where sweet corn $T_{\text{base}} = 10$ °C and oat $T_{\text{base}} = 5.5$ °C.

Cover crop stand counts, plant height, and AGB yield were collected on 10 June 2014 and 12 June 2015, with three samples collected per whole plot from a 0.37-m² area in 2014 and from a 0.14-m² area in 2015. Cover crop biomass samples were

dried at 60 °C, ground mechanically using a 0.5-mm sieve, and stored in plastic vials until analysis. N content of cover crop biomass was determined by redrying samples for at least 24 h before analysis, with total carbon and total N determined using flash combustion (Thermo Fisher Scientific Flash EA 1112 NC Analyzer; Thermo Fisher Scientific Inc., Waltham, MA). Soil samples were collected in all cover crop plots on the same date as cover crop sampling to a depth of 30 cm; 10 samples were collected and composited for each plot. Soils were analyzed for both ammonium-N and nitrate-N content. Nitrate-N was measured after extraction with 2 M potassium chloride using the vanadium reduction of nitrate method as described in Doane and Horwath (2003). Ammonium-N was determined using the Berthelot reaction (Rhine et al., 1998). Sweet corn was harvested at maturity (90 DAP in 2014 and 89 DAP in 2015) on 11 Sept. 2014 and 11 Sept. 2015. Yield was determined as both fresh weight (FW) yield (in megagrams per hectare) and ear yield (in 1000 ears/ha) by harvesting marketable ears in rows three and four of each six-row plot. Ears were counted and weighted immediately (unhusked) in the field for FW yield calculation.

Statistical analysis. Statistical analysis was completed using SAS (Statistical Analysis System, version 9.2; SAS Institute, Cary, NC). Cover crop biomass, N content, N yield, and carbon (C):N ratio were analyzed with analysis of variance (ANOVA) by year using Proc MIXED, with blocks as a random effect. For sweet corn yields, each study year was evaluated separately, and ANOVA was conducted to determine significant effects of cover crop and N rate (Proc MIXED) with block and block × cover crop as random effects. Interaction effects were explored further with nonlinear regression (Proc NLIN). The AONR was determined for each cover crop treatment by year using linear plateau and quadratic plateau response curves using Proc NLIN (Bullock and Bullock, 1994; Cerrato and Blackmer, 1990). The root mean square error (RMSE) was used to determine which model best represented the data. Differences in AONR between cover crop treatments and no cover crop can be used to assess the potential for cover crop species to supply N to the subsequent crop (e.g., Pantoja et al., 2015).

Results and Discussion

Cover crops. Average cover crop growing conditions were similar between years; however, isolated temperature and rain events led to variation in cover crop growth, biomass yield, and N yield between seasons. Monthly air temperatures during the 2014 cover crop growing season were 1 to 3 °C greater than 30-year normal temperatures, averaging 5, 14, and 20 °C in April, May, and June, respectively. In 2015, the monthly temperatures during the cover crop growing season

were 0 to 4 °C greater than 30-year normal temperatures, averaging 8, 15, and 18 °C in April, May, and June, respectively. The 2015 cover crop growing season had warmer temperatures at the end of April and early May compared with 2014, regardless of similar average temperatures for May between the 2 years. This temperature increase led to greater GDD (Fig. 1). Total rainfall was similar between seasons (19.6 cm in 2014 and 19.1 cm in 2015), although monthly distribution differed. In 2014, conditions were wetter in April and early May followed by weeks of low rainfall into late May, necessitating one irrigation event in 2014 (Fig. 2). In contrast, 2015 had less precipitation in April and early May, followed by a large (>10 cm) rain event in mid May, coinciding with that month's spike in temperatures.

Cover crop growth in 2015 was much greater than in 2014, reflecting the differences in growing conditions (2015 had more favorable growing conditions). In 2014, BC and CV stand density was less than 25% and 72%, respectively, of expected rates, whereas oat had good establishment in both the oat and BC + O treatments (Table 1). The BC cover crop had significantly less biomass and N yield compared with other treatments (Table 2). Conversely, CV had the greatest N content, the greatest N yield, and lowest C:N ratio of the cover crops (Table 2). The small amount of BC in the BC + O treatment led to slightly greater N content of all biomass and greater N yield compared with oat. In 2015, cover crop biomass was 10 times greater compared with 2014. The oat and BC + O treatments had similar biomass and N content, but the slight, nonsignificant differences led to greater N yield with BC + O. CV had the greatest N content but resulted in similar N yields as BC + O and oat. BC grew better in 2015 compared with 2014, but only produced an N yield of 15 kg·ha⁻¹. It is also interesting to note that the C:N ratio of BC was 17.0 in 2015, greater than 11.5 in 2014.

The 2014 CV production was less than the AGB range reported in the literature. Biederbeck et al. (1993), Büchi et al. (2015), Gan et al. (2016), and Mooleki et al. (2016) reported aboveground dry matter between 600 to 3990 kg·ha⁻¹; and Büchi et al. (2015) and Mooleki et al. (2016) reported N yields between 50 and 161 kg·ha⁻¹ N. CV production in 2015 (3717 kg·ha⁻¹, 134 kg·ha⁻¹ N) was close to the greatest values reported previously. In addition, the C:N ratios of CV were similar for both years of this study (9 in 2014 and 12 in 2015) and similar to previously reported values (Büchi et al., 2015; Lupwayi and Soon, 2016). However, the plant density of CV in 2015 was much greater than expected. It is likely that the seeding rate on the drill seeder was not set correctly, and thus it is unclear whether the biomass achieved was a result of overseeding or favorable growing conditions. The N yield and C:N ratio of CV in 2015 indicates that CV has some promise as a spring-seeded green manure.

BC AGB production was much less than reported in other studies [500–3280 kg·ha⁻¹ (Fakhari et al., 2015; Parr et al., 2011; Rochester and Peoples, 2005)], with our 2015 results at the low end of the reported range. In addition, N yield was less than expected (20 and 164 kg·ha⁻¹) based on previous studies (Ghaffarzadeh, 1997; Parr et al., 2011; Rochester and Peoples, 2005). The N content of BC was less than CV, resulting in a greater C:N ratio. The poor growth and N yield of BC in both growing seasons suggests that April-

through-May planting dates coupled with a June termination date may not allow for adequate growth in the Central Sands region of Wisconsin.

The oat biomass and N yield was 10 times greater in 2015 compared with 2014. The N yield range from 2014 to 2015 was similar for oat cover crops as measured in a previous study in the region [7–91 kg·ha⁻¹ N (Andraski and Bundy, 2005)]. To varying magnitudes, oat AGB variability has been documented in other Wisconsin-based

Fig. 1. Accumulated growing degree days during the cover crop and sweet corn growing seasons (2014 and 2015), calculated using Growing Degree Days (°C) = $[(T(^{\circ}\text{C})_{\text{daily max}} + T(^{\circ}\text{C})_{\text{daily min}})/2] - T_{\text{base}}$; the daily maximum temperature was 30 °C and the daily minimum temperature was 10 °C. T_{base} is the base temperature for each plant, where sweet corn $T_{\text{base}} = 10^{\circ}\text{C}$ and oat $T_{\text{base}} = 5.5^{\circ}\text{C}$. Cover crop planting occurred on 24 Apr. 2014 and 17 Apr. 2015, and termination occurred on 10 June 2014 and 16 June 2015. Sweet corn planting took place 13 June 2014 and 19 June 2015, and harvest took place 11 Sept. 2014 and 2015.

Fig. 2. Weekly accumulated precipitation and individual irrigation events for sweet corn growing season at Hancock, WI, in 2014 and 2015. Cover crop planting occurred on 24 Apr. 2014 and 17 Apr. 2015, and sweet corn planting occurred on 13 June 2014 and 19 June 2015. Termination was on 10 June 2014 and 16 June 2015 for cover crops, and on 11 Sept. 2014 and 2015 for sweet corn harvest.

Table 1. Seeding rate, expected germination rate, and expected plant density for each treatment; and actual plant density and average plant height at time of termination of each cover crop treatment in 2014 and 2015. For the BC + O treatment, the oat and berseem clover were planted and counted separately, and the plant height was not measured (NM).

Cover crop	Target seeding rate (kg-ha ⁻¹)	Expected germination rate (%)	Expected plant density (1,000 plants/ha)	2014		2015	
				Actual plant density 2014 (1,000 plants/ha)	Plant ht 2014 (cm)	Actual plant density 2015 (1,000 plants/ha)	Plant ht 2015 (cm)
CV	67	85	365	264	22	981	33
BC	13	93	4,409	1,057	12	3,539	25
BC + O							
Oat	67	85	2,370	1,923	NM	3,280	NM
Berseem	11	93	3,950	970	NM	1,080	NM
Oat	134	85	4,740	4,705	16	6,014	44

CV = chickling vetch; BC = berseem clover; BC + O = berseem clover and oat.

Table 2. Cover crop biomass, nitrogen (N) content, N yield, and carbon (C):N ratio for each cover crop treatment in 2014 and 2015 (different units are used for biomass by year). Analysis of variance results are also reported.

Cover crop	2014				2015			
	Biomass (kg-ha ⁻¹)	N content (g-kg ⁻¹)	N yield (kg-ha ⁻¹)	C:N	Biomass (Mg-ha ⁻¹)	N content (g-kg ⁻¹)	N yield (kg-ha ⁻¹)	C:N
CV	258 a	45.2 a	11.6 a	9.22 d	2.77 b	36.5 a	101 a	11.6 c
BC	72 b	37.7 b	2.7 d	11.5 c	0.66 c	23.0 b	15 c	17.0 b
BC + O	333 a	25.4 c	8.5 b	16.1 b	4.37 a	23.5 b	103 a	18.1 ab
Oat	274 a	21.9 d	5.9 c	18.8 a	4.33 a	20.6 b	89 b	20.8 a
Treatment	P value							
CC	0.0007	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0015	0.0024

Within columns, means followed by the same letter are not significant different ($\alpha = 0.05$).

CC = cover crop; None = no cover crop; CV = chickling vetch; BC = berseem clover; BC + O = berseem clover and oat; NR = nitrogen rate.

studies. For example, Andraski and Bundy (2005) noted 5-fold differences in oat biomass (590–3010 kg-ha⁻¹) among years. Also in Wisconsin, Contreras-Govea and Albrecht (2006) measured spring-planted oat biomass with a mean weight of 7700 kg-ha⁻¹ after 77 d of growth (mid April–late October); the 2015 oat biomass was little more than half the biomass of this full-season oat stand. It is interesting to note that greater oat biomass was achieved in our study in 2015 (with a spring seeding and only 60 d of growth) compared to Andraski and Bundy (2005). Andraski and Bundy (2005) also reported oat C:N ratios of 31 and 33 in two of their study years, which are greater than our results.

The BC + O treatment in both 2014 and 2015 was statistically similar to the oat treatment for biomass yield but resulted in greater N yield, presumably because of the BC addition (Table 2). Previous studies have shown similar results. Rinnofner et al. (2008) reported greater biomass and N yield in 1 of 2 years with species mixtures of legumes plus nonlegumes compared to single-specie plantings of legumes or nonlegumes. Parr et al. (2011) demonstrated that a rye-hairy vetch mixture resulted in the greatest biomass and N yield among nine different monoculture plantings of cover crops, although the mixture was not always greater than the hairy vetch or rye alone.

In our study, the cover crops had minimal effect on residual nitrate and ammonium at the time of termination. In 2014, oat and BC + O had the least nitrate content (1.18 and 1.33 mg-kg⁻¹, respectively), but these were 1 mg-kg⁻¹ less than the no cover crop treatment (2.12 mg-kg⁻¹). Ammonium-N content was not significantly different among treatments in 2014 or 2015, and nitrate-N content was not significantly different among treatments

in 2015. These results are similar to a previous study with spring-seeded green manure cover crops in this region, which resulted in no differences in nitrate or ammonium content after cover crop termination (West et al., 2016). It is important to note that the plant-available N content of soil in this study was very low and it is likely that any residual N from the previous cropping season had leached out in the fall or spring before the period of rapid cover crop growth.

Sweet corn. Mean monthly air temperatures during the 2014 sweet corn growing season deviated from –5 to 2 °C around the 30-year normal temperatures, averaging 20, 19, 20, and 15 °C in June, July, August, and September, respectively. Mean monthly air temperatures during the 2015 sweet corn growing season deviated –3 to 1 °C around the 30-year normal temperatures, averaging 18, 21, 19, and 18 °C in June, July, August, and September, respectively. Accumulated GDDs were greater in 2014 than in 2015, accumulating 891 and 845 GDDs, respectively. Total accumulated water throughout the sweet corn growing season was 548 mm (276 mm from irrigation) in 2014 and 519 mm (256 mm from irrigation) in 2015.

Sweet corn yields were quite different between years, with 2014 producing much less yield compared to 2015. The cause of the lower yields (both cover crop and sweet corn) in 2014 was not immediately evident, because the soil conditions at the time of planting were quite uniform between years, the GDD days for each crop and seasonal rainfall amounts were similar between years, and the soil (texture and classification) was the same between the sites. In 2014, statewide yields were 18.5 Mg-ha⁻¹ for processing sweet corn and 12.5 Mg-ha⁻¹ for fresh market sweet corn (U.S. Department of Agriculture

National Agricultural Statistics Service, 2016). In 2015, statewide yields were 18.1 Mg-ha⁻¹ for processing sweet corn and 14.4 Mg-ha⁻¹ for fresh market sweet corn (U.S. Department of Agriculture National Agricultural Statistics Service, 2016, 2016). The maximum yields in our 2015 experiment were slightly greater than the statewide average, whereas maximum yields in 2014 were 50% to 80% of the statewide average. The only difference between the field locations was that the 2014 sweet corn followed 2 years of field corn, whereas 2015 sweet corn followed a more diverse crop rotation. Continuous corn rotations have been shown to result in lower yields (e.g., Stanger and Lauer, 2008), but it is uncertain whether this effect occurs on sweet corn as well.

ANOVA showed there was a significant effect of cover crop, N rate, and their interaction on both FW and ear yield in each year (Table 3). The nature of the interaction effect was explored more fully using non-linear, plateau-based regression (both linear and quadratic plateau). In 2014, yields at 0 and 56 kg-ha⁻¹ N were similar, and in some cases were greater, with no N (Figs. 3 and 4). Preliminary statistical analysis that included the zero N yields resulted in a lack of convergence, and plateau response curves could not be fit. Because the goal of this regression analysis was to identify the N rate that maximized yield, the yields at 0 kg-ha⁻¹ N were not included in the analysis in 2014. Removing these data points allowed Proc NLIN to estimate the AONR (the N rate at which yield plateaued). For yields in 2014, both linear and quadratic plateau results are reported (Table 4) because neither exhibited the lowest RMSE consistently across cover crop treatments. In 2015, the linear plateau resulted consistently in the lowest RMSE

Table 3. Treatment means and analysis of variance results for sweet corn yield [both fresh weight (FW) and ear] for the 2014 and 2015 growing seasons.

Treatment	2014		2015	
	FW yield (Mg·ha ⁻¹)	Ear yield (1,000 ears/ha)	FW yield (Mg·ha ⁻¹)	Ear yield (1,000 ears/ha)
CC				
None	6.55 c	27.1 b	13.2 c	42.7 b
CV	8.57 a	35.6 a	14.5 ab	45.1 b
BC	7.62 b	31.4 a	14.1 ab	45.1 b
BC + O	6.68 b	29.2 a	13.8 bc	42.8 b
Oat	5.78 c	24.7 b	14.6 a	48.0 a
NR				
0	1.88 c	11.1 b	1.64 c	7.01 c
56	1.54 d	8.33 b	6.76 b	26.0 b
112	5.98 b	28.1 a	18.0 a	55.8 a
168	10.1 a	40.3 a	19.3 a	58.3 a
224	10.7 a	41.7 a	19.1 a	60.7 a
280	12.2 a	48.1 a	19.5 a	60.7 a
Treatment	<i>P</i> value			
CC	<0.0001	<0.0001	0.0011	0.0013
NR	<0.0001	<0.0001	<0.0001	<0.0001
CC × NR	<0.0001	<0.0001	0.0002	0.0082

Within columns, means followed by the same letter are not significant different ($\alpha = 0.05$).

CC = cover crop; None = no cover crop; CV = chickling vetch; BC = berseem clover; BC + O = berseem clover and oat; NR = nitrogen rate.

(Figs. 5 and 6). No differences among any AONR values were determined because of very high 95% confidence intervals; thus, response curves are presented only to describe the nature of the response (linear or quadratic) and to reflect whether there is any evidence for the potential of the cover crop to supply N.

For FW yields in 2014, similar trends were exhibited in both the linear and quadratic plateau response curves (Table 4), which include 1) CV resulted in similar yields to no cover crop, but may be optimized yield with less N (Figs. 3 and 4); and 2) BC and BC + O led to greater yield plateaus compared with no cover crop, but required more N to achieve the yield increase (Figs. 3 and 4). The potential positive effect of CV on reducing AONR is interesting because there was not an abundance of CV biomass, and only 11.6 kg·ha⁻¹ N in the AGB could contribute to this N credit. Other evidence that CV was supplying N to sweet corn can be

Fig. 3. Sweet corn fresh weight yield and response to nitrogen fertilizer application [as linear plateau (LP) or quadratic plateau (QP) models, whichever resulted in lower root mean square error values] in 2014 after five cover crop treatments. NONE = no cover crop; CV = chickling vetch; BC = berseem clover; BC + O = berseem clover and oat; OAT = oat.

Fig. 4. Sweet corn ear yield (1000 ears/ha) and response to nitrogen fertilizer application [as linear plateau (LP) or quadratic plateau (QP) models, whichever resulted in lower root mean square error values] in 2014 after five cover crop treatments. NONE = no cover crop; CV = chickling vetch; BC = berseem clover; BC + O = berseem clover and oat; OAT = oat.

seen in the FW yield with no N, which was 6.02 Mg·ha⁻¹ for CV and ranged from 0.12 to 1.42 Mg·ha⁻¹ in other treatments (Fig. 3). However, it is unclear why this effect did

not occur in CV with 56 kg·ha⁻¹ N (Fig. 3). The CV regrew through the majority of the sweet corn growing season and may have resulted in an in-season N transfer to the

sweet corn crop (Fig. 7). Facultative N transfer from legume intercrops to grasses has been documented in other studies (Redmon et al., 1995; Schipanski and Drinkwater, 2012; Tzanakakis et al., 2017) using the ¹⁵N natural abundance method to quantify N fixation and ultimately transfer to the companion crop. The positive effect of BC sweet corn yield is even more surprising considering how little BC biomass was produced in 2014. The quadratic nature of response to N following BC or BC + O (Figs. 3 and 4) reveals that any yield gains that occurred required more N to achieve them; maximum yields were achieved with the greatest N rate used in this study (280 kg·ha⁻¹). BC + O and oat were best expressed with different response curves (quadratic plateau and linear plateau, respectively), further indicating that the small amount of BC did impact the nature of sweet corn yield response to N.

Table 4. Linear and quadratic plateau regression results for fresh weight and ear yield for sweet corn in 2014.

Cover crop	AONR (kg·ha ⁻¹)	Plateau yield (Mg·ha ⁻¹)	RMSE	AONR (kg·ha ⁻¹)	Plateau yield (1,000 ears/ha)	RMSE
Linear plateau						
None	187	11.2	0.61	154	42.4	1.60
CV	129	11.5	1.06	132	49.1	1.26
BC	275	13.1	2.92	228	51.6	8.63
BC + O	257	12.4	2.04	250	50.6	6.73
Oat	183	9.87	1.07	186	41.6	10.6
Quadratic plateau						
None	246	11.3	0.30	213	43.1	1.22
CV	165	11.5	1.07	172	48.8	1.39
BC	280	14.7	2.15	280	52.9	9.18
BC + O	280	12.3	0.63	280	49.8	5.08
Oat	266	10.2	1.67	280	45.4	8.18

AONR = agronomically optimum nitrogen (N) rate as indicated by the N rate at which yields plateau; RMSE = root mean square error; None = no cover crop; CV = chickling vetch; BC = berseem clover; BC + O = berseem clover and oat.

Fig. 5. Sweet corn fresh weight yield and response to nitrogen fertilizer application (as linear plateau models) in 2015 after five cover crop treatments. NONE = no cover crop; CV = chickling vetch; BC = berseem clover; BC + O = berseem clover and oat; OAT = oat.

Fig. 6. Sweet corn ear yield (1000 ears/ha) and response to nitrogen fertilizer application (as linear plateau models) in 2015 after five cover crop treatments. NONE = no cover crop; CV = chickling vetch; BC = berseem clover; BC + O = berseem clover and oat; OAT = oat.

Fig. 7. Chickling vetch regrowth in sweet corn stand, 21 July 2014. Chickling vetch required three treatments of herbicide for full termination. The first occurred on 10 June (with Credit Extra[®]), the second on 16 June (with 2,4 D Amine 4 and Parallel[®]), and the third occurred on 31 July (with Plus Herbicide, and Laudis[®]). Sweet corn was planted 13 June 2014 in Hancock, WI.

Neither CV nor BC appeared to supply N in 2015, even though the CV had 101 kg-ha⁻¹ N in AGB. The 2015 results are consistent with previous work comparing sweet corn yield benefit of leguminous cover crops on sandy soils. Johnson et al. (2012) measured minimal N benefit from spring-planted field pea cover crop in the Central Sands and West et al. (2016) reported no N credit from spring-planted field pea also in the Central Sands. Cherr et al. (2007) documented no sweet corn yield benefit from fall-planted white vetch in sandy soil in Florida. Parr et al. (2011) also determined no N credit from legumes (berseem clover, red clover, or crimson clover) on sandy soils in North Carolina. Thus, our findings in 2015 agree with other studies on leguminous cover crops, suggesting rapid mineralization in sandy soil and subsequent leaching of plant-available N beyond the root zone prevent N benefit to sweet corn crop.

Oat as a green manure had variable effects across seasons on its impact on the two yield measures and in relation to the no cover crop treatment. Oat had a similar AONR value as no cover crop in 2014 for FW yield (comparing within linear or quadratic plateau responses), but the yield plateau was slightly decreased (Table 4). In contrast, for FW yields in 2015, oat had greater plateau yields compared to no cover crop (Fig. 5) while also exhibiting no potential N credit; in fact, the reported AONR value was slightly greater for oat compared to no cover crop. The large amount of oat biomass in 2015 did not have a large effect when looking at full response curves, but did result in the greatest yields when averaged over all N rates (Table 3). It is interesting to note that the N yield of oat biomass in 2015 was 89 kg-ha⁻¹ and the C:N ratio was 20.8 but did not result in a positive

effect on AONR. If anything, a potential immobilization effect was observed. These results are in contrast to those by Andraski and Bundy (2005), who, in another study conducted at the HARS, showed that a fall-planted oat cover crop (which winter-kills) resulted in a reduction in the economically optimum N rate for the subsequent corn crop in 2 of 3 years. On a well-drained sandy loam, Snapp and Surapur (2018) showed that a rye cover crop did not change plant-available N at the time of corn planting, but increased plant-available N relative to no cover crop when N fertilizer was applied. Thus, it seems likely that grass green manures can supply N to the subsequent crop, but only in studies when they were fall-seeded and when field corn (a longer season and greater N demand crop compared to sweet corn) was the crop grown.

The oat and BC + O treatments displayed different effects for FW yield, having opposite effects from each other in 2014 and 2015. The N response curve for FW yield for BC + O was clearly quadratic in nature, whereas oat was linear in 2014 (Fig. 3). Including BC with oat led to greater AONR values but had a greater yield plateau. The N response curves for oat and BC + O for ear yield in 2014 were quadratic, and yields plateaued at the greatest N rate in the study (280 kg-ha⁻¹), although plateau yields were somewhat greater for BC + O. It is very surprising that a small amount of BC growth could cause the BC + O treatment to respond more similarly to BC than oat. Similar AONR values and yield plateaus were observed in 2015 between BC + O and oat for both FW and ear yield (Figs. 5 and 6).

The N benefits of combined grass and legume cover crops are not clearly elucidated in the literature. When seeded with oat that would be harvested as a grain crop, BC resulted in greater oat biomass, greater subsequent corn yields in 2 of 4 years, and greater economic return compared to the control (Ghaffarzadeh, 1997). On sandy soils, Parr et al. (2011) measured no N benefit of combined grass and legume biculture cover crop treatments; however, Sainju et al. (2005) did measure an N benefit from a biculture cover crop treatment when the subsequent crop was sorghum (but there was a negative effect on yield when the subsequent crop was cotton). Clearly, the benefit and limitations of biculture cover crop plantings are regional and crop specific, as well as a function of cover crop growth.

Conclusion

Implementation of spring-planted cover crops remains a challenge on sandy soils. Even when cover crop growing conditions were similar, cover crop growth was not consistent. All cover crop species did not produce much biomass in 2014, but CV led to a potential reduction in AONR, and BC led to a potential FW yield increase compared to no cover crop use. Thus, there is

some, albeit slight, evidence that CV and BC can benefit crop production on sandy soils. It is unclear which role the confounding effect of CV regrowth had in this effect. All cover crops tended to have greater calculated FW yield plateau values in 2015, but often required more N to achieve the yield increase; no cover crops in 2015 appeared to supply N to sweet corn. There is also an indication that oat cover crops led to a tie-up of plant-available N, in contrast to previous studies in this region. When BC was planted with oat, the effect of the cover crop treatment was more similar to the single planting of BC rather than a single planting of oat. The fact that BC had any effect is quite surprising, given that less than 15 kg-ha⁻¹ N was present in the AGB. BC did not produce much biomass when planted alone and would not be recommended as a spring cover crop in this region. Ultimately, the mechanism by which the legume covers benefited sweet corn is not known. The use of spring-seeded green manure cover crops typically benefited yield, but the benefit did not come from supplying N. Based on the results of this study, it is not likely that consistent N benefits from spring-seeded cover crops will occur; thus, farmers may be better served with fall-seeding green manures in this production system.

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