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Interseeding cover crops in corn: Establishment, biomass, and competitiveness in on-farm trials

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Abstract

Broadcast interseeding cover crops in corn (*Zea mays* L.) from the V2–V7 corn growth stages provides farmers the opportunity to establish cover crops over large areas quickly compared with drill interseeders. The objectives of this research were to evaluate broadcast interseeded cover crop establishment and biomass production as well as cover crop effect on corn grain yield in farmer's fields in Michigan. In 2017 and 2018, annual ryegrass (*Lolium multiflorum* Lam.), crimson clover (*Trifolium incarnatum* L.), and oilseed radish (*Raphanus sativus* L.) were broadcast interseeded at the V3 and V6 corn growth stages in nine farm fields. Cover crop density was measured 30 d after interseeding; cover crop density and biomass were measured in October prior to grain corn harvest. Cover crop density varied across site-years; annual ryegrass usually had the highest density. Fall biomass production of oilseed radish was usually equal to or greater than annual ryegrass and crimson clover biomass. Rainfall during the interseeding period improved cover crop emergence. Cover crop density and biomass were higher in sites that were tilled prior to corn planting compared with no-till, likely due to better seed to soil contact. Grain yield did not differ in the cover crop vs. no cover crop control treatments. Successfully establishing cover crops by broadcast interseeding in corn is dependent on specific location conditions; conventional tillage and rainfall improved establishment and biomass production.

1 | INTRODUCTION

Cropping system diversity increases cash crop productivity by enhancing soil biodiversity and nutrient cycling (McDaniel, Tiemann, & Grandy, 2014; Tiemann, Grandy, Atkinson, Marin-Spiotta, & McDaniel, 2015). Cropping systems in the midwestern United States are dominated by corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] (Aguilar et al., 2015). Adding cover crops increases plant diversity in corn and soybean cropping systems and provides a variety of ecosystem services including protecting soil from erosion (Panagos et al., 2015), suppressing pests (O'Reilly, Robinson, Vyn, & Van Eerd, 2011), increasing biological N_2 fixation (Dabney et al., 2010), and improving soil quality (Clark, 2007). Blanco-Canqui et al. (2015) summarized the effect of cover crops on various ecosystem services including soil C stocks. Cover crops increased soil organic C stocks (0.1–1 Mg ha^{-1} yr^{-1}); the magnitude was dependent on cover crop biomass, years in cover crops, and the initial soil C level. Inclusion of cover crops in cropping systems increases soil aggregation and soil organic matter (SOM) (McDaniel et al., 2014) and improves field water storage capacity (Nichols, 2015), improving the

Abbreviations: DAI, days after interseeding; SOM, soil organic matter.

sustainability of corn-based cropping systems that dominate the upper Midwest.

Establishing cover crops in a corn-based cropping system is difficult due to the limited number of field days following grain harvest (Baker & Griffis, 2009). Interseeding cover crops in the early vegetative stages of the corn life cycle is an option for seeding cover crops (CTIC, 2017). Annual ryegrass (*Lolium multiflorum* Lam.) and crimson clover (*Trifolium incarnatum* L.) (Abdin et al., 1998; Abdin, Coulman, Cloutier, Faris, & Smith, 1997; Belfry & Van Eerd, 2016; Caswell, Wallace, Curran, Mirsky, & Ryan, 2019; Curran et al., 2018; Grabber, Jokela, & Lauer, 2014; Scott, Mt. Pleasant, Burt, & Otis, 1987; Youngerman, DiTommaso, Curran, Mirsky, & Ryan, 2018; Zhou, Madramootoo, MacKenzie, Kaluli, & Smith, 2000), as well as oilseed radish (*Raphanus sativus* L.) (Belfry & Van Eerd, 2016; Roth, Curran, Wallace, Ryan, & Mirsky, 2015) have been successfully interseeded after the V2 corn growth stage (Abendroth, Elmore, Boyer, & Marlay, 2011) without reducing corn grain yield. New research has shown that these cover crop species can establish when interseeded at any growth stage from V2 to V7 (Brooker, Renner, & Sprague, 2020). More than 75% of this research was conducted on soils classified as silt loams, clay loams, or clays. Furthermore, almost all of this research was in small plots; only Curran et al. (2018) evaluated drill interseeded cover crop performance in on-farm strip trials where 12 of the 16 field sites were silt loam textured soils with 2–4% SOM. Many farm fields in the U.S. Midwest have lighter soil textural classes, lower SOM, and often undulating topography (Ladoni, Basir, Robertson, & Kravchenko, 2016). Muñoz et al. (2014) reported greater cereal rye (*Secale cereale* L.) biomass in topographical depressions due to favorable hydrology and higher SOM. The contribution of cover crops including cereal rye and red clover (*Trifolium pratense* L.) to soil C was greatest on slopes and summits compared with field depressions (Ladoni et al., 2016), suggesting that field topography influences SOM and cover crop establishment in farm fields.

Using a modified grain drill to interseed cover crops is a slow process and reduces farmer efficiency. Broadcast interseeding provides farmers an option to cover large fields much faster, which may appeal to some farmers and help increase adoption of cover crop interseeding. However, a major concern with broadcast interseeding is poor cover crop establishment (Noland et al., 2018). Drilling or broadcasting cover crops followed by some incorporation method improved cover crop establishment compared with broadcast seeding alone due to improved seed-to-soil contact in silt loam soils in Minnesota (Noland et al., 2018). Furthermore, across various seeding methods, rainfall following cover crop seeding improved cover crop establishment in France (Constantin, Durr, Tribouillois, & Justes, 2015; Tribouillois, Constantin, & Justes, 2018) and in the United States (Collins & Fowler, 1992 Wilson, Baker, & Allan, 2013), with the number of consecutive days without significant rain or irrigation after seeding being the most important factor contributing to poor cover crop establishment (Tribouillois et al., 2018).

Core Ideas

- Rainfall during the interseeding period improved cover crop emergence.
- Oilseed radish produced biomass equal to or greater than annual ryegrass and crimson clover biomass.
- Cover crops did not reduce corn grain yield.

Although research has shown that cover crops can be interseeded in corn after the V2 growth stage without reducing corn grain yield, there is limited research in no-till fields (Belfry & Van Eerd, 2016; Caswell et al., 2019; Curran et al., 2018; Grabber et al., 2014), fields with greater than 50% sand (Curran et al., 2018; Zhou et al., 2000), and fields with varying topography (Muñoz et al., 2014; Ladoni et al., 2016). The objectives of our research were to determine establishment, biomass production, and competitiveness of interseeded cover crops in corn in on-farm field trials in varying corn production systems.

2 | MATERIALS AND METHODS

Field experiments were conducted in 2017 and 2018 at nine locations throughout Michigan representing many of the corn-producing regions of the state (Table 1). Field sites were selected based on uniformity of topography and the farmer's interest and ability to broadcast interseed cover crops; farmers made all field and crop management decisions except for the cover crop species and interseeding timings. Management practices for each field are shown in Table 1. Interseeders included both a broadcast spreader that overseeded the cover crops as well as specially designed interseeders with drop tubes to spread seed between the corn rows. Glyphosate [*N*-(phosphonomethyl)glycine]-resistant corn was planted in 76-cm rows between 28 April and 31 May at populations ranging from 69,160–83,980 seeds ha^{-1} (Table 1). Weeds were managed with tillage or a burndown herbicide application with no soil residual activity prior to planting corn. Annual ryegrass, crimson clover, and oilseed radish (La Crosse Seed LLC) were interseeded in strips parallel with corn rows at the V3 and V6 corn stages. The V3 interseeded dates ranged from 1 June to 19 June, and V6

TABLE 1 Location, field management, and cover crop interseeding information for on-farm experiments conducted in Michigan in 2017 and 2018

Location	Year	Latitude/Longitude	Soil type	Soil description	pH	SOM	Till	Corn planted	Rate[a]	V3	V6	AR	CC	OR
												kg ha^{-1}		
Springport	'17	42°14′53″ N, 84°24′19″ W	Riddles sandy loam	Fine-loamy, mixed, active, mesic Typic Hapludalfs	5.9	1.6	No	31 May	83,980	19 June	27 June	16.8	22.4	11.2
Hickory Corners[b] A	'17	42°24′35″ N, 85°22′07″ W	Kalamazoo loam	Fine-loamy, mixed, active, mesic Typic Hapludalfs	6.6	2.0	No	8 May	71,630	1 June	19 June	33.6	33.6	22.4
Hickory Corners B	'17	42°24′35″ N, 85°22′07″ W	Kalamazoo loam		5.9	1.8	Yes	28 Apr.	69,160	1 June	19 June	33.6	33.6	22.4
Clayton	'17	41°51′25″ N, 84°14′18″ W	Glynwood loam	Fine, illitic, mesic Aquic Hapludalfs	7.2	3.2	No	13 May	79,100	17 June	28 June	24.7	13.5	6.7
Hillman	'17	45°03′40″ N, 83°54′02″ W	Negwegon silt loam	Fine, mixed, semiactive, frigid Oxyaquic Glossudalfs	–	–	Yes	14 May	79,100	14 June	5 July	16.8	22.4	11.2
Hart	'17	43°42′06″ N, 86°20′32″ W	Spinks Tekenink loamy sand	Sandy, mixed, mesic Lamellic Hapludalfs	6.6	1.5	Yes	13 May	70,395	5 June	16 June	16.8	22.4	11.2

(Continued)

TABLE 1 Continues

Location	Year	Latitude/Longitude	Soil type	Soil description	pH	SOM	Till	Corn planted	Rate[a]	V3	V6	AR	CC	OR
Springport	‘18	42°14′53″ N,84°24′19″ W	Hillsdale Riddles sandy Loam	Coarse-loamy, mixed, active, mesic Typic Hapludalfs; fine-loamy, mixed, active, mesic Typic Hapludalfs	6.2	1.8	No	25 May	74,100	16 June	21 June	8.4	11.2	7.2
Hickory Corners	‘18	42°24′35″ N,85°22′07″ W	Kalamazoo loam		6.6	2.0	No	2 May	69,160	1 June	14 June	16.8	22.4	11.2
Hillman	‘18	45°03′40″ N,83°54′02″ W	Algonquin Springport complex	Fine, mixed, semiactive, frigid Aquic Hapludalfs; fine mixed, semiactive, frigid Typic Epiaquolls	7.7	–	Yes	17 May	80,275	7 June	28 June	16.8	22.4	11.2

Note. SOM, soil organic matter; AR, annual ryegrass; CC, crimson clover; OR, oil seed radish.

[a] Corn planting population.

[b] Hickory Corners is the location of the Michigan State University Kellogg Biological Station.

TABLE 2 Cumulative growing season and interseeding period[a] precipitation for each site and year for cover crops interseeded in corn at on-farm locations in Michigan in 2017 and 2018

Site	Year	Cumulative precipitation (1 Apr.–30 Oct.)	Cumulative precipitation interseeding period[a]
		mm	
Springport	2017	565	88
Hickory Corners[b] A	2017	628	120
Hickory Corners B	2017	628	120
Clayton	2017	466	140
Hillman	2017	519	151
Hart	2017	643	141
Springport	2018	553	70
Hickory Corners	2018	641	146
Hillman	2018	395	55

[a] Interseeding period was from 7 d prior to the V3 interseeding until 30 d after the V6 interseeding timing.
[b] Hickory Corners is the location of the Michigan State University Kellogg Biological Station.

dates ranged from 14 June to 5 July (Table 1). Interseeded strip width ranged from 6 to 40 corn rows based on the width of the interseeder. Recommended seeding rates were 16.8, 22.4, and 11.2 kg ha^{-1} for annual ryegrass, crimson clover, and oilseed radish, respectively, but rates varied somewhat based on farmer preferences (Table 1). Strips were replicated either three or four times depending on spatial constraints and no cover control strips were always included; strip length varied between locations based on each farmer's field dimensions and ranged from 30 to 300 m. At the Springport 2017 and 2018 sites, randomization of treatments was forced so additional subsamples were collected to capture variability within each cover crop strip.

Precipitation data were collected throughout the growing seasons from a network of weather stations located throughout Michigan using the nearest measurement station to each field within the Enviro-weather Network (Enviro-weather, 2019) (Table 2). Cover crop emergence was evaluated 30 days after each interseeding (DAI) timing by placing 0.25 m^2 quadrats between corn rows. The number of seeds by weight of each species was determined for the seed sources used; percent emergence was calculated by counting the number of emerged plants divided by the number of seeds based on the seeding rate (kg ha^{-1}). The number of subsamples ranged from 2 to 10 based on the width and length of the cover crop strips at each site. In October, prior to corn harvest, cover crop density was measured in adjacent quadrats to those described above, and aboveground biomass was harvested, dried in an oven at 80 °C for a minimum of 3 d, and weighed. Corn was harvested for grain in each cover crop and the no cover crop control strips; yield was recorded using either a combine yield monitor or a weigh wagon and adjusted to 15.5% moisture.

2.1 | Statistical analyses

SAS 9.4 (SAS Institute Inc.) was used for all data analysis.

Cover crop and corn performance varied between sites, so each site was analyzed separately. Normality of data was checked by examining residual distribution, and a Poisson distribution was considered for density data; however, this did not change the results. The MIXED procedure was used to compare the fixed effects of cover crop species, interseeding timing, and the interaction for cover crop emergence 30 DAI and in October, cover crop biomass in October, and corn grain yield. Replication was considered a random effect. The effect of tillage system on cover crop establishment and biomass production was also analyzed using the MIXED procedure. Fields that were managed by no-till or conservation tillage (>30% residue remaining) were compared with fields that were tilled. Comparisons of least square means at $P \leq .05$ were made if F tests were significant ($P \leq .05$) using t tests conducted by the SAS pdmix800 macro (Saxton, 1998). Differences in seeding rates affected density comparisons between cover crop species; however, it is important to understand the number of plants emerged in an area rather than just the percent emergence.

3 | RESULTS AND DISCUSSION

3.1 | Cover crop emergence

Measured 30 DAI, annual ryegrass, crimson clover, and oilseed radish densities ranged from 3 to 201, 4 to 105, and 9 to 52 plants m^{-2}, respectively, when combined over interseeding timings (Table 3). At three sites, Clayton 2017, Hickory Corners A 2017, and Hickory Corners 2018, annual

TABLE 3 Cover crop density 30 d after interseeding at each location and year comparing cover crop species and interseeding timings

Cover crop	2017 Clayton	Hillman	Springport	Hickory Corners A	Hickory Corners B	Hart	2018 Hillman[a]	Springport	Hickory Corners
	plants m^{-2}								
Annual ryegrass	35a[b]	146a	52a	47a	201a	77a	166a	3b	29a
Crimson clover	25a	92b	20b	33a	56b	23b	105ab	4b	19a
Oilseed radish	20a	21 c	16b	21a	20b	13b	52b	9a	18a
±SEM	±9	±13	±5	±16	±16	±7	±16	±1	±8
Interseeding time	plants m^{-2}								
V3	21a	66b	27a	43a	113a	48a	–	8a	28a
V6	32a	106a	31a	24a	72b	27b	–	2b	10b
±SEM[c]	±8	±11	±4	±13	±13	±6	–	±1	±6

[a] Cover crops seeded at V3 at the "N" site in 2018 had not emerged by 30 d after interseeding.
[b] Within columns, means with the same letter are not significantly different at α = .05 according to Fisher's LSD.
[c] Standard error of mean for LSD comparisons.

TABLE 4 Cover crop density in October at each location and year comparing cover crop species and interseeding timings

Cover crop	2017 Clayton	Hillman[a]	Springport	Hickory Corners A	Hickory Corners B	Hart	2018 Hillman	Springport	Hickory Corners
	plants m^{-2}								
Annual ryegrass	62a[b]	–	69a	44a	173a	55a	188a	5a	1b
Crimson clover	22ab	–	12b	34a	40b	12b	42b	<1a	3b
Oilseed radish	15b	–	15b	24a	25b	12b	25b	8a	14a
±SEM	±13	–	±9	± 17	±14	±6	±26	±3	±3
Interseeding time	plants m^{-2}								
V3	35a	–	26a	37a	93a	36a	82a	4a	6a
V6	30a	–	38a	31a	66a	16b	87a	6a	3a
±SEM[c]	±9	–	±8	±16	±12	±5	±22	±2	±2

[a] Cover crop density was not recorded at the Hillman site.
[b] Within columns, means with the same letter are not significantly different at α = .05 according to Fisher's LSD.
[c] Standard error of mean for LSD comparisons.

ryegrass density was equal to that of crimson clover and oilseed radish. At four of the sites, Hillman, Springport, Hickory Corners B, and Hart all in 2017, annual ryegrass density exceeded crimson clover and oilseed radish densities (Table 3). At the Springport 2018 site only, oilseed radish density was greater than annual ryegrass and crimson clover densities (Table 3). Crimson clover density was greater than oilseed radish density at the Hillman 2017 site only (Table 3). Cover crop density 30 d after the V3 interseeding was equal to or greater than the density 30 d after the V6 interseeding in all site-years except Hillman in 2017 (Table 3). Average emergence as a percent of the seeded rate ranged from 1 to 20%, 2 to 23%, and 12 to 62% for annual ryegrass, crimson clover, and oilseed radish, respectively (data not shown).

By October, annual ryegrass, crimson clover, and oilseed radish densities ranged from 1 to 173, 1 to 40, and 14 to 25 plants m^{-2}, respectively, when combined over interseeding timings (Table 4). Annual ryegrass densities often increased from the 30 DAI measurements to the October measurements, indicating the potential for more emergence throughout the season. Oilseed radish densities were similar comparing 30 DAI and October measurements with the exception of the Hillman 2018 site. For both of these species, the carrying capacity, or the maximum number of individuals of a given species an area can sustain, of the seeded area was not exceeded. Crimson clover densities declined during the growing season, suggesting that the carrying capacity for the seeded area was exceeded and intraspecific competition occurred or that crimson

TABLE 5 Cover crop density 30 days after interseeding (DAI) and in October (Harvest), and cover crop biomass in October combined over interseeding timings comparing tilled fields with no-till fields

Tillage	Annual ryegrass		Crimson clover		Oilseed radish	
	30 DAI	Harvest	30 DAI	Harvest	30 DAI	Harvest
	plants m^{-2}					
Tilled	157a[a]	181a	83a	32a	26a	25a
No-till	38b	35b	23b	16a	15a	13a
±SEM	±12	±16	±16	±8	±8	±8
Tillage	kg ha^{-1}					
Tilled	366a		334a		479a	
No-till	64b		47b		246b	
±SEM[b]	±68		±67		±76	

[a]Within columns, means with the same letter are not significantly different at α = .05 according to Fisher's LSD.
[b]Standard error of mean for LSD comparisons.

clover seedlings did not tolerate conditions under the corn canopy and died. Annual ryegrass density in the fall was greater than crimson clover and oilseed radish densities in 4 of the 8 site-years and greater than oilseed radish in only 1 site-year (Table 4). At Hickory Corners A 2017 and Springport 2018, cover crop species had similar densities despite vastly different seeding rates (Table 4). Oilseed radish density was greater than annual ryegrass and crimson clover densities at the Hickory Corners 2018 site (Table 4). By October, cover crop density was similar for the V3 and V6 interseedings in all site-years except the Hart 2017 location (Table 5). Cover crop stands in October as a percent of the seeded rate ranged from <1 to 23%, <1 to 32%, and 10 to 17% for annual ryegrass, crimson clover, and oilseed radish (data not shown). Despite large differences in seeding rate (seeds per area) for each species, there were often no differences in density comparing the species, and sometimes a species with a lower seeding rate produced more individuals compared with a species with a higher seeding rate.

Other research has shown that rainfall following interseeding is critical for cover crop establishment (Collins & Fowler, 1992; Constantin et al., 2015; Tribouillois et al., 2018; Wilson et al., 2013). Wilson et al. (2013) reported that precipitation within a week of aerial seeding cereal rye was the most important factor in determining successful establishment. Researchers in France analyzed the emergence of 10 cover crop species at 18 experimental sites and concluded that the number of consecutive days without significant water input after seeding was of most significance (Tribouillois et al., 2018). Some of our field sites with higher precipitation (Table 2) had greater cover crop densities (Hickory Corners B, Hillman 2017) (Table 4); however, this was not always the case. For example, the Clayton 2017 site received 140 mm of precipitation during the interseeding period (Table 2) but had relatively low cover crop density numbers. Conversely, the Hillman location received the lowest precipitation of any site during the interseeding period (55 mm) but had relatively high cover crop density. Since precipitation did not explain emergence patterns well, we considered soil surface textural since sandy soils transmit water more slowly than clay soils under unsaturated conditions, potentially reducing seed germination. Most of our field sites were loam soils with the exception of Springport in 2017 and 2018 and Hart in 2017 (Table 1). Cover crop establishment was not improved at our field sites with loam compared with sandy loam surface textural class; however, we do not have an extensive data set to make a robust comparison. Wilson et al. (2014) reported that germination of cereal rye on the soil surface under laboratory conditions was more strongly dependent on soil moisture content compared with water potential, and concluded that overseeding onto coarse-textured soils should be avoided if there had not been a recent rainfall or if rainfall was not expected within the days following seeding. We decided to compare fields that were tilled (<30% crop residue) and those that were not tilled or where conservation tillage was used, as this was one of the only major management differences between sites. In conservation tillage systems with crop residue on greater than 30% of the soil surface there is a limited amount of contact of cover crop seeds with the soil, potentially reducing seed imbibition and germination. Results from this analysis showed that at 30 DAI, annual ryegrass and crimson clover densities were higher when seeded into conventionally tilled fields compared with no-till fields, and annual ryegrass density was higher at harvest in conventionally tilled compared to no-till fields (Table 5). It is likely that more seeds fell into cracks in the soil and had better seed-to-soil contact for improved emergence in conventionally tilled fields, and less seed-to-soil contact occurred in conservation tillage systems, including no-till. Furthermore, crop residues may have prevented a seed from reaching the soil or may have inhibited light interception by newly emerged seedlings.

TABLE 6 Cover crop biomass in October prior to corn harvest at each location and year for cover crop species combined over interseeding timings and each interseeding timing combined over cover crop species

Cover crop	2017						2018		
	Clayton	Hillman	Springport	Hickory Corners A	Hickory Corners B	Hart	Hillman	Springport	Hickory Corners
	kg ha^{-1}								
Annual ryegrass	56a[a]	612a	44b	35b	241b	202ab	248a	8b	<1b
Crimson clover	11a	539a	16b	152b	196b	40b	46b	0b	25b
Oilseed radish	63a	709a	262a	436a	1103a	456a	261a	108a	259a
±SEM[b]	±18	±167	± 54	±96	±164	±97	±44	±15	±52
Interseeding time	kg ha^{-1}								
V3	27a	550a	201a	255a	824a	270a	188a	45a	152a
V6	60a	689a	13b	161a	202b	189a	182a	33a	37b
±SEM	±14	±153	±44	±77	±139	±79	±40	±12	±46

[a] Within columns, means with the same letter are not significantly different at $\alpha = .05$ according to Fisher's LSD.
[b] Standard error of mean for LSD comparisons.

3.2 | Cover crop biomass

Cover crop biomass was greater when interseeded at the V3 timing compared with the V6 timing at the Springport 2017, KBS B 2017, and KBS 2018 sites (Table 6). Oilseed radish, annual ryegrass, and crimson clover biomass ranged from 63 to 1,103 kg ha^{-1}, 0 to 612 kg ha^{-1}, and 0 to 539 kg ha^{-1}, respectively, when combined across interseedings (Table 6). Annual ryegrass biomass was comparable to interseeded annual ryegrass biomass in Pennsylvania (250 kg ha^{-1}; Curran et al., 2018) and in dry years in Quebec (400 kg ha^{-1}; Zhou et al., 2000). Oilseed radish biomass was less than that observed in Quebec (1,767 kg ha^{-1}); however, Quebec research evaluated sweet corn rather than field corn (Belfry & Van Eerd, 2016). Crimson clover biomass was comparable to biomass produced in sweet corn in Quebec (507 kg ha^{-1}; Belfry & Van Eerd, 2016). At the Clayton and Hillman sites in 2017, all cover crop species produced similar biomass, while at the Hart 2017 and Hillman 2018 sites, oilseed radish produced more biomass compared with crimson clover only, and more biomass compared with both annual ryegrass and crimson clover in all other site-years (Table 6). Annual ryegrass produced more biomass compared with crimson clover at the Hillman 2018 site-year only, with values of 248 and 46 kg ha^{-1}, respectively. In previous research, higher fall biomass production occurred in years where precipitation was equal to or above the 30-yr average, compared with site-years with below normal precipitation (Curran et al., 2018).

Cover crop biomass was greater in fields conventionally tilled compared with those under conservation tillage (Figure 1). Combined over interseeding timings, annual ryegrass produced 366 kg ha^{-1} in tilled fields compared with only 38 kg ha^{-1} in no-till fields, crimson clover produced 334 kg ha^{-1} compared with 47 kg ha^{-1} in no-till fields, and oilseed radish produced 479 kg ha^{-1} in tilled fields compared with 246 kg ha^{-1} in no-till fields (Table 5). The cover crop density and biomass results indicate that greater seed-to-soil contact in tilled fields may improve cover crop establishment and biomass production throughout the season. Additionally, total biomass production at the Hillman 2017 (conventional till) and KBS B 2017 (no-till) was very high (Figure 1). We believe that increased cover crop light interception occurred at these sites due to lower corn yields (both sites), reduced corn population (KBS B 2017), and possibly earlier crop senescence at the northernmost site (Hillman). Low corn populations have lower leaf area index (LAI) and light interception (Subedi, Ma, & Smith, 2006) and lowering corn populations improved the success of interseeding (Baributsa et al., 2008; Youngerman et al., 2018). A shorter maturing corn hybrid was planted at the Hillman site in 2017 and earlier senescence and a lower corn yield occurred at this northern location. Cover crops were harvested in early to mid-October; the first freeze at Hillman occurred on 16 October, while at KBS, first freeze occurred on 25 October. Many factors influence the establishment of cover crops including precipitation, tillage, corn hybrid, population, and row spacing, growing degree days, and the length of the cover crop growing season.

3.3 | Cover crop competition with corn

Cover crops did not enhance nor reduce corn grain yield in any site-year except for Clayton 2017. At this site,

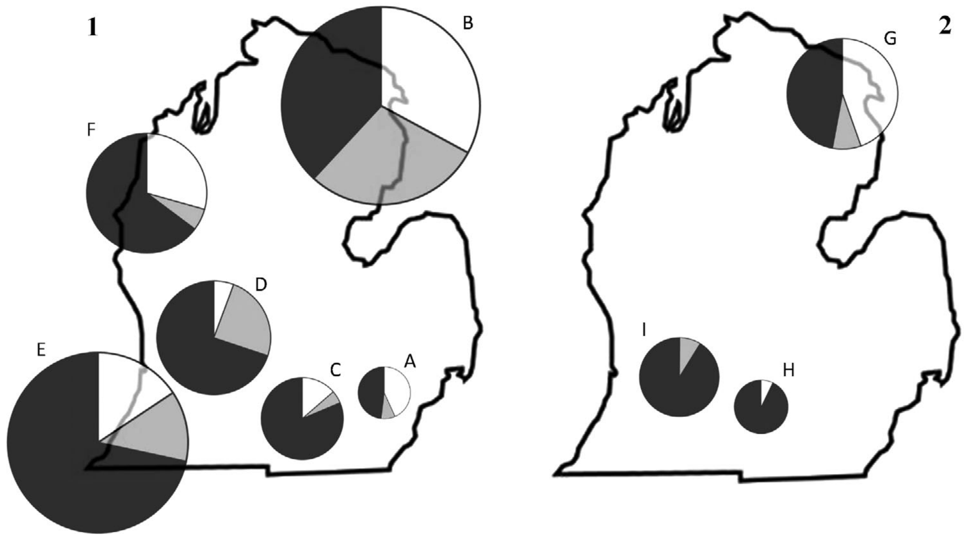

FIGURE 1 (1) 2017 and (2)2018 cover crop biomass by location. Each circle represents the average combined biomass of annual ryegrass, crimson clover, and oilseed radish. The size of each circle is proportional to the amount of biomass produced compared with the highest-producing site (B – 1,859 kg ha^{-1}). Within each circle, the average amount of biomass produced by annual ryegrass (white), crimson clover (gray), and oilseed radish (black) is shown. 2017: A – Clayton; B – Hillman; C – Springport; D – Hickory Corners A; E – Hickory Corners B; F – Hart. 2018: G – Hillman; H – Springport; I – Hickory Corners

TABLE 7 Corn grain yield at each location and year for each combination of cover crop species and interseeding timing compared with the no cover crop control

Species and interseeding timing	2017						2018		
	Clayton	Hillman	Springport	Hickory Corners A	Hickory Corners B	Hart	Hillman	Springport	Hickory Corners
	Mg ha^{-1}								
Annual ryegrass V3	12.0 bc[a]	7.7a	10.6a	9.5a	8.7a	12.4a	9.4a	11.0a	8.1a
Annual ryegrass V6	11.4cd	7.7a	10.7a	9.5a	8.7a	11.4a	9.0a	11.5a	8.9a
Crimson clover V3	12.3ab	9.1a	10.7a	9.3a	8.8a	12.3a	9.2a	11.5a	7.9a
Crimson clover V6	12.0bc	8.3a	10.9a	8.8a	9.1a	11.4a	9.7a	11.5a	8.8a
Oilseed radish V3	12.8a	8.0a	10.7a	9.1a	8.5a	11.7a	9.3a	11.2a	8.0a
Oilseed radish V6	11.1 d	7.7a	10.9a	9.7a	8.9a	11.1a	9.3a	11.4a	8.7a
No cover	11.9bc	7.7a	–[b]	9.5a	8.7a	11.2a	9.3a	11.2a	8.7a
±SEM[c]	±0.2	±0.4	±0.1	±0.3	±0.3	±0.4	±0.3	±0.3a	±0.4

[a] Within columns, means with the same letter are not significantly different at $\alpha = .05$ according to Fisher's LSD.
[b] Farmer did not harvest no cover control strips.
[c] Standard error of mean for LSD comparisons.

corn yielded less where oilseed radish was interseeded at V6 compared with the no cover control (Table 7). This location received sufficient rainfall (Table 2), and cover crop biomass was quite low compared with other locations (Table 6); therefore, we do not believe that cover crops were the actual cause of yield variability at this site. At all other sites, there were no differences in corn grain yield when compared with the untreated no cover crop control (Table 7).

4 | CONCLUSIONS

Cover crops can be broadcast interseeded in corn in June after the V2 growth stage in various production systems without impacting corn grain yield. Many factors affect the establishment of interseeded cover crops in corn; however, our results indicate that seed-soil contact may be important and some form of tillage prior to or at the time of interseeding can improve cover crop establishment and biomass production, regardless of cover crop species. Other factors that influence the success of interseeded cover crops are precipitation during the interseeding period, which we defined as 1 wk prior to through 30 DAI, and light penetration through the corn canopy in fields following interseeding and again in the early fall as corn senesces, which will be affected by corn hybrid selection, growing degree days, and yield potential. The desired ecosystem benefits of different cover crop species should be considered when choosing a species to interseed. Oilseed radish was the most successful species in this experiment as it produced as much or more biomass compared with annual ryegrass and crimson clover at all locations. However, oilseed radish winter kills and soil erosion could be a problem the following spring. Annual ryegrass and crimson clover biomass production were more variable, but these species were successfully interseeded in conventionally tilled fields and in fields with greater light penetration and adequate precipitation. Annual ryegrass provides farmers with an overwintering cover crop option. Crimson clover could provide N to a subsequent crop; however, it does not consistently overwinter in Michigan. Cover crop mixtures were not evaluated in this experiment; some of the farmer cooperators are interseeding mixtures to ensure establishment of at least one species within a field area and potentially providing multiple ecosystem services. Further research should evaluate a broader range of cover crop species and mixtures with varying proportions of grass seed to optimize establishment of all cover crop species (Finney, White, & Kaye, 2016; Hayden, Ngouajio, & Brainard, 2014; Murrell et al., 2017; Wortman, Francis, & Lindquist, 2012). Additional knowledge on how soil surface residues influence interseeding success would be beneficial to provide farmers with better recommendations for interseeding cover crops across a broad range of farming systems.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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