Frost-seeding Forage Legumes Into Small Grain Cover Crops

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Dedication

This thesis is dedicated to the hard working men and women farming in Minnesota who are interested in using the techniques discussed in the thesis. I hope the information in it may help them be successful in some way.

Abstract

Frost-seeding forage legumes into small grain cover crops is an option for many farm operations. The objective of this study was to determine the affect of frost-seeding date and small grain cover crop on the establishment and yield of alfalfa (*Medicago sativa* L.) as well as a red and ladino clover (*Trifolium pratense* L. *and Trifolium repens* L) mix. Seeding dates included; early winter, late winter, and spring seedings. Fall planted cover crops included; control of no cover, spring oats (*Avena sativa*), winter wheat (*Triticum aestivum*), and winter rye (*Secale cereale*). Seeding date was the most significant factor affecting legume plant populations. The spring seeding resulted in the highest populations and yield in five of six site years. Cover crop use increased plant population and yield, with no large difference among the cover crops used. Results illustrate the risk of frost-seeding, but also indicate the potential success with favorable conditions.

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LITERATURE REVIEW

Alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.), and ladino clover (*Trifolium repens* L.) are commonly grown forage legumes in the upper Midwest (Sustainable Agriculture Network, 1998). In organic and conventional crop rotations, alfalfa and red clover can suppress weeds (Mutch, Martin, and Kosola, 2003), provide high quality livestock feed, and biologically fixed N for companion and subsequent crops (Hesterman et al 1992; Sheaffer and Seguin, 2003). Alfalfa has greater long term persistence than red clover, but red clover has greater seedling vigor and seeding year yields (Sheaffer et al, 2003). While less widely used, ladino clover is an excellent living mulch, green manure, and beneficial insect attractant (Sustainable Agriculture Network, 1998).

Most legume seedings in Minnesota occur in early to mid-May after the ground has thawed and dried enough to support heavy equipment without compaction (Undersander et al, 2004). Conventional spring seedings use tillage and seeding equipment to provide critical shallow seed placement and seed-soil contact (Undersander et al, 2004). Even though temperatures are appropriate for seeding at this time, access to fields can be delayed with this technique due to precipitation or wet soils. This can delay spring plantings, reducing seasonal yields and giving weeds an advantage over the forages.

An alternative seeding technique to drilling the seed in the spring is frost-seeding, in early or late winter, which uses soil heaving during the natural soil freeze-thaw cycles to bury seeds and provide good soil contact. Typically, frost-seeding occurs in the late winter after most or all snow has melted and before the ground thaws.

This occurs in mid-March in much of the Midwest (Smith, Bula, and Walgenbach, 1986). Frost-seeding allows producers to spread the spring planting workload over a longer period of time (Tesar and Marble, 1998). If conditions are favorable, frost-seeded plants will have an earlier start to the growing season, providing an opportunity to be more competitive with weeds (Booth, Murphy, and Swanton, 2003).

When establishing legumes, organic and conventional farmers may also frost-seed with the use of small grain cover crops such as winter wheat (*Triticum aestivum*), winter rye (*Secale cereale*), and spring oats (*Avena sativa*) (Sustainable Agriculture Network, 1998). Commonly planted in the fall, these small grain crops capture residual nutrients from the previous crop and hold it until spring. Their residue also provides ground cover, reducing soil erosion. Legumes can then be frost-seeded or drilled into the cover crop. In the spring, the oats will not regrow, but the residue will suppress weed growth, reduce erosion and retain soil moisture until the legume seeds can establish. Rye and wheat will regrow in the spring and in addition to providing weed suppression, provide income from grain or forage (Blaser et al, 2006; Brink and Marten, 1986).

Since frost-seeding legumes into small grain cover crops is not as common as seeding them together, less information is available on practices to maximize the success of this technique. However, optimum seeding rates for frost-seeding of red clover with small grain cover crops were determined in Iowa (George, 1984). The optimal seeding rates for wheat (*Triticum aestivum* L.) ranged from 300 to 400 small grain seeds m^{-2} and 900 to 1200 seeds m^{-2} for red clover (Blaser et al, 2006). They reported that the small grains negatively impacted red clover yield in the establishment year, but not in subsequent years. They also found that increasing the red clover seeding rate increased final red clover DM (Dry Matter) yields in four of six years, but did not consistently impact forage quality of the red clover (Blaser, Singer, and Gibson, 2007).

Successful frost-seedings have yield levels similar to conventional spring seedings. Singer, Casler, and Kohler (2006) found frost-seeded red clover seeding year yield ranging from 3.4 to 7.7 Mg ha^{-1} (340 to 770 g m^{-2}) in Iowa and Wisconsin. Seeding year yields of conventionally established alfalfa in Minnesota range from 2.7 to 7.0 Mg ha^{-1} (270 to 700 g m^{-2}) (Minnesota Varietal Trials, 2009). Rehm et al, (1998) reported seeding year red clover yields from 3.1 to 6.5 Mg ha^{-1} (310 to 650 g m^{-2}) for a variety of establishment methods.

Frost-seeding can be riskier than conventional seeding (Singer et al, 2006). Factors that affect the success of frost-seeding include a risk of premature germination during the winter and subsequent freezing of seedlings with possible seedling injury or death. The minimum germination temperature requirement for alfalfa and red clover is 1^{o}C. However, at 4^{o}C, alfalfa and red clover seeds take 7.5 days to germinate versus 1 day at 19^{o}C (Wilsie, 1962). Also, alfalfa seedlings have little survivability of freezing temperatures (-10^{o}C) before having three to six true leaves visible and red clover does not gain this survivability until having at least seven to nine true leaves, which can take 5 weeks (Arakeri and Schmid, 1949; McKenzie, Paquin and Duke, 1988). Also, under growth chamber conditions, Arakeri and Schmid (1949) using -10^{o}C as a potential killing temperature for alfalfa seedlings, found good survival before the cotyledons broke through the soil (87% for alfalfa and 69% for red clover), almost no survival from cotyledons opening until 3-5 leaf stage (23% for alfalfa and 1% for red clover) and 48% and 39% survival of 3-6 leaf alfalfa and red clover respectively at that temperature. McElgunn (1973) found that alternating temperatures of 2^{o}C for 12 hours followed by 13^{o}C for 12 hours, like those found in the beginning and end of winter reduce both the rate of germination and the total germination of alfalfa, red clover and several other legumes.

FROST-SEEDING FORAGE LEGUMES INTO SMALL GRAIN COVER CROPS

Few frost-seeding studies have been conducted in winter climates typical for Minnesota. Since Minnesota's climate is different from Iowa, where more frost-seeding research has been conducted, more research is needed to determine the impacts of Minnesota's climate on frost-seeding legumes. Additionally, while small grain cover crops and frost-seeding of legumes have been studied, more information is needed from the Midwest on the impact of the combination of small grain cover crops and frost-seeding dates on the success of legume establishment. The objective of this study was to determine the affect of frost-seeding date and small grain cover crop species on the establishment and yield of legumes in the establishment year.

MATERIALS AND METHODS

Research was conducted at three sites in two years. The three sites included two at Rosemount, MN and one at Lamberton, MN. The studies were conduced for the 2007 and 2008 growing seasons. Although the experiment was conducted at these sites two consecutive years, it did not observe the same seeding over multiple years, rather new plots were used during the second year of the experiment. This provided six site years of data. The soil at two locations at Rosemount, MN (44^{o}53'N, 93^{o}13'W) is a Tallula silt loam at Site 1 (course-silty, mixed mesic Typic Hapludoll) and a Waukegan silt loam at Site 2 (Fine-silty over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludolls). The Rosemount sites are 3 km apart and the soils vary in subsoil characteristics. The Site 1 Tallula soil has a silt loam top soil underlain by clay whereas the Waukegan soil at Site 2 has a shallow topsoil underlain with gravel, providing little water holding capacity compared to the Tallula soil. At the location in Lamberton (44^{o} 13’N, 95^{o} 15’W) the soil is a Webster clay loam (fine-loamy, mixed, mesic Typic Endoaquolls). For both Rosemount sites the soil pH, extractable P, and exchangeable K were respectively 6.5, 70 kg ha^{-1}, and 300 kg ha^{-1}. Soil at the Lamberton site had a pH of 6.5, an extractable P of 10 kg ha^{-1} ppm and exchangeable K of 311 kg ha^{-1}.

The experiment was a randomized complete block with treatments in a split-split plot arrangement with three replications. Whole plot treatments were small grain cover crop species and consisted of a no cover crop control, ‘Jim’ oats, ‘Expedition’ winter wheat, and common winter rye. All were seeded at a rate of 300 seed m^{-2}. Subplots were seeding dates; early winter, late winter, and spring seedings. Sub-subplots were the legume crops; ‘Pioneer 54H91’ alfalfa (753 seed m^{-2}) and clover/grass mixture containing common organic red clover (270 seed m^{-2}), ‘Alice’ Ladino clover (215 seed m^{-2}), BG-34 perennial ryegrass (160 seed m^{-2}), ‘Climax’ timothy (592 seed m^{-2}) and ‘Lincoln’ smooth bromegrass (160 seed m^{-2}). In this experiment, the grasses seeded in mixture with the clovers did not establish due to little germination or survival across all six site years. Therefore, data will not be presented on the grass populations or yields, all legume comparisons are between legumes only. Also, the clover species (Red Clover and Ladino) was not identified therefore the legume treatments will be collectively referred to as alfalfa and clovers in the rest of this manuscript.

The previous crops on the fields at all sites were small grains. The Lamberton location is certified organic. The Rosemount locations, while not certified organic have not had any addition of chemical fertilizers or pesticides for the last three years. In the fall whole plots were uniformly disked and harrowed to incorporate residue before seeding of small grain cover crop treatments. Control plots of no cover crop were left fallow until legume treatments were applied. Cover crops were drilled in 15cm rows on 1 Sept. 2006 and 12 Sept. 2007 in Rosemount and 22 Aug. 2006 and 16 Aug. 2007 in Lamberton.

The first of the sub-plot treatments was the early winter seeding date. It was performed when the ground was frozen and snow was expected or had fallen on: 14 Dec. 2006 and 12 Dec. 2007 at Rosemount, and on 11 Dec. 2006 and 12 Dec. 2007 at Lamberton. In December 2007, a snow storm came before seeding at Rosemount. To prevent the seed from blowing away, the seed was broadcast and immediately incorporated into the snow using snowshoes. Late winter seedings were conducted when most of the snow had melted and the top few centimeters of soil froze at night and thawed during the day. Seed was spread in the morning when the ground was frozen to prevent soil compaction. These seedings occurred on 26 Mar. 2007 and 20 Mar. 2008 in Rosemount, and 17 Mar. 2007 and 18 Mar. 2008 in Lamberton. Spring seedings occurred after the ground had thawed and dried enough for equipment use. These occurred on 18 Apr. 2007 and 15 Apr. 2008 in Rosemount and on 18 Apr. 2007 and 17Apr. 2008 in Lamberton. The two sub sub-plot treatments of the alfalfa and clovers had plot sizes of 1.8 by 2.4 m at Rosemount, and 1.5 by 3 m at Lamberton. The plots were uniformly broadcast by hand.

At Rosemount plant population data was collected for the establishment year from three 0.09 m^2 quadrants and averaged per sub sub-plot on 26 Sept. 2007 and 30 Sept. 2008. In Lamberton plant population data was collected with two 0.25 m^2

quadrants and averaged per sub sub-plot on 17 May 2007, 4 Oct. 2007, and 12 June 2008. No weed control measures or other maintenance practices were taken on the sites during the growing seasons.

Biomass yield was determined for the establishment year for the live cover crops of winter wheat and rye as well as the legumes. Cover crop biomass was harvested and weighed 23 May 2007 and 17 Jun. 2008 at Rosemount and 17 May 2007 and 20 Jun. 2008 at Lamberton. Legume biomass was harvested and weighed at Rosemount on 23 Sept. 2007 and 30 Sept. 2008. At Lamberton legume biomass was harvested and weighed 4 Oct. 2007 and 24 Nov. 2008. Samples were harvested by hand from one 0.25 m^2 quadrant per sub sub-plot to a stubble height of 3 cm. Plant biomass was dried at 60^{o}C for 3 days and weighed. Yields are expressed on a dry matter basis.

In addition to plant population and yield data, thirty year historical records of daily minimum temperatures, maximum temperatures, and snow depth were collected for Rosemount and Lamberton.

An Analysis of Variance (ANOVA) was performed using PROC MIXED function of SAS (SAS Institute, 1999) to test for differences in plant population and dry matter (DM) yield due to cover crop species, planting date, legume species, and their interactions. Cover crop species, planting date and legume species were considered independent variables and fixed effects in the ANOVA while the replications at each site were considered random. Treatment effects were considered significant at $P < 0.05$. Analysis of variance was first conducted with locations and years pooled, however when their interactions were significant, the analysis was rerun separating the years and locations. This separated data will be presented in the manuscript. Several of the seedings had very poor stand establishment, resulting in a dataset that was not normally distributed. All of the data was square root transformed to produce data that was normally distributed and the back-transformed data was used in the analysis of variance. The transformation created normally distributed yield data. While improving the distribution, the transformation did not normalize the plant population data. This plant population data will still presented to provide a picture of the relationships between the treatments. For significant data, $P < 0.05$, treatments were separated with the least significant difference LSMEAN procedure with a Macro designed to convert mean separation output to letter groupings in PROC MIXED.

RESULTS AND DISCUSSION

Weather Conditions

Weather is a significant factor in all of agriculture. This experiment was no exception. The air temperatures and precipitation were important factors in this experiment.

Air temperatures from January through April for both years at both locations were similar to the 30 year normal (Fig. 1). Maximum and minimum air temperatures at Rosemount for 2007 were 0.1 and 0.3^{o}C above average respectively from January through April and in 2008 were 2.3 and 1.2^{o}C below average for the season. At Lamberton, January through April maximum and minimum air temperatures for 2007 were 1.9^{o}C below and 0.6^{o}C above normal respectively. During the same period in 2008 the maximum and minimum temperature averages were below normal, 3.7 and 1.6^{o}C respectively.

From January to April Rosemount precipitation levels were 6.1mm above the 30 year normal in 2007 and 1.8mm above normal in 2008. Lamberton precipitation was 4.8 mm above normal from January through April in 2007 and 6.7mm below normal in 2008. During the early part of the 2007 growing season (April, May and June) Rosemount precipitation was 13mm below normal and Lamberton precipitation was 2mm below normal. Later in the summer weather patterns became more erratic with July below normal (82mm in Rosemount and 54mm in Lamberton) with large thunderstorm events in August creating monthly precipitation levels well above normal at both sites (114mm in Rosemount and 65mm in Lamberton). These dramatic thunderstorms came in downpours, causing surface runoff and flooding rather than infiltration into the soil profile at both sites. For April, May and June in 2008 Rosemount was 5mm above normal and Lamberton was 2mm above normal. For the rest of the growing season Rosemount precipitation levels were well below normal, reaching drought conditions in July. This lack of rainfall through a large portion of the growing season resulted in lower overall plant establishment and yield than if rain patterns were more typical. For seedlings with little root structure, lack of rainfall can be a serious risk to establishment. With limited capacity to access water deep in the soil profile, the seedlings have a much lower chance of survival, thus limiting the success of a new seeding. Further discussion on the relevance of the weather conditions will follow in the manuscript.

Plant Populations

The analysis of variance for plant populations data indicated many significant interactions ($p < 0.05$) among and between sources of variation in this experiment including; year, location, cover crop species, seeding date and legume species. Due to the significant interactions between years and locations, legume plant population data for each of the six site years will be presented independently (Table 1). Seeding date had the largest impact on establishment year legume populations followed by legume species type. There were also differences in the interactions between legume and cover crop species. The differences in plant populations based on treatments and the potential reasons for the results observed will be described in the following section.

Seeding Date

Legume seedling establishment was poor for all but the 2008 growing season at Rosemount Site 2 and Lamberton (two of six years). Seeding date appears to be the most consistent factor affecting legume populations for all six site years (Table 1). Specifically, the spring seedings resulted in a higher plant populations and the early winter seeding resulted in lower legume populations in all six site years (Table 2). However, even while the spring seedings did result in legume populations considered appropriate , 20 to 50 plants m^{-2} for alfalfa and 60 to 100 plants m^{-2} for clovers (Sheaffer et al, 2003), the stands in the 2007 growing season did not produce adequate yields (George, 1984). During the 2008 growing season all three of the spring seedings resulted in excellent legume populations of greater than 120 plants m^{-2}. The success of the Lamberton site in the 2008 growing season may have been because snow cover prevented germination until the temperatures were more conducive to successful germination and establishment.

Cover Crops

Use of spring oat residue, winter wheat, or winter rye cover crops improved legume populations in both years and locations at Rosemount compared to the control of no cover crop. However the three cover crops had similar effects. Cover crops did not affect legume populations at Lamberton (Table 2). Benefits of cover crops or residue may be due to the cover crops reducing soil temperature fluctuations in the top layer of soil thus reducing the number of damaging freeze-thaw cycles and insulating the air around the newly germinated seedlings (Baker and Swan, 1966).

Legumes

Even though the clovers were seeded at half the rate of alfalfa, they had higher populations than alfalfa for both years at both Rosemount locations and populations were similar for the legumes at Lamberton. Gist and Mott, (1956) found clovers to be less affected by shade than alfalfa, which is a possible reason for the superior establishment of clovers over alfalfa with cover crops at Rosemount. Another possible reason for higher clover populations is that red clover is known to have greater seedling vigor then alfalfa (Sheaffer and Sequin, 2003).

Legume x Cover Crops

In the 2008 growing season there was a significant interaction between cover crops and legumes for legume plant populations at Rosemount Site 2 and Lamberton (Table 1). At Rosemount this interaction occurred because clovers seeded into winter wheat reached populations of 408 plants m^{-2}, significantly higher than that obtained with any other treatment combination and alfalfa seeded into the no cover control had populations of 60 plants m^{-2}, significantly lower than that obtained with any other treatment (Table 2). The only variation to this trend was seen at the anomalous date from the Lamberton site in 2008. That year alfalfa performed best when seeded into the no cover control with a population of 373 plants m^{-2} and clovers were most successful when seeded into spring oats (383 plants m^{-2}).

Dry Matter Yield

As with legume populations, the analysis of variance for DM yield indicated many interactions among and between cover crop species, seeding dates, and legume species. Similarly, results for yield will be presented independently for each site year (Table 3). Also similar to legume populations, seeding dates had the largest impact on legume yield. Other impacts on yield came from cover crops, cover crop and legume interactions, legume species, and seeding date by legume interactions.

Several of the early winter and late winter seedings had legumes establish, but did not produce enough biomass to harvest (Table 4). This may be due to lack of rainfall, or may be due to the impact of seeded date on the establishment of the legumes.

Seeding Date Impact

Seeding date had the largest impact on legume yield for all site years (Table 3). The spring seeding date produced the highest yields in all cases except for Lamberton in 2008 (Table 4). In Lamberton in 2008 the early winter seeding produced the highest yields followed by the late winter and then the spring seeding, the opposite result of the other sites and years. It is evident that something happens to the seeds over the winter that kills or damages the seeds. Given the low temperatures at which these seeds will begin breaking dormancy and imbibing water, it is likely that the seeds in the field can be damaged by imbibing water then freezing again before reaching conditions that are suitable for successful establishment. As for why the early winter seeding at Lamberton for 2008 was so successful, somehow these damaging conditions were avoided. Another possible explanation for the success is the weather conditions, which will be discussed in the weather conditions section.

Cover Crops

Cover crops established well for each site year. Biomass was not collected in the fall when cover crops were established. In the spring of legume establishment, biomass data was collected the live covers of winter rye and winter wheat (Table 5). Cover crop treatments resulted in similar legume yields at all locations and years except at Rosemount Site 1 in 2007 where winter rye produced higher legume yields. The rye may have protected the seeds from freeze-thaw events, allowing better establishment, or it may have reduced weed competition more than the other cover crops, allowing the legumes to gain a competitive advantage.

Also, Rosemount Site 2 in 2007 had differences in legume yield based on cover crops because use of a cover crop treatment resulted in higher legume yields than the no cover control, however the cover crops not different from each other (Tables 3 and 6). This indicates that seeding legumes into a cover crop of some type, whether oat residue or a live cover, can increase the yield of the legumes compared to not seeding into a cover crop. Even with high yielding cover crops like winter wheat and rye in 2008 at Lamberton, differences between all three cover crops were not significant.

Seeding Date x Cover Crop

A seeding date by cover crop interaction occurred for 2007 at Rosemount Site 1 and Site 2 as well as Rosemount Site 2 in the 2008 (Table 3). At Site 1, the legumes had higher yields when seeded into winter wheat in the spring. At Site 2 the three cover crops produced similar yields, but the control of no cover resulted in dramatically lower legume yields than the cover crops (Table 6).

Legume Species

Yields of alfalfa differed from those of the clovers for both years at Rosemount Site 2 and Lamberton in 2007 (Table 3). While the clovers did establish at higher populations, they were only higher in yield than alfalfa at Rosemount Site 2 in 2007. In the other two occurrences where there was a significant difference between legume yields, alfalfa had a greater yield than the clovers. What conditions were present that caused one species to have an advantage over the other is unclear. It may have been a factor that was undocumented such as weed competition.

Seeding Date x Legume Species

The seeding date by legume species interactions were significant for all six site years with the clovers seeded in the spring producing higher yields than the other combinations every time except twice (Tables 3 and 4). In Rosemount Site 1 in 2008 alfalfa seeded in the spring produced the highest yield. Then in Lamberton in 2008 the early winter alfalfa seeding outperformed the other treatments, followed by early winter x clovers and late winter x clovers. Again, this is partially due to the strong differences in seeding date success as well as the difference between legumes.

Discussion

Another reason for the poor establishment of the two frost-seeding dates is the possible germination of the legume seeds at low temperatures and subsequent freezing and death of those seedlings. The ability to germinate at low temperatures is beneficial for an early start to the growing season, but also increases the chance of legumes suffering frost damage or death. Thus, the success of frost-seeding legumes appears to be dependent on delaying seed germination until there is a reduced chance of experiencing the killing temperatures after germination.

In the second half of March for both years and both locations seedlings were exposed to such conditions (Fig. 1). The snow pack had melted, maximum and minimum temperatures rose above freezing for several days, temperatures then fell below freezing for several days. These conditions were more extreme for some years than others. For example, Rosemount in March 2007 experienced no snow, maximum and minimum temperatures above freezing from 24 Mar. through 4 Apr. After that minimum temperatures were below freezing until 16 Apr. and maximum temperatures were below freezing until 9 Apr. In comparison, Lamberton in 2008 experienced snow cover from 1 Jan. 2008 through 1 Mar. Minimum daily air temperatures rose above freezing from 15 Apr. through 25 Apr. then fell below freezing for 4 days while maximum temperatures stayed above freezing.

In order to examine the potential impact of weather on establishment of legumes, snow depth, maximum daily air temperatures, and minimum daily air temperatures for January through April for the past 30 years were collected for Rosemount and Lamberton. Data was reviewed to determine the number of times each year that conditions occurred that would allow for germination then death of frost-seeded legumes. The conditions included; no snow cover, maximum and minimum temperatures above 5^{o}C for 5 or more days, followed by maximum and minimum temperatures below 0^{o}C. These conditions occurred at least once at Rosemount in 24 of 30 years and at Lamberton in 23 of 30 years, sometimes occurring more than once in a season. In 1998 these conditions occurred three times in four months at both locations. This exercise illustrates the relatively high potential risk of failure of frost-seedings in Minnesota.

Conclusion

Whether one is establishing an alfalfa or clover stand, the factor most affecting the success of establishing legume stands in this study was the seeding date. A spring seeding appears to be less risky for establishing a legume stand than frost-seeding either in early or late winter. Seeding in the spring reduced chances of the seeds experiencing conditions that cause germination then death. However, if conditions are favorable such as, snow cover throughout the winter and a fast spring thaw, then frost-seedings can result in yields similar to a spring seeding. This may be due to seeds beginning to grow earlier in the season, which provides competitive advantage to utilize available resources such as water and nutrients over weeds. If a producer is willing to accept the risk and is interested in frost-seeding legumes, it is possible to reduce the risk of failure. Do not seed in early winter, instead wait until as late as possible in March to reduce the chance of the seeds experiencing conditions where they could germinate and be killed. However, it is important to spread the seed before the soil thaws, so the soil is not compacted in the process. Anticipating when the soil will thaw is difficult, so delaying seeded must be balanced with expected thawing.

In this study, small grain cover crops only had a positive impact on legume yield in two of the six site years. There was no management of the cover crops, other than to harvest mechanically. More aggressive management of the cover crops such as clipping or grazing in the spring may have resulted in improved legume stand establishment and yield. Although cover crops did not improve yields, even without managing them, they did not hurt yields either. Considering all their benefits, planting cover crops can be a useful practice for farmers.

Lastly, this study also illustrates that alfalfa and clovers can be used in this system with satisfactory results. Legume yields differed only half of the time and when they were different, alfalfa produced greater yields twice and clovers once.

As little research has been conducted on frost-seeding with legumes and small grains in recent years, there is opportunity for further research. A comprehensive study of the use of newer varieties of alfalfa and clovers in frost-seeding has not been conducted. It may be useful to look for varieties that delay germination until optimal conditions are more likely. Additionally, a comprehensive look at the newer small grain varieties and their compatibility with this practice may be enlightening. Besides observing differences in varieties, a study of different seeding rates for the small grains as well as seeding rates for legumes may improve the success of this practice. Since the clovers were seeded in a mix, they may be more competitive with alfalfa on their own at higher seeding rates. Lastly, a study that looks more closely at the concept of the minimum temperatures for germination of several varieties of alfalfa and clovers would be valuable to determine numerical risk factors for these frost-seedings to improve management outcomes.

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Figure 1. Daily temperature extremes and snow depth for Rosemount, MN and Lamberton, MN from December 2006 through April 2007.

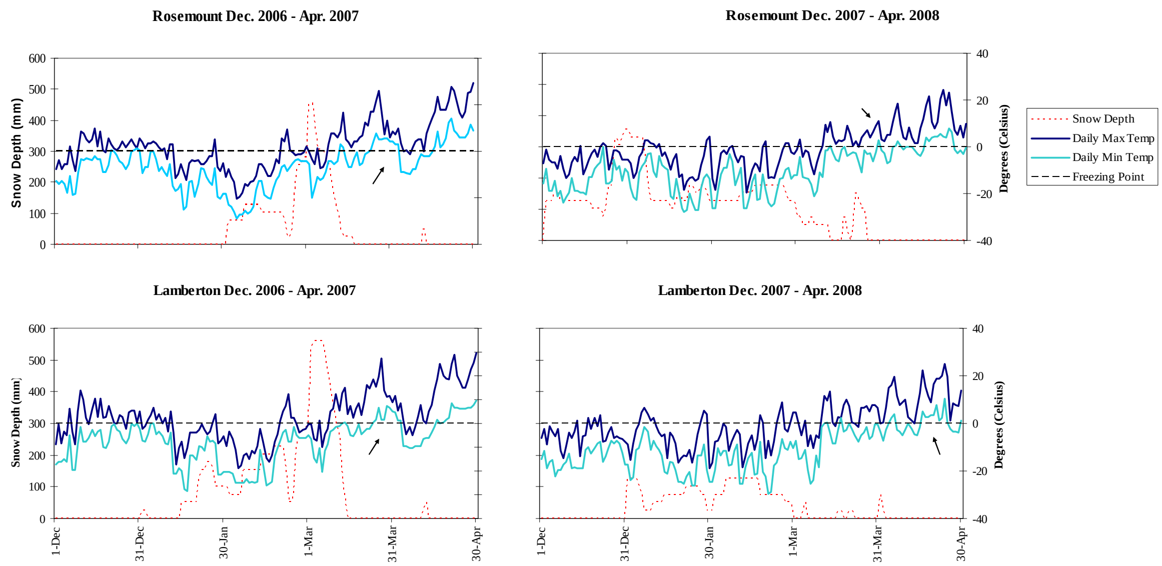

Table 1. Analysis of variance probabilities for legume plant populations at harvest for each year at three locations. Results represent main treatment effects for 2007 and 2008 growing seasons.

Source	Num df	Den df	Rosemount Site 1 2007	Rosemount Site 1 2008	Rosemount Site 2 2007	Rosemount Site 2 2008	Lamberton 2007	Lamberton 2008
			Pr > F					
Cover Crop (C)	3	6	**0.01**	**0.04**	**0.01**	**0.02**	0.18	0.39
Seeding Date (D)	2	40	**<.0001**	**<.0001**	**0.00**	**<.0001**	**<.0001**	**<.0001**
C x D	6	40	0.49	**0.05**	0.20	0.59	0.19	0.28
Legume (L)	1	40	**<.0001**	**0.01**	**<.0001**	**<.0001**	**0.04**	0.06
C x L	3	40	0.92	0.60	0.73	**0.02**	0.17	**0.02**
D x L	2	40	0.13	0.06	0.52	0.51	**0.04**	0.22
C x D x L	6	40	0.13	0.15	0.11	0.45	0.25	0.77

Table 2. Effect of seeding date, cover crop and legume species on plant populations at three locations.

		Rosemount Site 1		Rosemount Site 2		Lamberton		
Treatment		2007	2008	2007	2008	2007	2008	Mean
		plants m⁻²						
Seeding Date								
Early Winter		18 b †	96 b	31 b	62c	0 c	33 c	42
Late Winter		51 a	288 a	40 b	172 b	11 b	326 b	147
Spring		56 a	272 a	54 a	268 a	99 a	565 a	216
Cover Crop								
Spring Oats		34 bc	195 ab	54 a	147 ab	37	342	126
Winter Rye		64 a	284 a	50 a	175 a	39	287	152
Winter Wheat		42 b	255 a	45 a	259 a	43	281	147
Control		26 c	139 b	18 b	88 b	27	323	116
Legume								
Alfalfa		22 b	175 b	19 b	103 b	33 b	318	116
Clover Mix		61 a	262 a	64 a	231 a	41 a	298	155
Legume x Cover Crop								
Alfalfa	Spring Oats	17	140	24	116 cd	39	302 bcd	108
	Winter Rye	37	209	26	127 cd	33	295 abcd	132
	Winter Wheat	21	207	22	110 cd	33	223 d	120
	Control	12	142	4	60 d	26	373 abc	101
Clovers	Spring Oats	51	250	84	178 bc	35	382 a	142
	Winter Rye	90	359	73	223 b	46	280 bcd	174
	Winter Wheat	64	304	67	408 a	54	339 ab	173
	Control	39	136	33	116 cd	28	273 cd	130

† Treatment means within a column and treatment group followed by the same letter are not significantly different at the 0.05 confidence level

Table 3. Analysis of variance probabilities for legume yields at harvest for each year at three locations. Results represent main treatment effects for 2007 and 2008 growing seasons.

			Rosemount Site 1		Rosemount Site 2		Lamberton	
Source	Num df	Den df	2007	2008	2007	2008	2007	2008
			Pr > F					
Cover Crop (C)	3	6	**0.00**	0.93	**0.00**	0.11	0.27	0.37
Seeding Date (D)	2	40	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
C x D	6	40	**<.0001**	0.99	**0.00**	**0.01**	0.06	0.69
Legume (L)	1	40	**0.00**	0.08	**<0.0001**	**<.0001**	**0.00**	0.53
C x L	3	40	**0.01**	0.51	**<.0001**	0.35	0.24	0.21
D x L	2	40	**<.0001**	**0.05**	0.09	**<.0001**	**0.02**	**0.03**
C x D x L	6	40	**0.00**	0.59	**0.00**	0.36	0.07	0.69

Table 4. Effect of seeding date on yield of legumes at three locations.

Treatment		Rosemount Site 1 2007	Rosemount Site 1 2008	Rosemount Site 2 2007	Rosemount Site 2 2008	Lamberton 2007	Lamberton 2008	Mean
		grams m^{-2}						
Seeding Date								
Early Winter		19 c†	0 b	37 c	0 b	0 c	403 a	77
Late Winter		62 b	0 b	99 b	0 b	3 b	320 b	80
Spring		106 a	231 a	123 a	114 a	30 a	253 c	143
Legume								
Alfalfa		68 a	175	20 b	69 a	14 a	323	81
Clover Mix		60 b	262	153 a	7 b	7 b	328	119
Seeding Date x Legume								
Early Winter	Alfalfa	37 d	0 c	0	0 c	0 d	425 a	77
	Clovers	0 e	0 c	73	0 c	0 d	381 a	76
Late Winter	Alfalfa	76 c	0 c	14	0 c	0 d	316 b	66
	Clovers	47 d	0 c	185	0 c	6 c	324 b	93
Spring	Alfalfa	91 b	284 a	45	20 b	22 b	227 c	98
	Clovers	121 a	178 b	200	207 a	37 a	279 b	187

† Treatment means within a column and treatment group followed by the same letter are not significantly different at the 0.05 confidence level

Table 5. Cover crop biomass DM yield at three locations.

	Rosemount Site 1		Rosemount Site 2		Lamberton		
	2007	2008	2007	2008	2007	2008	Mean
	gram m⁻²						
Winter Wheat	378	597	411	593	312	1331	649
Winter Rye	242	664	486	729	441	1659	796

† Harvest date 23 May

‡ Harvest date 17 Jun.

§ Harvest date 17 May

Harvest date 20 Jun.

Table 6. Effect of seeding date and cover crop on yield at three locations.

Treatment		Rosemount Site 1 2007	Rosemount Site 1 2008	Rosemount Site 2 2007	Rosemount Site 2 2008	Lamberton 2007	Lamberton 2008	Mean
		grams m^-2						
Cover Crop								
Spring Oats		34 c†	195	100 a	21	37	342	97
Winter Rye		64 a	284	103 a	37	39	287	104
Winter Wheat		42 b	255	128 a	56	43	281	106
Control		26 c	139	13 b	38	27	323	91
Seeding Date x Cover Crop								
Early Winter	Spring Oats	0 e	0	33 ef	0 d	0	431	76
	Winter Rye	42 d	0	28 fg	0 d	0	361	74
	Winter Wheat	33 d	0	71 de	0 d	0	383	81
	Control	0 e	0	14 fg	0 d	0	437	75
Late Winter	Spring Oats	38 d	0	129 ab	0 d	0	302	80
	Winter Rye	128 ab	0	122 cd	0 d	3	299	87
	Winter Wheat	80 c	0	146 bc	0 d	10	288	151
	Control	0 e	0	0 g	0 d	0	390	65
Spring	Spring Oats	94 bc	237	139 ab	62 c	35	232	136
	Winter Rye	150 a	239	158 a	110 b	30	240	151
	Winter Wheat	82 c	235	168 a	167 a	28	226	151
	Control	97 bc	214	26 ef	115 b	26	314	132

† Treatment means within a column and treatment group followed by the same letter are not significantly different at the 0.05 confidence level