Comparing Methods for Overseeding Winter Rye into Standing Soybean

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Core Ideas
• Several methods of overseeding a winter rye cover crop into soybean were tested.
• Tractor-mounted seeders reduced soybean yield by 4% relative to an aerial seeder.
• Each seeder was equally variable across the seeding path with an average CV of 34%.
• Rye growth was influenced by weather and possibly by seeding density (a covariate).
• Seeding rate and timing may be more important factors than choice of equipment.

ABSTRACT
In the upper Midwest, short growing seasons make it difficult to establish cover crops in corn (Zea mays L.)–soybean [Glycine max (L.) Merr.] rotations. Overseeding before cash crop harvest may allow more time for growth, but practical methods need to be evaluated. Over 2 yr, this study assessed three winter rye (Secale cereale L.) overseeding techniques into standing soybean in mid-September: aerial seeding (AS), tractor-mounted air-flow spreader (TAF), and tractor-mounted fertilizer broadcast spreader (TBS). All treatments had equal variability in seeding density across plots. When rye was overseeded using the TAF and TBS treatments, soybean yield was reduced by approximately 4% relative to the AS treatment. In spring, seeding treatments impacted aboveground biomass production and N uptake in a year with good growing conditions (2010–2011), but not in a year with poor growth conditions (2011–2012). The impact of seeding method in the first year of the study was more likely due to differences in seeding density of the treatments, which was used as a covariate in this study. In a year with good growing conditions, the treatments with lower seeding densities had more spring biomass production, likely due to compensatory growth. Overall, measured values of aboveground biomass ranged from 39 to 467 kg ha⁻¹, whereas aboveground N uptake ranged from 2.1 to 15.3 kg ha⁻¹. Based on these findings, research efforts should focus on evaluating optimal seeding rates and timing, rather than choice of seeding method, to reduce impact on soybean yields and maximize cover crop benefits.

Abbreviations: AS, aerial seeding; BLUPs, best linear unbiased predictors; CV, coefficient of variability; TAF, tractor-mounted air-flow spreader; TBS, tractor-mounted broadcast spreader.

In recent decades, the 2-yr corn (Zea mays L.)–soybean [Glycine max (L.) Merr.] rotation has come to dominate the agricultural landscape in the upper Midwest (Randall, 2003; Karlen, 2004), despite potential environmental consequences. This mainly occurred to offset losses in corn and soybean land area in the southern United States (Hart, 2006), but also because of increased uses for the two crops for industrial purposes, particularly in the food and transportation industries (Karlen et al., 2006; Wallendar et al., 2011). The United States is also a large player in the world trade market, exporting 10 to 20% of its corn and approximately 50% of its soybean crops each year (USDA, 2017, 2018). Despite the economic benefits of this cropping system, it degrades soil quality over time (Karlen et al., 2006) and can result in significant losses of nitrate (NO₃⁻–N) to ground and surface waters (Dinnes et al., 2002; Oquist et al., 2007; Tomer and Liebman, 2014). Research has shown that excess N is the main cause of hypoxia in the Gulf of Mexico (Rabalais et al., 2001). Of the Mississippi watersheds, the Upper Mississippi Basin contributes 40% of the total N flux despite only making up 16% of the drainage area (Aulenbach et al., 2007). As the demand for biofuels increased starting in the mid-2000s, millions of acres of retired farmland have been returned to crop production (Collins, unpublished statement before the U.S. Senate Committee on Environment and Public Works, 2006; Newton and Kuethe, 2015), and in so doing have increased the negative impacts of such an intensive cropping system. To meet these growing demands on our cropland while protecting natural resources, alternative...
management practices must be adopted that reduce NO$_3$–N leaching while sustaining productivity.

Using cover crops during the non-growing season is one solution for reducing NO$_3$–N loss because it can increase the amount of time the land is covered in growing vegetation. Cover crops function as catch crops by removing inorganic N from the soil profile and holding it in organic forms (Dinnes et al., 2002). This includes residual N from fertilizer or manure used for the previous crop. In the following spring, the cover crop residue decomposes and the organic-bound N is slowly released to the succeeding crop after it is mineralized (Ruffo and Bollero, 2003), although this appears to be dependent on the cover crop species used (Hashemi et al., 2013; Ruark et al., 2018).

Although some studies have found that subsequent corn yields may be decreased by cover crops, particularly when grass species are used (Tollenaar et al., 1993; Kaspar and Bakker, 2015), others reported that yields increased after long-term use of cover crops (Ball-Coelho and Roy, 1997; Ball-Coelho et al., 2005; Basche et al., 2016; Seifert et al., 2018). Studies in soybean have also shown mixed results, but as long as appropriate management techniques were used, yields were maintained or increased (Moore et al., 1994; Ruffo et al., 2004; Strock et al., 2004; Basche et al., 2016; Seifert et al., 2018).

Although many crops have been evaluated for potential use as cover crops, cereal rye is particularly effective at reducing NO$_3$–N leaching (Ditsch et al., 1993; McCracken et al., 1994; Strock et al., 2004; Fisher et al., 2011; Meisinger and Ricigliano, 2017) and stabilizing inorganic N within agronomic depths of soil (Lacey and Armstrong, 2015). Legumes like hairy vetch (Vicia villosa Roth) and crimson clover (Trifolium incarnatum L.) also have the ability to scavenge residual N fertilizer, but Meisinger et al. (1990) found that cereals were superior. Brassicas such as forage radish (Raphanus sativus L.) and rape (Brassica napus L.) have been found to take up more fall N than winter rye (Secale cereale L.) (Dean and Weil, 2009), but the disadvantage is that radishes are freeze-killed and do not scavenge N in the spring, and rape does not reliably overwinter in cold areas. Rye is notably cold-tolerant, making it especially useful for northern climates where it can scavenge N during the fall and spring (Dabney et al., 2001). Additional advantages of rye include improved soil structure, an increase in soil organic matter, reduction of soil erosion, (Snapp et al., 2005), and suppression of weeds (Barries and Putnam, 1983; Liebl et al., 1992; De Bruin et al., 2005; Werle et al., 2018).

Despite the fact that the benefits of cover crops have been known for some time (Odland and Knoeblauch, 1938; Beale et al., 1955), the adoption of this practice in the upper Midwest has been low. According to the 2017 Census of Agriculture, only 8.5% of cropland was planted to cover crops in Michigan, 6.1% in Wisconsin, and 2.6% in Minnesota (USDA, 2019). Progress has been made over the past few years, however, as the overall increase in cover cropped acreage was 33% across the region between 2012 and 2017 (USDA, 2019).

Using satellite data, Seifert et al. (2018) confirmed that cover crop acreage increased in the Midwest from 2008 to 2016, but noted that there were stark differences in adoption between southern Illinois, Indiana, and Ohio—where cover crops are more popular—and the more northern regions. Again, this is likely due to the short growing season and the influence it has on successful establishment. Using meta-analysis techniques, Miguez and Bollero (2005) and Marcillo and Miguez (2017) concluded that grass cover crops in the north central United States would only have marginal yield benefits on cash crops because late fall cover crop growth is limited. Using an analysis of average weather patterns in southwestern Minnesota, Strock et al. (2004) suggested that rye would only be a successful cover crop in 1 of every 4 yr. In the three previously mentioned studies, however, temperatures were already cool when cover crops were planted after harvest of the preceding crop in late fall.

One solution is to broadcast a cover crop into the standing cash crop to extend the growing season. Frye et al. (1988) showed that this resulted in earlier crop growth than drilling the seed after harvest. This is especially useful in soybean plants, which leave minimal residue on the ground over winter. There are two main broadcast methods that are currently in use: a spreader mounted to a high-clearance tractor or vehicle and aerial seeding via fixed-wing aircraft or helicopter. Both have their advantages and disadvantages. Aerial seeding is typically faster and keeps heavy machinery out of the field. For example, Robison (unpublished presentation at the Indiana Certified Crop Advisor Conference, 2011) reported using a highboy with a broadcast seeder was only able seed 4 to 5 ha h$^{-1}$ but that aerial applicators seeded up to 81 ha h$^{-1}$ in Indiana. On the other hand, application costs with aerial seeding can vary greatly depending on location and availability of service and it may not result in a consistently uniform stand (Wilson et al., 2014). Using a high-clearance vehicle to broadcast seed may provide more consistency across the field and may be done with equipment already on hand or through rentals from a local cooperative. However, it requires the use of heavy equipment in the field, which can lead to compaction, tends to be slower and may damage the standing crop. These seeding techniques have not been evaluated against one another for seeding effectiveness or variability. The objectives of this study were to: (i) compare the seeding variability and rye biomass yields of aerial seeding vs. a tractor-mounted airflow spreader and a tractor-mounted fertilizer bucket spreader; (ii) evaluate the impact of the seeding method on soybean yields; and (iii) characterize the amount of N in aboveground rye biomass prior to termination.

**MATERIALS AND METHODS**

This study was conducted at the University of Minnesota’s Rosemount Research and Outreach Center near Rosemount, MN, during two fall–winter seasons (2010–2011 and 2011–2012) in different fields. Both fields were farmed in a conventionally tilled corn and soybean rotation, and were planted in soybean the year of seeding with 0.76-m row spacing. The soil at both sites was predominantly Waukegan silt-loam (fine-silty, very sandy, mixed mesic Typic Hapludolls) with 0 to 1% slopes. Representative soil samples from 0 to 15 cm were collected on the day of broadcast seeding for routine soil tests (Brown, 1998), and KCl-extractable ammonium N (NH$_4^+$–N) and NO$_3$–N were also determined (Table 1). A weather station located within 3 km was used to measure precipitation and temperature continuously.

Seeding treatments were replicated three times in 2010–2011 and four times in 2011–2012 in a randomized complete block design. Three treatments applied winter rye across 12 rows (9 m plot width) of standing soybean by broadcast methods, including aerial seeding (AS), tractor-mounted air-flow spreader (TAF), and tractor-mounted broadcast spreader (TBS). The length of the plots were 402 m in 2010 and 487 m in 2011, and all samples, except soybean yields, were collected from a 4 m by 21 m (0.01 ha) area within the larger plots. All treatments used uncertified ‘Rymin’ winter rye. For the AS treatment, seed was applied on 9 Sept. 2010 and 15 Sept. 2011 by a commercial company with a modified bucket spreader.
the number of seeds in a 0.25-m² quadrat were counted twice and the variability of each seeding method across the width of the plots, any seeds caught in the canopy to fall to the ground. To determine 16 Sept. 2010 and 21 Sept. 2011, 2 d after seeding to allow time for and soybean grain yield. Rye seeding density was characterized on dry matter yields and percentage N in collected plant matter.

<table>
<thead>
<tr>
<th>Year</th>
<th>pH</th>
<th>Bray-P</th>
<th>Organic matter</th>
<th>K†</th>
<th>NO₂−N†</th>
<th>NH₄⁺−N†</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010–2011</td>
<td>5.5</td>
<td>9.0</td>
<td>4.5</td>
<td>89.0</td>
<td>4.6</td>
<td>3.4</td>
</tr>
<tr>
<td>2011–2012</td>
<td>7.3</td>
<td>147.0</td>
<td>3.9</td>
<td>98.0</td>
<td>3.8</td>
<td>2.3</td>
</tr>
</tbody>
</table>

† Extractable.

attached to a helicopter. The dates were chosen based on helicopter/operator availability and weather conditions (low wind and high visibility). The company was asked to seed at a rate of 112 kg ha⁻¹ (341 seeds m⁻²) and they flew one pass per block. For the TAF and TBS treatments, seed was applied on 14 Sept. 2010 and 19 Sept. 2011. In 2010, this delay in seeding after the AS treatment was due to wet field conditions, and we decided to delay seeding by the same amount of time in 2011 to maintain consistency in the experiment. We used a tractor modified for a row-crop system with narrow tires and 0.6 m (2 ft) clearance. A Gandy Orbit-Air applicator (Owatonna, MN) spread seeds over 12 rows with separate spreaders every 0.76 m (one placed between each row) for the TAF treatment, whereas a bucket fertilizer spreader with spinning plate was used in the TBS treatment to broadcast seed. Both of the tractor-mounted spreaders were calibrated using factory settings to apply at a rate of 112 kg ha⁻¹ (341 seeds m⁻²).

Measurements throughout the fall included seeding density and soybean grain yield. Rye seeding density was characterized on 16 Sept. 2010 and 21 Sept. 2011, 2 d after seeding to allow time for any seeds caught in the canopy to fall to the ground. To determine the variability of each seeding method across the width of the plots, the number of seeds in a 0.25-m² quadrat were counted twice and averaged in every other soybean inter-row for six seeding density estimates per plot in 2010 and five estimates per plot in 2011. The coefficient of variation (CV) for each seeding method was calculated by dividing the standard deviation in the seeding density across rows by the average seeding density across rows and multiplying by 100.

In both years, it was noted that the calibration of each spreader type had not been sufficient, which resulted in different seeding rates (measured as seeding density) for each treatment (Table 2)—an error on our part and not a true effect of the treatments. To account for this, the average seeding density measurements for each plot were included as a covariate in our statistical analyses, as described further below. Soybean grain yields were harvested from each larger plot on 12 Oct. 2010 and 17 Oct. 2011 to determine whether any seeding methods impacted yield relative to one another. A weigh wagon was used to determine the wet yield for each plot. Subsamples of the grain were collected, dried at 60°C to constant mass, and weighed to determine dry grain yield.

Rye aboveground biomass was collected on 5 Apr. 2011 and 5 Apr. 2012 to estimate cumulative ryegrass growth in the spring. Rye was clipped at the soil surface in six quadrats (0.25 m²) and combined into one sample per plot. Plant matter was dried at 60°C, weighed to determine dry matter yields, and then ground with a Wiley mill to pass through a 2-mm screen. From the ground samples, total N was determined with a combustion analyzer (Vario EL CNS Analyzer, Elementar Analysensysteme, GmbH, Hanau, Germany) following the methods of Horneck and Miller (1998). Total N uptake was calculated as the product of aboveground dry matter yields and percentage N in collected plant matter.

Data from the study were analyzed using PROC MIXED (SAS Institute, 2010) with replicates and years considered as random variables. The seeding density was analyzed as a covariate for all rye biomass and N uptake analyses. All interactions that included “year” were assessed by year-specific inference using best linear unbiased predictors (BLUPs) as described by Littell et al. (2006). Treatment means were compared using the least-square means, when appropriate (SAS Institute, 2010). Interactions and simple effects were considered significant at p ≤ 0.05.

RESULTS AND DISCUSSION

Weather

Average temperature and precipitation for each cover crop season are compared with the 30-yr mean in Fig. 1. Fall (September–November) and winter (December–February) temperatures were near average, whereas the spring (March and April) was cooler during the 2010–2011 season. Fall and spring were wetter than average, especially in September and April. The 2011–2012 season was warmer than normal, especially between November and March. The fall was particularly dry with a deficit of 14.7 cm below the 30-yr average from September to November, whereas the winter and spring received average precipitation.

One of the key factors for establishing an overseeded cover crop is a precipitation event near the seeding date. Wilson et al. (2013) reported that rainfall within 7 d of seeding was the most important factor in determining fall biomass production of winter rye. In fall 2010, the TAF and TBS treatments received 4.7 cm of rain within 7 d and the AS treatment received 2.1 cm. Conditions were drier in 2011 with all three treatments receiving only 0.75 cm of rain.

Seeding Variability

Seeding methods did not impact the seeding density CV across the width of the row and there were no differences between years. The CV was 36.4, 27.1, and 37.8% for AF, TAF, and TBS, respectively, for an average of 34.4%. This suggests that the seeding variability of each of the application methods was similar, although the variability...
for all of them tended to be above the recommended percentage. For example, Lawrence and Yule (2007) reported a single traverse of a fertilizer spreader resulted in a CV of less than 15%, and Tissot et al. (2002) reported that a CV lower than 20% can be considered as acceptable.

In this study, only a single pass of each applicator was characterized, although most agricultural fields in the Midwest require multiple passes. In Indiana, one aerial applicator did not know the swath width of the spread pattern and left 24-m gaps in seeding across multiple fields (Robison, 2010). The swath width can be affected by wind, weight of the seed, and the height of the aircraft. Broadcasting from a tractor-mounted spreader may be more precise across a whole field since seeds are less affected by these characteristics, but the effective swath width needs to be taken into consideration to account for proper overlap. Lawrence and Yule (2007) found that the realistic CV of whole field applications of fertilizer averaged 33.1%, much higher than that of a single pass.

Soybean Yield

Soybean yield in 2010–2011 was significantly higher than yield in 2011–2012 (Table 3), regardless of treatment. This was likely due to drier than average conditions in August (data not shown) and September 2011, which may have caused reductions in yield. In addition, winter rye application method significantly affected soybean yield, although the treatment × year interaction was not significant (Table 3). The TAF and TBS treatments, which involved driving a tractor through standing soybean, reduced soybean yields by approximately 4% compared with the AS treatment. On the other hand, others have reported no soybean losses using a modified drop seeder for overseeding cereal rye and annual ryegrass (*Lolium multiflorum* L.) (Johnson et al., 1998; Smith and Kallenbach, 2006). Observations of the plots after seeding in the current study suggested that plant damage (i.e., crop lodging) was not the cause of the yield loss, but it is possible some pod shattering occurred as the tractor drove through the TAF and TBS plots. Other studies have concluded that overseeded rye does not compete with the soybean for moisture and nutrients and does not interfere with the main crop harvest (Johnson et al., 1998; Smith and Kallenbach, 2006; Hively and Cox, 2001), so this was unlikely an issue in the current study, particularly because the rye plants were not sufficiently tall to be cut by the combine.

This is an area that would benefit from more research, as timing of application may be crucial. The TAF and TBS plots were seeded approximately 5 d after the AS treatments in both years due to limitations in field conditions. Environmental conditions are one factor that can drive pod shattering in soybean (Quick and Buchele, 1974); thus, the difference in treatment application timing could potentially be a factor in this study.

Aboveground Rye Biomass

The year × treatment interaction was significant for spring aboveground rye biomass production (Table 4). There were significant differences between years, with all treatments in 2010–2011 having more growth than treatments in 2011–2012. This was likely due to the more favorable moisture conditions during Fall 2010 than in Fall 2011.

Interestingly, seeding method treatment impacted biomass production in 2010–2011 but not in 2011–2012. The order of highest to lowest spring biomass production in 2010–2011 (when means were adjusted for seeding density as a covariate) was AS > TAF > TBS. This is an inverse relationship to the measured seeding density of these treatments, which were from highest to lowest, TBS > TAF > AS (Table 2). This suggests that rye seedlings in the AS and TAF treatments, which had the lowest seeding densities after application, were able to increase biomass production relative to the
Nitrogen Uptake in Aboveground Rye Biomass

The measured values of spring aboveground rye biomass ranged from 414 to 467 kg ha$^{-1}$ in 2010–2011 and 39 to 173 kg ha$^{-1}$ in 2011–2012. In New York, Hively and Cox (2001) reported 200 kg ha$^{-1}$ of rye biomass in 1 of 2 yr of their study. Rye in that study was broadcast at 100 kg ha$^{-1}$ after soybean harvest and failed to establish in the second year. In Iowa, rye biomass accumulated 410 kg ha$^{-1}$ in fall and 1870 kg ha$^{-1}$ by early May (Johnson et al., 1998) when seeded at approximately 125 kg ha$^{-1}$. Our average spring biomass was well below their reported fall biomass, demonstrating the limitations in growing cover crops in more northern regions.

**Nitrogen Uptake in Aboveground Rye Biomass**

The trends seen in N uptake of the winter rye were similar to those seen in aboveground biomass production. There was a significant year × treatment interaction (Table 4) and all treatments in 2010–2011 had significantly more N uptake than those in 2011–2012. In addition, the seeding methods impacted N uptake in 2010–2011, but not in 2011–2012. Since biomass production is used to calculate N uptake, these results are not surprising. It is well established in the literature that cereal biomass production is strongly correlated with N uptake (Ball-Coelho and Roy, 1997; Lyons et al., 2017; Noland et al., 2018).

The measured aboveground N uptake values ranged from 14.6 to 15.3 kg ha$^{-1}$ in 2010–2011 and 2.1 to 8.2 kg ha$^{-1}$ in 2011–2012 and were similar to the ranges found in other studies. In New York, rye broadcast after soybean harvest took up approximately 4 kg N ha$^{-1}$ (Hively and Cox, 2001) whereas N uptake from overseeded rye in Maryland ranged from 3.4 to 39.5 kg ha$^{-1}$ (Fisher et al., 2011) in the aboveground biomass. These values were also similar to aboveground N uptake from rye drilled after harvest in warmer regions. Kessavalou and Walters (1999) reported N accumulations ranging from 9 to 60 kg ha$^{-1}$ after soybean in Nebraska. In the current study, rye was drilled in nearby plots following soybean harvest in both years of this study and we collected aboveground biomass samples in the spring (data not shown). The total N uptake in the drilled rye averaged 0.2 kg ha$^{-1}$ in 2010–2011 and 0.8 kg ha$^{-1}$ in 2011–2012. This indicates that overseeded rye scavenged more N than rye drilled after harvest, but more research is needed to directly compare these methods.

**CONCLUSIONS**

In this study, winter rye was successfully overseeded into standing soybean using three different techniques. In a year with more favorable growing conditions (i.e., normal temperatures and good moisture), broadcast seeding method appeared to impact biomass production, although it is suspected that seeding rates were more influential than the actual methods themselves. The lowest seeding rates had the most growth. In a year with poor growing conditions (i.e., a dry year), the seeding methods and rates did not matter. In the end, (i) the seeding method used did not matter as much as external factors like the weather, and (ii) none of the seeding methods produced yields comparable with those that have been achieved in warmer climates. Future research should focus on determining the ideal range of seeding rates for broadcast seeding methods and whether broadcast seeding is comparable to drilling after harvest.

**ACKNOWLEDGMENTS**

Funding for the project was provided by the Minnesota Board of Water and Soil Resources.

**REFERENCES**


**Table 4**: Aboveground biomass production and the associated total N uptake of winter rye overseeded into soybean near Rosemount, MN, for the spring sampling. Statistical analyses were only conducted on means adjusted for the seeding density covariate. Measured means are shown for practical comparison to other studies.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Adjusted means</th>
<th>Measured means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aboveground rye biomass</td>
<td>Total N uptake</td>
</tr>
<tr>
<td></td>
<td>kg ha$^{-1}$</td>
<td>kg ha$^{-1}$</td>
</tr>
<tr>
<td>2010–2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS</td>
<td>43.2 ± 91.9 a</td>
<td>2.41 ± 3.27 a</td>
</tr>
<tr>
<td>TAF</td>
<td>41.7 ± 92.2 b</td>
<td>2.36 ± 3.28 b</td>
</tr>
<tr>
<td>TBS</td>
<td>40.9 ± 92.4 c</td>
<td>2.33 ± 3.29 c</td>
</tr>
<tr>
<td>2011–2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS</td>
<td>39.5 ± 91.9 d</td>
<td>2.29 ± 3.27 d</td>
</tr>
<tr>
<td>TAF</td>
<td>40.0 ± 92.4 d</td>
<td>2.31 ± 3.29 d</td>
</tr>
<tr>
<td>TBS</td>
<td>40.0 ± 92.5 d</td>
<td>2.31 ± 3.29 d</td>
</tr>
</tbody>
</table>

Significance

- Treatment: NS‡
- Year: **
- Treatment × Year: **

‡ NS, nonsignificant.

**Significance at the $\alpha = 0.01$ level.

† Means with the same letter within columns are not significantly different ($p > 0.05$).
Hively, W.D., and W.J. Cox. 2001. Interseeding cover crops into soybean
Hart, C.E. 2006. Feeding the ethanol boom: Where will the corn come from? Iowa
6 of 7 dl.sciencesocieties.org/publications/age
Ball, B.C. 1986. Cereal production with broadcast seed and reduced tillage: A
Beale, O.W., G.B. Nutt, and T.C. Peele. 1955. The effects of mulch tillage on
De Bruin, J.L., P.M. Porter, and N.R. Jordan. 2005. Use of a rye cover crop
doi:10.2134/agronj2005.0098
Basche, A.D., T.C. Kaspar, S.V. Archontoulis, D.B. Jaynes, T.J. Sauer, T.B. Parkin,
Beale, O.W., G.B. Nutt, and T.C. Peele. 1955. The effects of mulch tillage on
Duffy, and A .P. Mallarino. 2006. Crop rotation effects on soil quality at
Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin,
Moore, M.J., T.J. Gillespie, and C.J. Swanton. 2000. Effect of cover crop mulches on
Randall, G.W. 2003. Present day agriculture in southern Minnesota: Is it sustainable? Southern Res. and Outreach Center, Univ. of Minnesota, Waseca, MN.