Evaluation of cover crops

drill-interseeded into corn across the Mid-Atlantic

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This article reports on field experiments that addressed two primary objectives: (1) compare cover crop establishment and biomass production of drill-interseeded grass and legume cover crops and corn performance across the Mid-Atlantic region and (2) determine if timing of interseeding cover crops into corn (V2–V6) influences cover crop performance and corn grain yield. Earn 1.5 CEUs in Soil & Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/614.

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Left: Cover crop legume mixture interseeded into corn using a specialized cover crop drill interseeder (Interseeder Technologies, Woodward, PA) developed to no-till drill cover crops into early standing no-till corn (below).

Integration of winter cover crops into corn and soybean cropping systems has the potential to improve soil and water quality (Clark, 2007; Reicosky and Forcella,1998; Scholberg et al., 2010). The combination of above- and belowground growth of overwintering cover crops has been shown to increase soil aggregate stability (Steele et al., 2012), decrease nitrogen (N) leaching, and limit phosphorus (P) runoff (Adeli et al., 2011; Qi and Helmers, 2009). Furthermore, N retention from grass cover crops and biological N fixation from legume cover crops can reduce N fertilizer and manure application requirements (Dabney et al., 2010), particularly for high-N-demand crops such as corn. Integration of winter cover crops can also contribute to pest management in annual grain systems by competing with weeds (Teasdale, 1996), providing habitat for beneficial arthropods that consume weed seeds or insect pests (Meiss et al., 2010; Ward et al., 2011; Zehnder et al., 2007), breaking crop-to-crop disease transmission (Krupinsky et al., 2002), and by providing bridges between crops for beneficial soil organisms such as mycorrhizal fungi (Kabir and Koide, 2002; Lehman et al., 2012).

Currently, there is increased focus on cover cropping incentive programs in the United States in an effort to improve soil and water quality, but adoption of cover cropping remains low at a national scale (2.9% of U.S. annual croplands) and highly variable among growing regions (Wade et al., 2015). A recent survey indicated that inconsistent or poor establishment is the most limiting factor that prevents adoption of cover cropping by conventional and organic farmers (Wayman et al., 2016). Regional trends clearly indicate that narrow growing season windows in the northern mid-Atlantic and upper Midwest contribute to low cover cropping adoption rates in annual grain crop rotations (NCR SARE and CTIC, 2016).

In a corn–soybean rotation, cover crop species selection is typically restricted to winter cereals since many legume and other broadleaf cover crop species cannot tolerate late establishment following corn harvest (Singer, 2008). Even winter cereal establishment can be problematic; Strock et al. (2004) determined that cereal rye would likely establish in only one of four years in southwestern Minnesota. Farsad et al. (2011) concluded that seeding cereal rye after corn silage in Massachusetts occurred too late to optimize nutrient retention and recommended the use of shorter-season, earlier-harvested corn cultivars that allow for earlier planting of cereal rye. Feyereisen et al. (2013) demonstrated strong climatic (fall and spring growing degree days) impacts on cereal rye biomass potential using simulated growing season windows based on local average corn grain harvest and soybean planting dates in the Corn Belt and Mid-Atlantic regions.

Best management practices developed in the late 20th century for interseeding cover crops into corn were predominantly in the context of tillage-based production systems; there is a need to develop technology that applies to no-till grain production systems. Interseeding strategies for no-till grain production that have been investigated most recently include late-season broadcasting of cover crops into a standing crop relatively late in the corn growing season using aerial equipment (Wilson et al., 2014) or ground equipment such as high-boy drop seeders (Hively et al., 2015). Aerial broadcasting via fixed-wing craft or helicopter has been used to seed cover crops into standing corn, but distribution can be uneven (Baker and Griffis, 2009) and has limited potential due to unpredictable weather, lack of aerial applicators, poor stands due to pilot operator error and seed predation, and high costs (Wilson et al., 2014). Furthermore, aerial seeding applications are typically more effective in tilled systems compared with no-till systems. Consistent establishment of broadcast-interseeded cover crops with aerial or ground equipment likely requires uniform soil disturbance and some incorporation to promote seed imbibition.

Broadcast interseeding cover crops into cash crops earlier in the growing season was a common and recommended practice in the 1940s (Dickey, 1947); research investigating various interseeding strategies has been conducted periodically over the last several decades (Abdin et al., 1998; Belfry and Van Eerd, 2016; Scott et al., 1987; Triplett, 1962). For example, cover crop interseeding is more common in low-input or organic annual grain production systems as a method to build soil health and provide N to the following cash crop (Baributsa et al., 2008; Exner and Cruse, 1993). In a trial conducted under organic management, Baributsa et al. (2008) showed that red clover interseeded into V5 to V7 corn did not reduce corn yield and could produce enough dry matter to provide N to a subsequent crop. In no-till conventional systems, drill-seeding cover crops rather than broadcasting potentially offers greater consistency in establishment due to better soil–seed contact, particularly under intermittent soil moisture conditions (Meisinger et al., 1991).

The need to refine previous interseeding practices and develop alternative strategies that are compatible with

Fig. 1. Annual ryegrass interseeded at V5 corn harvested for silage. Photo taken in late October in north-central Pennsylvania.

no-till annual grain production systems has led to the development of novel equipment. The machine used in our research is a specialized cover crop drill interseeder (Interseeder Technologies, Woodward, PA) developed to no-till drill cover crops into early standing no-till corn (V5–V7 growth stage) or other crops that are planted on 30-inch row spacings (Fig. 1). Greater consistency in cover crop establishment prior to corn grain harvest could facilitate farmer adoption and increase the impact of cover cropping on soil and water quality conservation. Therefore, our goal was to develop best management practices for the employment of the cover crop no-till drill interseeder in Mid-Atlantic U.S. corn grain systems. We report on field experiments that addressed two primary objectives: (1) compare cover crop establishment and biomass production of drill-interseeded grass and legume cover crops and corn performance across the Mid-Atlantic region and (2) determine if timing of interseeding cover crops into corn (V2–V6) influences cover crop performance and corn grain yield.

Field experiments were conducted at 16 locations spanning corn production regions in Maryland, Pennsylvania, and New York (Table 1). At each location, we imposed four treatments with three to four replicates depending on field size constraints. The four interseeded cover crop treatments were: (1) no cover crop control; (2) annual ryegrass seeded at 20 lb/ac; (3) a legume mixture consisting of red clover, crimson clover, and hairy vetch seeded at 10 + 20 + 15 lb/ac, respectively; and (4) annual ryegrass plus the same legume mixture seeded at 10 + 5 + 10 + 7.5 lb/ac, respectively, for annual ryegrass, red clover, crimson clover, and hairy vetch.

Soils were mostly silt loams or sandy loams with organic matter ranging from 2.0 to 4.8% (Table 1). Tillage history (five years) at study locations ranged from continuous no-till to conventional tillage, and most locations historically utilized corn–soybean rotations or grass–hay. In each field study, Roundup Ready corn was planted in May in 30-inch rows at 28,000 to 35,000 seeds/ac following a glyphosate burndown application (Table 1). Fertility (NPK) was amended at each location based on soil test recommendations. One week prior to cover crop seeding, glyphosate was applied POST to control emerged weeds. Soil-applied residual herbicides were not used in this study as previous research has shown that some active ingredients can be problematic to cover crop establishment (Wallace et al., 2017). Cover crops were seeded in three rows on 7.5-inch spacing between each 30-inch cash-crop row.

Aboveground cover crop biomass was evaluated in the fall (Table 1). Corn grain was harvested at the plot level with either a small-plot combine equipped with an integrated weigh and moisture scale at research farms or with a combine and weigh wagon at on-farm locations. Corn was harvested for silage at two locations. Cover crop dry matter was also evaluated the following spring at most locations just prior to cover crop termination using the methods described above.

We conducted a supplemental field experiment at Rock Springs, PA to evaluate the effect of interseeding timing on cover crop performance and corn grain yields. In each year, corn followed a soybean crop, and an annual ryegrass–red clover mixture (20 + 10 lb/ac) was interseeded at five corn growth stages (V2, V3, V4, V5, and V6). Experiments were replicated four times, and Roundup Ready corn was planted at 33,000 plants/ac. The same weed management and data collection methods as previously described in the cover crop performance study (above) were utilized to evaluate cover crop and corn grain yield performance.

Results and discussion

Cover crop biomass

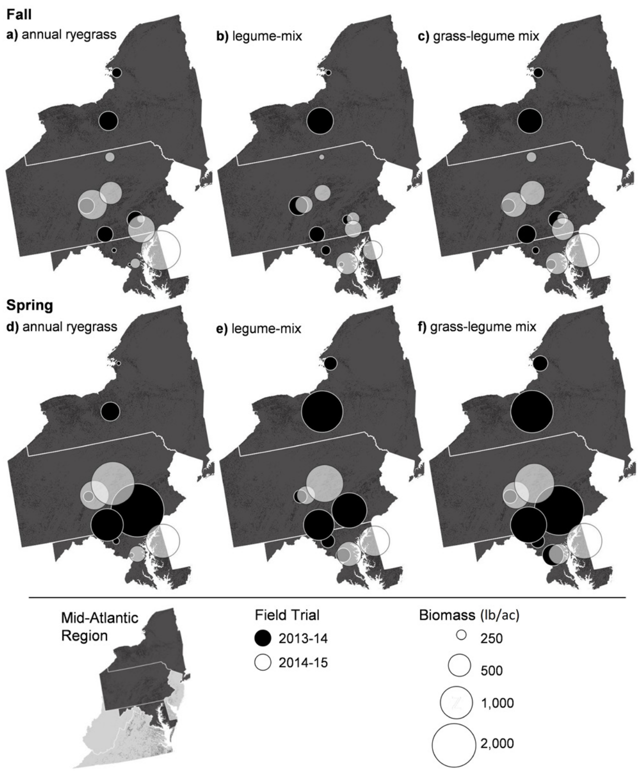
Interseeded cover crop biomass across Mid-Atlantic locations that grew corn for grain was variable across both locations and years (Fig. 2). Interseeded annual ryegrass biomass was highly variable across locations, ranging from 7 to 1,393 lb/ac in the fall and from 14 to 2,527 lb/ac in the spring. In general, the legume mixture produced lower biomass than annual ryegrass; mean biomass across all treatments ranged from 22 to 634 lb/ac in the fall and from 162 to 1,536 lb/ac in the spring. In comparison, annual ryegrass–legume mixture biomass ranged from 43 to 1,034 lb/ac in the fall and from 170 to 2,204 lb/ac in the spring. Differences in cumulative precipitation during the corn growing season likely contributed to broad trends showing higher fall biomass production across interseed-

Table 1. Location and field information for cover crop interseeding studies in 2013–2014 and 2014–2015 in Maryland (MD), Pennsylvania (PA), and New York (NY).

	Study location background				Field operations						
County, State (Year)	Tillage history	Soil texture	Soil pH	OM (%)	Previous crop	Pre-plant tillage	Corn maturity (d)	Plant rate (1000/ac)	Corn planting	Cover crop interseeding	Corn harvest
Frederick, MD (2013)	reduced till	gravelly silt loam	7.2	2.5	corn	turbo till	114	30	May 21	Jun 20	Oct 27
Prince George, MD (2013)	full-till	silt/sandy loam	6.5	2.2	soybean	full-till	111	28	May 17	Jun 21	Oct 22
Queen Anne, MD (2014)	no-till	sandy loam	7.1	NA	corn	no-till	105	28	May 8	Jun 18	Oct 20
Prince George, MD (2014)	full-till	silt/sandy loam	6.5	2.2	corn	full-till	111	28	May 20	Jun 19	Nov 3
Lancaster, PA (2013)	no-till	silt loam	6.2	2	soybean	no-till	102	30	May 14	Jun 25	Oct 15
Franklin, PA (2013)	no-till	sandy loam	7	NA	corn	no-till	114	33	May 23	Jun 24	Oct 17
Centre, PA (2013)	no-till	silt loam	5.6	2.5	soybean	no-till	96	30	May 15	Jun 25	Oct 15
Lancaster, PA (2014)	no-till	silt loam	6.9	4.8	soybean	no-till	107	32	May 9	Jun 17	Oct 14
Lancaster, PA (2014)	mixed	silt loam	6.3	2	soybean	no-till	110	30	May 14	Jun 19	Oct 14
Centre, PA (2014)	mixed	silt loam	6.9	2	soybean	no-till	97	30	May 9	Jun 18	Oct 31
Union, PA (2014)	no-till	silt loam	6.5	3	soybean	no-till	102	30	May 14	Jun 23	Nov 4
Bradford, PA (2014)	no-till	silt loam	6.2	3.9	grass hay	no-till	92	32	May 15	Jun 24	Nov 17
Franklin, PA (2014)	no-till	silt loam	6.8	NA	corn	no-till	113	33	May 9	Jun 14	Sep 11
Cayuga, NY (2013)	reduced till	silt loam	7.5	2.9	corn	reduced till	87	32	May 15	Jun 25	Oct 15
Jefferson, NY (2013)	reduced till	silt loam	7.2	2.5	corn	reduced till	95	30	May 17	Jun 24	Oct 17
Cortland, NY (2013)	mixed	silt loam	6.7	3.3	corn	full-till	102	35	May 4	Jul 2	Sep 24

ed cover crop treatments in 2014 compared with 2013 at several Mid-Atlantic locations (Fig. 2).

Corn was grown for silage at two locations. Fall cover crop biomass ranged from 43 to 719 lb/ac and 1,276 to 2,059 lb/ac across treatments at the Pennsylvania and New York locations, respectively (data not shown). Generally higher cover crop biomass levels at these locations can be attributed, in part, to earlier corn harvest (mid-September, Table 1) when compared with corn grain locations where harvest ranged from mid-October to mid-November. This trend is consistent with previous and ongoing field trials that demonstrate a positive interseeded cover crop biomass production response to early maturing or early harvested corn, which provides a longer fall cover crop growth window in which the cover crop is unimpeded by light competition with the cash crop. High cover crop biomass at the New York corn silage site was



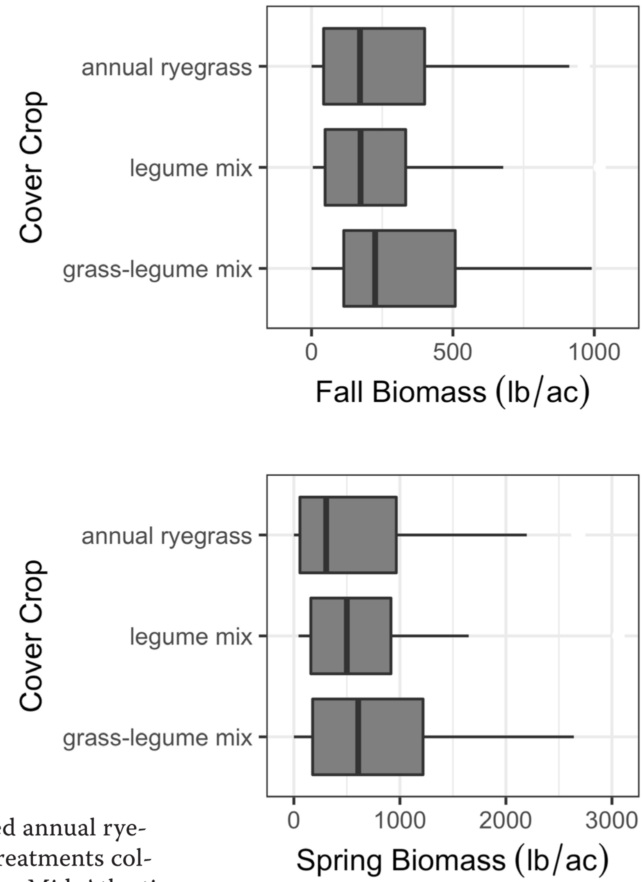
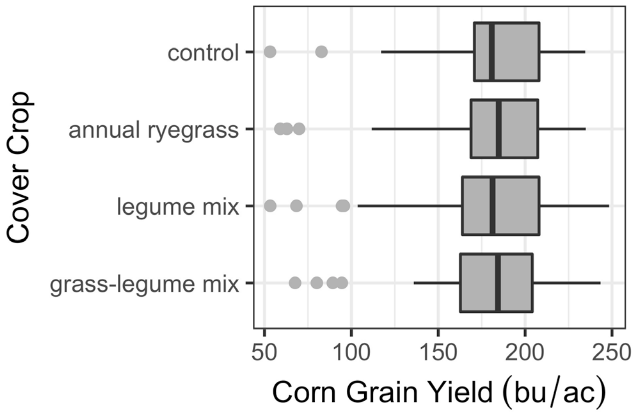


Fig. 2, above: Mean aboveground biomass (lb/ac) of interseeded annual ryegrass, legume mixture, and annual ryegrass–legume mixture treatments collected in late fall (**a-c;** *n*=14) and in late spring (**d-f;** *n*=11) across Mid-Atlantic locations growing corn for grain in 2013–2014 (black) and 2014–2015 (white). Circles are scaled using mean biomass values, which range from 7 to 1,393 lb/ac across treatments and site-years in the fall and from 14 to 2,527 lb/ac in the spring. **Fig. 3, right:** Fall and spring aboveground biomass (lb/ac) of interseeded annual ryegrass, legume mixture, and annual ryegrass–legume mixture treatments. Box plots include samples across treatment replicates and sites years (fall *n*=50; spring *n*=40). Horizontal lines within each boxplot indicate the median and whiskers extend to 1.5 × interquartile range. Treatments with same letter are not significantly different (using Tukey's test; $P > 0.05$) based on log-normal models.

also likely due to high soil nutrient levels from past applications of dairy manure.

Mean cover crop biomass differed among cover crop treatments in late fall and spring across study locations that grew corn for grain (Fig. 3). Interseeding annual ryegrass–legume mixtures resulted in higher mean biomass in fall and spring compared with interseeding annual ryegrass alone. Interseeded legume mixtures resulted in similar levels of mean biomass compared with other treatments in the fall and were greater than annual ryegrass in the spring. The effect of study location, however, accounted for the greatest proportion of the cover crop treatment response variance for models of fall and spring cover crop biomass. Legume species in annual ryegrass–legume mixture treatments comprised more than 50% of mean biomass levels in both fall (55%) and spring (58%). Legume biomass was not sorted to species in legume mixture treatments, but general observations suggest that red clover and crimson clover biomass production was greater than hairy vetch.

Our results indicate that both annual ryegrass and legume species can be successfully integrated into Mid-Atlantic corn–soybean crop rotations using drill-interseeding methods, but establishment and fall biomass production can be highly variable. One factor that may influence establishment success, as well as biomass of individual species within cover crop mixtures, is the level of residual N during the corn growing season. Our observations suggest that biomass production of annual ryegrass, an N-scavenging species, was lower at study locations where N was likely limited compared with other locations with a history of higher soil fertility. The highest level of fall biomass production, averaged across cover crop treatments, occurred at a dairy farm with a history of manure



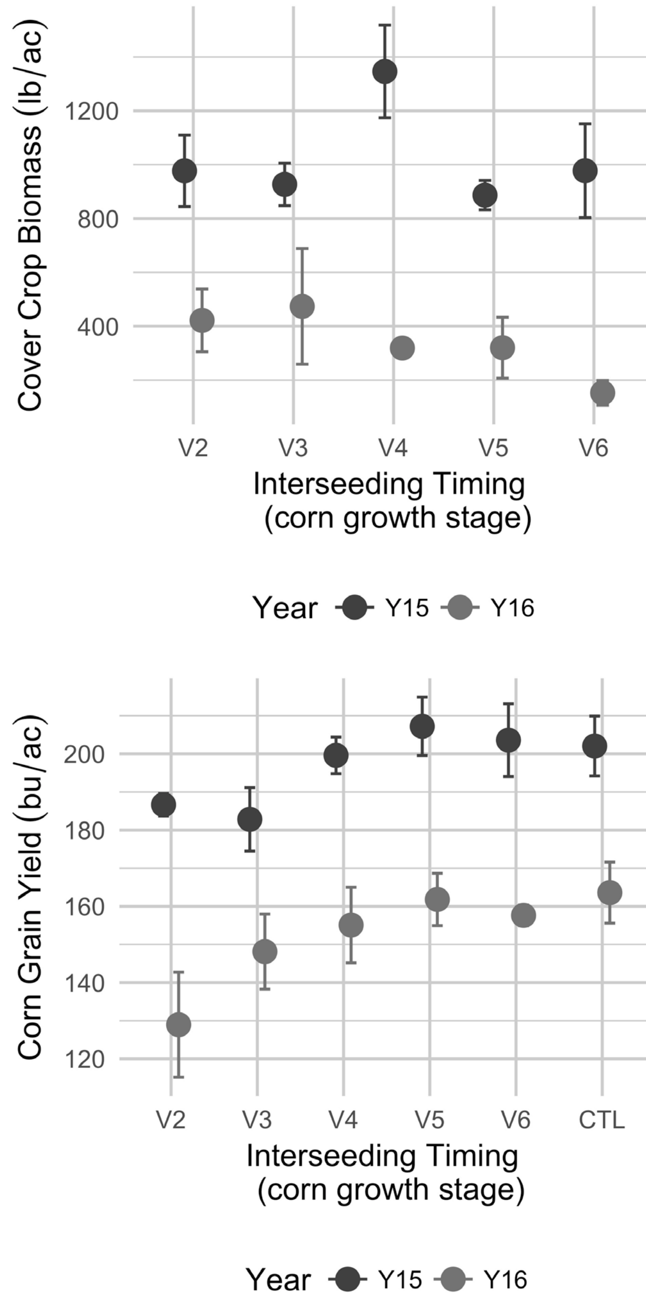


Fig. 4, above: Corn grain yield (bu/ac) in four interseeded cover crop treatments: control, annual ryegrass, legume mixture and annual ryegrass-legume mixture. Box plots include samples across treatment replicates and sites years (n=50). Horizontal lines within each boxplot indicate the median and whiskers extend to 1.5 × interquartile range. Treatments are not significantly different (using Tukey's test; $P > 0.05$) based on log-normal models. **Fig. 5, right:** Effect of interseeding timing on: (a) fall cover crop biomass (lb/ac) and (b) corn grain yields (bu/ac) in 2015 and 2016 field experiments. Data are treatment means and standard errors. The main effect of study year was significant (using Tukey's test; $P < 0.05$) in each model. The main effects of interseeding timing are presented. Interseeder-timing treatments with same letter are not significantly different (using Tukey's test; $P > 0.05$) based on log-normal models.

application that likely had comparatively higher residual soil N compared with other locations. Also, at this farm, the corn was harvested as silage rather than grain, thereby allowing earlier light penetration into the canopy, which can increase fall growth. Under these scenarios, interseeded annual ryegrass monocultures may be preferable given N-scavenging potential. Annual ryegrass has a dense, shallow root system that can reduce nitrate leaching and improve water infiltration (De Baets et al., 2006; Hansen and Djurhuus, 1997; Zhou and Shangguan, 2007). However, soil nitrate can drop to low levels during corn grain fill in Mid-Atlantic corn–soybean systems (Forrestal et al., 2012), which may limit cover crop growth potential as the corn canopy allows more light penetration in early fall. Under more limited residual soil N conditions, interseeded legume or grass–legume mixtures may be preferred.

Our results suggest that use of cover crop mixtures can improve cover crop yield performance and stability in interseeded systems. Previous studies have demonstrated that cover crop polycultures can improve yield performance and stability compared with cover crop monocultures (Smith et al. 2014; Wortman et al. 2012), but further research is necessary to understand trade-offs between greater yield stability and the potential for greater management complexity when using cover crop mixtures in interseeded systems.

Corn yield and interseeding timing

Interseeded cover crop treatments did not affect corn grain yields across Mid-Atlantic locations (Fig. 4). Evaluation of treatment means by site-year identified only one

Interseeder use: A CCA perspective

by Tracy Hmielowski

Prior to the development of the cover crop no-till drill interseeder, growers could either spread seed into an existing crop via airplane or wait to plant after a cash crop was harvested. Spreading seed from the air is expensive, and waiting until post-harvest often does not provide enough time for a cover crop to establish.

Dean Collamer, a CCA with Growmark FS in Pennsylvania, has 39 years of experience in the region. Throughout his career, Collamer has observed major changes in agronomic practices including cover crop planting. Farmers using the interseeder to plant cover crops into the cash crops before harvest are more likely to get cover established. In addition, the interseeder provides a way to plant a cover crop with precision and little soil disturbance.

Adding cover crops into any system will require changes, and producers need to be aware of how using the interseeder may alter other management practices. For example, Collamer says growers who intend to use the interseeder to establish cover crops may need to change their herbicide management plans. The long-acting herbicides commonly used in corn will inhibit the establishment of cover crops and need to be avoided.

| Interseeding into corn in June.

Common concerns addressed

One criticism from early users of the interseeder is the need to run the equipment at a slow speed when planting the cover crop. While unable to increase the speed at which cover crop seeds can be planted, the interseeder can be adapted to sidedress fertilizer. Adapting the equipment to accomplish two tasks simultaneously does not speed up the process but can save time overall.

In the eastern U.S., the majority of acres planted with interseeded cover crops are in corn. Collamer says that the 30-inch spacing of the interseeder is compatible with corn spacing. In addition, the presence of a cover crop does not interfere with corn harvest due to the difference in the crop heights. Interseeding into soy, however, can cause problems at harvest. This is because the equipment used to harvest soybeans is run low to the ground. The presence of a cover crop can slow equipment and potentially cause harvest loss due to pore threshing or screening.

Collamer says that some producers are also concerned about yield loss due to competition between the cover crop and the cash crop, especially in a dry year when adding a cover crop could reduce the water available for the cash crop before harvest. However, Collamer says that while the earlier planting helps establish the cover crop, being shaded by the existing cash crop appears to keep the cover crop from putting on much growth and therefore minimizes negative impacts of the cover crop.

Integrating cover crops, like any other change in management practices requires producers to think through the costs and benefits. To establish a cover crop using the interseeder, farmers may need to adjust the type and timing of herbicide applications or sidedressing. Nevertheless, these small changes can have long-term benefits in soil health and reducing erosion and nutrient loss.

site where cover crop treatments resulted in lower corn grain yields than the no-cover-crop control, which we suggest was a function of poor drainage and excessive rains in a portion of the field that contained a higher proportion of cover crop treatments as a result of the randomization process.

Given farmer concerns about interseeding impacts on corn yields, we conducted a supplemental field experiment in Rock Springs, PA in 2015 and 2016 to evaluate the effect of interseeding timing relative to corn growth stages. Study year influenced both fall cover crop biomass and corn grain yield, but no interactions between year and interseeding timing were observed (Fig. 5). Lower observed cover crop biomass and corn yields in 2016 can likely be attributed to moderate drought conditions in June and July, whereas precipitation during this period in 2015 was near the 30-year average (data not shown). Corn growth stage (V2–V6) did not affect biomass production of the interseeded annual ryegrass–red clover mixture (Fig. 5a). However, interseeding timing did affect corn grain yields despite the lack of observed difference in cover crop biomass production (Figure 5b). Interseeding at the V2 stage resulted in lower corn grain yields compared with the untreated control and treatments interseeded at the V5 or V6 growth stage. Observed trends within the study year suggest that interseeding at the V3 stage also had the potential to negatively impact corn yield.

Based on these results, we recommend that cover crops be interseeded between the V4 to V6 corn growth stage to minimize any potential negative impacts on corn yield. Delaying interseeding to the V6 stage may decrease performance of interseeded cover crops due to hastened corn canopy closure as was observed in 2016 (Fig. 5b).

These results are supported by previous research that suggests either densely planted corn (>12,000 plants/ac) or crops that fully canopy, such as soybean, may be too competitive for interseeded cover crops (Baributsa et al., 2008; Belfry and Van Eerd, 2016; Stute and Posner, 1993). In our previous interseeder research, several field trials failed when interseeded cover crop species established but failed to survive the corn growing season due to the combination of corn interference and additional environmental stress such as periods of drought. Slug and earthworm herbivory has also been observed in previous field trials, which can have a significant impact on establishment and persistence of interseeded cover crops. Previous research has shown that both these invertebrates can damage plant seedlings (Douglas and Tooker, 2012; Eisenhauer et al., 2010) although earthworm herbivory is considered quite rare (Kirchberger et al., 2015).

Adoption and sustainable use of interseeded cover crops requires an integrated management approach to minimize pest problems. For example, interseeding cover crops at the V4 to V6 corn growth stage occurs during the critical period of weed control (Hall et al., 1992; Knezevic et al., 2002). Consequently, use of some common soil-applied residual herbicides in weed control programs can result in injury to interseeded cover crops. Recent research has sought to identify shorter-lived soil-applied residual herbicides that minimize risk of injury to interseeded cover crops but provide some residual weed control (Wallace et al., 2017). Challenging weed management scenarios that include the presence of glyphosate-resistant or multiple-resistant weeds such as Palmer amaranth may preclude adoption of cover crop interseeding, particularly in conservation tillage systems.

Conclusions

Our results highlight the viability of drill-interseeding as a method for integrating cover crops into corn production systems in the Mid-Atlantic U.S. Cover crops that performed well across the Mid-Atlantic included annual ryegrass, medium red clover, and crimson clover. Furthermore, our studies demonstrated that cover crop performance can be maximized and yield loss of the host corn crop minimized by interseeding cover crops between the V4 and V6 corn growth stage. Additional research is needed to identify soil and crop management factors that influence establishment and performance of interseeded monocultures and mixtures.

Changes to crop management that may optimize establishment and performance of interseeded cover crops include lower corn plant population rates (Baributsa et al., 2008), use of shorter day-length hybrids that allow for earlier grain harvest or harvest for silage, and selection of corn germplasm with leaf architecture that allows for greater sunlight penetration into the canopy. Each of these factors would lessen environmental stress on interseeded cover crops during establishment. Selection of cover crop species or mixtures that are locally adapted to the growing region and that will be responsive to residual soil N conditions may also help to optimize interseeding performance.

Moving forward, management goals of Mid-Atlantic producers will largely determine adoption rates of cover crop interseeding in corn production systems. Future research is still needed to more clearly define where and when interseeded cover crops are a better option than post-harvest establishment. Additional research is also needed to design integrated crop management strategies for interseeded systems that consider herbicide selection, fertility management, cover crop species selection, and cash crop relative maturity and population density to optimize both cover and cash crop performance and hasten adoption of cover crops in corn production systems.

See References on page 59

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Cover crops [continued from p. 25]

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