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FEATURE

Aerially seeding cover crops in the northern US Corn Belt: Limitations, future research needs, and alternative practices

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Incorporating cover crops into the two-year corn (*Zea mays* L.)–soybean (*Glycine max* L.) rotation can reduce soil erosion, increase soil organic matter, improve soil structure (Snapp et al. 2005), and reduce nitrate (NO_3) leaching (Strock et al. 2004; Fisher et al. 2011). However, it is often difficult to establish winter cover crops in the cooler climate and shorter growing season of the northern Corn Belt. Miguez and Bollero (2005) reported that grass cover crops in the north central United States would only provide marginal benefits due to low biomass production. Through growth simulations, Baker and Griffis (2009) found that the main limitations are degree days and photosynthetically active radiation. Strock et al. (2004) suggested that based on average weather patterns in southwestern Minnesota, winter rye (*Secale cereal* L.) would only be a successful cover crop in one out of four years.

In these studies, however, temperatures were already cool when the cover crop was planted following harvest of the preceding crop. As another option, Frye et al. (1988) suggested that broadcasting seed into a standing crop can result in earlier crop growth than drilling the seed after harvest. Through growth simulations based on field experiments, Feyereisen et al. (2006) recommended planting by September 15 to maximize biomass production, although studies in southwestern Minnesota reported that earlier planting (August 15) resulted in higher biomass production (Moncada and Sheaffer 2010). Many farmers and researchers are testing these concepts by aerially seeding cover crops during the early fall into a standing cash crop. Results have been mixed, and some areas of the country have seen more adoption of the practice than others.

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Aerial seeding has particularly increased in areas that have incentivized the use of cover crops. In Maryland, where there are concerns about agricultural pollution in the Chesapeake Bay, approximately 82,150 ha (203,000 ac) of cover crops were planted in 2007 with 12%, or 9,850 ha (24,300 ac), applied aerially (Powell 2008). The area more than doubled during the subsequent five years with 167,900 ha (415,000 ac) planted in the fall of 2012 (MDA 2014). This increase is likely related to the corresponding increase in dedicated funding for the Maryland Department of Agriculture's cover crop cost-share program (MDA 2010). Other areas that have seen an increase in aerial seeding are Indiana and Iowa, both important in corn and soybean production. In the fall of 2011, approximately 28,300 ha (70,000 ac) in northeast Indiana (Dave Robison, personal communication, 2012) and 8,100 ha (20,000 ac) in Iowa (Sarah Carlson, personal communication, 2012) were seeded aerially. In Iowa, this method was used for about half of the reported cover crop acreage.

In addition to increasing the window of opportunity for planting cover crops, there are other benefits of aerial seeding. It avoids a trip through the field with heavy machinery, reducing wheel traffic and compaction. This is particularly important when conditions do not allow entering a field. Aerial seeding also takes less time than drilling or broadcasting, thus freeing up farm labor (Mintz 2012). Robison (2011) reported that aerial applicators can seed up to 81 ha h^{-1}(200 ac hr^{-1}) in Indiana, while using a highboy to broadcast seed can only seed 4 to 5 ha h^{-1} (10 to 12 ac hr^{-1}).

However, aerial seeding is still considered a risky practice, and farmers in the northern Corn Belt are particularly hesitant, feeling that the practice is too unreliable (Dave Linn, Daniel Gillespie, Tony Thompson, Dean Thomas, personal communications, 2012). Collins and Fowler (1992) concluded that the high risk of failure offsets the advantages of overseeding compared with drilling. The objective of this paper is to discuss some of the limitations of aerial seeding, future research that is needed to overcome several of the barriers, and alternative cover cropping practices.

LIMITATIONS

Weather. Autumn precipitation and temperature are unpredictable in the northern Corn Belt. Strock et al. (2004) found that the probability of favorable weather for optimal cover crop establishment was 25% in southwestern Minnesota. Using the methods outlined in their paper, we compared the weather conditions of other areas in the Corn Belt to those of the fall of 2010, a successful cover crop year in southeastern Minnesota (figure 1), most likely due to warmer and wetter conditions compared with the 30-year average temperature and precipitation (Wilson et al. 2013). The likelihood of conditions favorable for fall establishment in each region was calculated by totaling the number of years with weather conditions similar to the successful year in southeastern Minnesota (wetter and warmer than usual) and dividing each total by 30 years.

By this analysis, southern Minnesota and Wisconsin have the lowest chance for successful establishment of cover crops (table 1). These two areas are the farthest north and thus the coldest. Southwestern Michigan has the highest chance for establishment with warmer temperatures and more precipitation, likely due to close proximity to Lake Michigan and the resulting increased moisture in the atmosphere. In central Iowa, there is just under a 50% chance, and in central Indiana and Illinois, cover crops will be successful in two out of three years. Precipitation tends to increase from west to east, which is apparent in the increasing chance of successful establishment from west to east. Correspondingly, Collins and Fowler (1992) concluded that broadcast seeding relied heavily on postseeding rainfall, and Wilson et al. (2013) reported that precipitation within one week of seeding was

Figure 1

Yearly departure from the southeastern Minnesota 30-year average temperature (1981 to 2010) versus departure from the southeastern Minnesota 30-year average precipitation during September to November. Shaded areas highlight the years with favorable weather conditions (wetter and warmer than the Minnesota average) for establishment of aerially seeded cover crops.

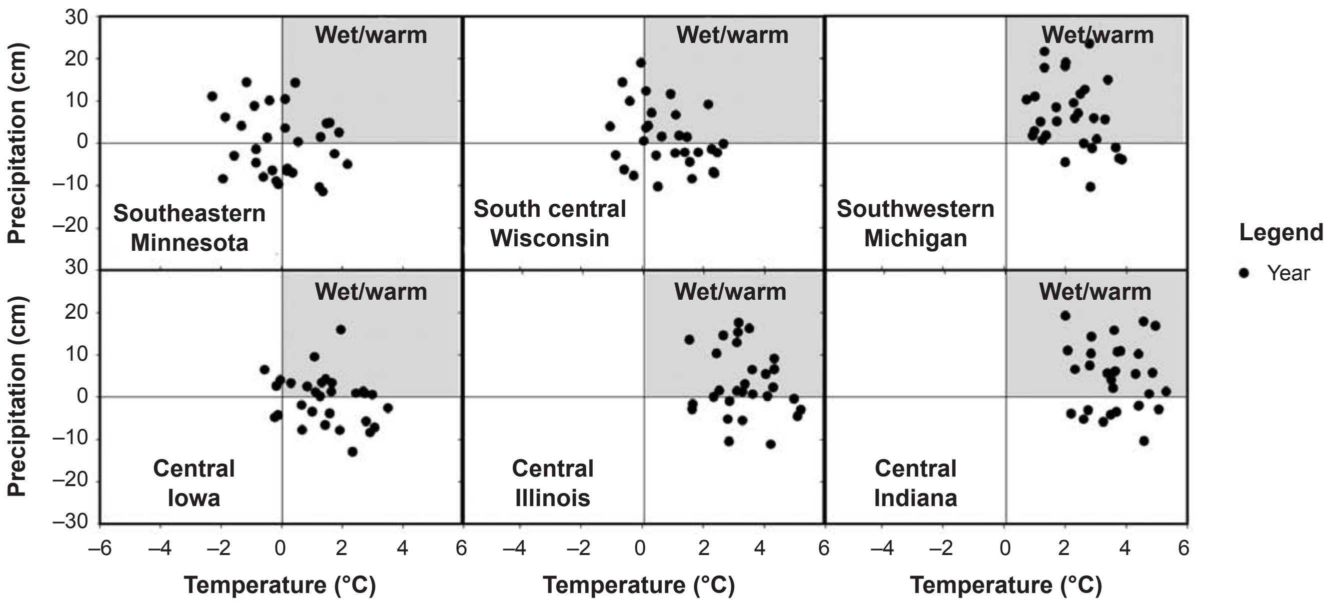

Table 1

Probability of favorable weather conditions for optimal cover crop establishment in various US regions.

Region	Probability (%)
Southeast Minnesota	27
South central Wisconsin	37
Southwest Michigan	77
Central Iowa	47
Central Illinois	67
Central Indiana	67

the most important factor in determining fall rye cover crop growth.

Aerial Applicators. At this point, aerial seeding is more art than science. There are multiple factors to take into consideration when applying seed, including wind speed/direction, weight of seed, broadcast width, height of flight, and shape of field. Pilots decide how high above the canopy they need to fly for a specific broadcast width depending on seed weight. Lighter seeds tend to float and may be more affected by the wind than heavier seeds. Seed mixes are more difficult to spread due to these differences, and the pilot must take this into consideration. The shape of the field also determines how the applicator will fly. Large square or rectangular fields are easier to navigate than fields with contours.

With all of these factors to consider, it is not surprising that aerial applications do not always provide the coverage that farmers want. In southeastern Minnesota, observed coverage with helicopter application ranges from 100% down to approximately 20% due to skips. In Indiana, one applicator left 24 m (79 ft) gaps across multiple fields (Robison 2010). With the need to improve application and a growing interest in cover cropping, a training session was held for aerial applicators in August of 2011 (Gardisser 2011). This training was mostly focused on fixed-wing aircraft applicators, however, so more education may be needed for helicopter pilots. Some have speculated that turbulence from the helicopter blades may make seeding even more unpredictable (Buckley 2011).

Potentially increasing the chance of poor application is a shortage of willing aerial applicators in the northern Corn Belt. The Allegan Conservation District surveyed aerial applicators throughout the Midwest and found that Wisconsin had 2 applicators for cover crops, while the states with more favorable weather had more: Michigan had 25 and Indiana had 7 aerial applicators (Mark Ludwig, personal communication, 2012). Gruver (2012) reported 7 cover crop applicators in Illinois. In the Iowa Cover Crop Business Directory, there are 14 aerial applicators in Iowa compared with 2 in Minnesota (Ogawa and Burke 2011). There is not a lack of aircraft operators in Minnesota (45 Minnesota-based pilots are registered members of the Minnesota Agricultural Aircraft Association), so the apparent cause is a lack of demand for aerial seeding. With an increase in seeded area in the state, it is possible that more applicators will become interested in seeding cover crops, and perhaps application costs will decrease.

Seed Predation. Aerially applied seed remains on the soil surface and becomes vulnerable to predation by insects, rodents, and birds. Farmers have reported significant losses (Lessiter 2009), and we have seen this at our research sites as well. In August 2010, we aerially seeded three corn fields in southeastern Minnesota; seed counts the day of seeding and one week later revealed a 48% to 98% loss. Davis and Leibman (2003) found that predation of weed seeds often found in corn

Table 2

Costs for aerially seeding winter cover crops at various locations during the fall of 2011.

Location	Seed	Seeding rate (kg ha^{-1})	Costs: Seed (US$ kg^{-1})	Costs: Aerial application (US$ ha^{-1})	Total (US$ ha^{-1})
Wilmington, Ohio*	Organic Winter Rye	94	0.66	25 to 40	87 to 102
Iowa†	—	84	—	40	79 to 86
Southeastern Minnesota‡	Winter Rye	112	0.52	62	120

*Ryan Alexander, personal communication, 2012.
†Sarah Carlson and Steve Berger, personal communications, 2012.
‡Melissa Wilson, personal communication, 2012.

and soybeans peaked in September with 5% to 18% of seeds eaten per day. Similarly, in Iowa, 80% to 90% of weed seeds in corn and soybeans were eaten in late August and September, compared with only 30% in July, early August, and October (O'Rourke et al. 2005). This time period coincides with aerial seeding, which may be one cause of our missing seed. These studies mainly focused on invertebrates, but there are other seed predators reported as well, including birds (Barnett and Comeau 1980) and mice (Cardina et al. 1996; Cromar et al. 1999).

We also observed that seed not removed by larger predators was frequently damaged by insects during germination. In other studies, ground beetles damaged the endosperm of germinating perennial ryegrass (*Lolium perenne*) and weeds like common chickweed (*Stellaria media*) and redroot pigweed (*Amaranthus retroflexus*) (Lund and Turpin 1977; Luff 1980), but we also observed slugs and millipedes eating seed. Lund and Turpin (1977) found that once seeds were damaged in this manner they did not germinate. Seed predation of surface-applied cover crops may be an important limiting factor, but available data are scarce.

Economics. One of the main drawbacks to planting cover crops is the cost (CTIC 2010), which includes buying seed, planting it, and, in the case of winter rye, killing it in the spring. Sometimes costs may be offset by an increase in cash crop yield the following year, but often economic returns are reduced (De Bruin et al. 2005). There are few studies examining the economics of aerially seeding a cover crop, but there have been multiple reports on the costs of seed and application (table 2). Seed costs are highly variable, depending on type of cover crop used and supply. For example, in 2010, cereal rye varied from US$0.32 to US$0.41 kg^{-1} (US$0.14 to US$0.19 lb^{-1}), annual ryegrass from US$1.04 to US$1.21 kg^{-1} (US$0.47 to US$2.10 lb^{-1}), and hairy vetch (*Vicia villosa*) from US$3.13 to US$4.63 kg^{-1} (US$1.42 to US$2.10 lb^{-1}) across Wisconsin, Minnesota, and Illinois (Gruver 2012). Aerial application costs are also inconsistent and depend on the number of trips per field (depending on seed weight), proximity of fields to a runway or landing site, fuel prices, and total acreage seeded (Carlson 2010).

The costs of aerial seeding are competitive or slightly higher than drilling after harvest of the main crop. The Iowa Farm Custom Rate Survey estimated that drilling small grains would cost US$38 ha^{-1} (US$15 ac^{-1}) on average with diesel priced at US$0.99 L^{-1} (US$3.75 gal^{-1}) (Edwards et al. 2012). Broadcasting the seed with a tractor was less expensive, costing US$29 ha^{-1} (US$12 ac^{-1}). In Minnesota, planting rye with a no-till drill was estimated to be US$53 ha^{-1} (US$21.50 ac^{-1}) with the price of diesel at US$0.95 L^{-1} (US$3.60 gal^{-1}) (Lazarus 2012). The fee for aerial seeding was approximately US$40 and US$62 ha^{-1} (US$16 and US$25 ac^{-1}) in Iowa and Minnesota, respectively (table 2). A benefit of aerial seeding is that it does not require additional labor, and other tasks on the farm may be completed in a timely manner. This is hard to monetize but should be taken into account when comparing the slightly higher costs with those of drilling the seed.

One way to reduce the cost of aerial seeding is through participation in a cost-share program. These programs are a primary reason that cover crop application in Maryland and Iowa has dramatically increased in recent years. For the fall of 2011, the Maryland Department of Agriculture (2011) offered up to US$210 ha^{-1} (US$124 base pay plus US$86 in additional incentives [US$85 ac^{-1}; US$50 base pay plus US$35 in additional incentives]) to farmers who aerially seeded. In Iowa, the Natural Resources Conservation Service (NRCS) paid approximately US$124 ha^{-1} (US$50 ac^{-1}) for cover crops (USDA NRCS-IA 2010). These amounts typically cover the cost of seed and application with enough left over to manage the crop in the spring.

In the midwestern United States, only 11% of farmers reported using cover crops in the past five years, yet 56% said they would plant cover crops if cost-sharing were available (Singer et al. 2007). Interestingly, there are cost-share programs available through the NRCS in most of the states in the region (table 3), so it seems that more effort is needed in advertising them. Also of note is that payments were typically lower in the northern states (approximately US$59 ha^{-1} [US$24 ac^{-1}] on average) compared with those further south (US$84 ha^{-1} [US$34 ac^{-1}]). Increased cost-sharing may be necessary to further promote cover cropping in the northern part of the region.

FUTURE RESEARCH

While there has recently been a study characterizing the factors that affect successful establishment of aerially seeded winter rye (Wilson 2012), more research is needed to improve success rates. For instance, the mechanics of aerial application need to be fine-tuned. Farmers are

Table 3

Natural Resources Conservation Service cost-share programs for the 2012 fiscal year.

State	Cover crop	Payment rate (US$ ha^{-1})	Reference
Iowa	Non-legumes	66.92	USDA NRCS-IA 2012
	Legumes	63.85	
Illinois	Non-legumes	87.62	USDA NRCS-IL 2012
	Legumes	95.78	
Indiana	Species mix	103.78	USDA NRCS-IN 2012
Michigan	Non-legumes	48.16	USDA NRCS-MI 2011
	Legumes	69.86	
Minnesota	Non-legumes	48.16	USDA NRCS-MN 2012
	Legumes	69.86	
Wisconsin	Non-legumes	48.16	USDA NRCS-WI 2012
	Legumes	69.86	

less likely to adopt the practice if applicators are doing a poor job of seeding fields. Researchers and pilots should focus on determining the optimal speed and height above the canopy to seed a variety of cover crops with enough overlap to avoid gaps. While some of this information has been disseminated for fixed-wing aircraft pilots, helicopter applicators will benefit from this knowledge as well.

Researchers should also focus on finding appropriate cultivars for aerially seeded winter cover crops. Because aerial application places seed on the soil surface, appropriate cultivars must germinate with less moisture and be resistant to potential seed predators. Currently, we only have a few species suitable for cover cropping that do not winterkill in the northern Corn Belt, with cereal grains, such as winter wheat (*Triticum aestivum*) and winter rye, being the hardiest. Some legumes, such as clovers (*Trifolium* sp.) and hairy vetch, may overwinter, but more cold-tolerant varieties would be useful to increase nitrogen (N) supply to the following cash crop.

ALTERNATIVE PRACTICES

Several alternative practices for establishing cover crops have been suggested, although few have been studied in the upper Midwest. One method, broadcasting with high clearance vehicles, is comparable to aerial seeding but has the same drawbacks since seed does not have good contact with the soil. Other methods include applying a coating to the seed, self-seeding, or applying the cover crop with manure (manure slurry seeding).

Broadcasting with High-Clearance Vehicles. Alternative means for broadcasting seed can include highboy seeders, tractors modified for higher clearance, and modified sprayers. These methods provide better uniformity of coverage than aerial seeding (Robison 2011; Mintz 2012; Wilson 2012).

However, highboys and modified tractors require more time and labor and added cost to retrofit equipment if it cannot be rented locally (Robison 2011; Mintz 2012). There is also concern that these methods can damage the standing crop, but Wilson (2012), Johnson et al. (1998), and Smith and Kallenbach (2006) reported no soybean yield losses when using modified drop seeders for overseeding cereal rye and annual ryegrass. As with aerial applications, however, seeding without incorporation is still highly dependent on weather, and precipitation is needed soon after seeding. Both types of application also generally require higher seeding rates due to higher seed mortality. A highboy drill recently developed in Pennsylvania has shown promise in initial testing.

Seed Coatings. There are a variety of seed coating technologies that have recently become available. The first is a polymer that prevents fall germination by absorbing moisture but not allowing the moisture to pass to the seed. Once the ground and seed freeze, the polymer matrix becomes cracked, and moisture is allowed to pass to the seed for spring germination. One use for this technology is to fall seed canola (*Brassica napus*) for a spring crop, but if conditions are dry in the fall, spring germination can be greatly decreased (Willenborg et al. 2004). The second type of coating is a temperature-activated polymer that only allows germination to occur above certain atmospheric or soil temperatures (Greene and Balachander 1999). This has been used successfully to increase early-planted corn and soybean emergence in multiple locations across the Midwest (Johnson et al. 1999; Gesch et al. 2012). One seeding service (Smith Seed Services, Halsey, Oregon) has developed a third coating specifically targeted for aerial seed applications. The manufacturer states that the coating adds density to the product, making it more accurate to apply from the air, and increases seed to soil contact, absorbing water to provide a consistent level of moisture around the seed (Smith Seed Services 2012). This product may increase the probability of successful establishment of aerially applied seed, but further research is needed. A major consideration is the additional cost of coated seed; since cover cropping is already an additional expense, coated seed may not result in monetary gain.

Self-Seeding. One way to reduce the cost for planting a cover crop each year is to allow the cover crop to self-seed by only killing it within soybean or corn planting rows and allowing it to produce seed in the interrow that can germinate in the fall. In Iowa, McDonald et al. (2008a) found that wheat exhibited more promise for self-seeding than rye or triticale, although all three cereals significantly reduced corn yields (McDonald et al. 2008b).

Manure Slurry Seeding. Mixing cover crop seed with manure slurry and applying it after harvest of the cash crop has been tested by researchers at Michigan State University. Harrigan et al. (2006) reported that plant density with this method was lower in Michigan than when the cover crops were drilled, but fall total biomass was similar or greater due to larger individual plants. This practice minimizes trips across the field while the manure provides moisture and nutrients to the developing crop. In return, cover crops coupled with manure minimize nutrient losses from the field (Parkin et al. 2006; Singer et al. 2008; Kovar et al. 2011). However, this practice can only be used after harvest of the cash crop, suggesting that, like drilling, it may not fit into the corn–soybean rotation in cooler climates.

CONCLUSIONS

Aerial seeding has allowed farmers in the upper Midwest to fit cover crops into the corn–soybean rotation. The practice has grown over the past few years in other areas, but in the northern Corn Belt adoption has been limited by unpredictable weather, lack of aerial applicators, poor stands due to pilot errors and seed predation, and high costs. There is some potential to increase adoption by improving application methods and the cultivars used for cover crops, which could in turn increase the demand for pilots willing to aerially seed in the region, thus bringing down the cost. However, the problems associated with broadcasting seed—predation and poor germination—will persist. Alternative practices for establishing cover crops show promise, but more research is needed to determine whether these practices can succeed consistently in the corn–soybean rotation in northern climates.

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