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Impacts of Spring-interseeded Cover Crops on Late-emerging Weed Suppression and Ground Cover in Corn (Zea mays L.) Production Systems

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IMPACTS OF SPRING-INTERSEEDED COVER CROPS ON LATE-EMERGING WEED SUPPRESSION AND GROUND COVER IN CORN (*ZEA MAYS* L.) PRODUCTION SYSTEMS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

IMPACTS OF SPRING-INTERSEEDED COVER CROPS ON LATE-EMERGING WEED SUPPRESSION AND GROUND COVER IN CORN (*ZEA MAYS* L.) PRODUCTION SYSTEMS

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Any alternative crop management strategy will only be adopted by growers if yield is not negatively impacted, fits within a current management practice, is easily implementable with minimal cost, or provides other beneficial features such as weed control or suppression. Corn production that incorporates a cover crop as an alternative weed control strategy and ground cover may support a sustainable system that is less dependent on herbicidal weed control. In addition, the cover crop may be used as a fall forage, act as a slow release fertilizer source the following year, and provide ground cover to reduce soil erosion.

In South Dakota, cover crop establishment cannot occur after corn harvest, as the growing season is too short, cold, and often dry. Therefore, interseeding cover crops into standing corn has the potential to establish, suppress late-emerging weeds, and provide late season ground cover. The purpose of this research was to examine if a cover crop mixture could be established in a standing corn crop at V5 growth stage, suppress weeds, and provide ground cover after corn harvest without negatively impacting corn yield.

Crimson clover (*Trifolium incarnatum*), winter wheat (*Triticum aestivum*) and lentil (*Lens culinaris*) were planted using broadcast or drill methods, as a mixture at a rate

of 5.4, 8.9, and 9.8 kg ha^{-1}, respectively, into V5 corn in field studies from 2010 – 2012. In 2010 - 12, the mix was planted at summit (SMT) and toeslope (TSP) locations in corn fields near Andover, SD. In 2011 – 12 the mix also was planted at SMT and TSP locations near Trail City, and in a flat field near Aurora, SD. Corn and cover crop and weed biomass were collected each fall.

Cover crops emerged about 14 d (days) after planting. Winter wheat and crimson clover were the only species that survived until corn harvest. The drill interseeding method had 76% more cover crop biomass than the broadcast method. Cover crops drill seeded reduced grass weed biomass by 38%. Regardless of seeding method, cover crops had no impact on corn grain yield.

These results indicate that cover crops could be established in standing corn with no adverse yield impact. These crops provided ground cover during and after the corn growing season and suppressed late-emerging grass weed growth. Therefore, interseeding this cover crop mix into standing corn may be a feasible alternative management strategy for getting a cover crop established, as SD weather is too cold, dry, and season too short for after harvest planting.

CHAPTER ONE

GENERAL INTRODUCTION

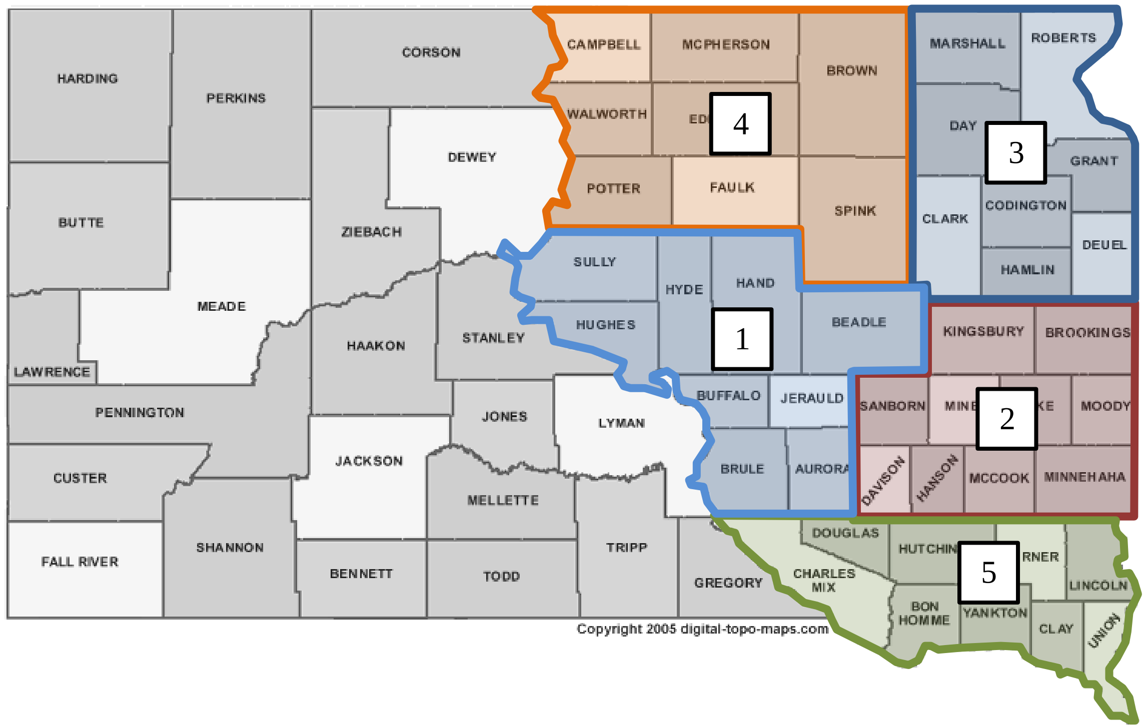
South Dakota Corn Production.

In South Dakota (SD), 95% of corn (*Zea mays* L.) production is performed under "dryland" farming conditions (USDA-NASS, 2012). Dryland farming is depicted as the method of farming that lacks the assistance of an alternative water source (e.g. irrigation), is uniquely dependent on the natural environmental precipitation, and requires specialized farming techniques and management practices to adapt to the restricted/limited moisture available during critical crop growth and developmental stages (Peterson et al., 2006). Furthermore, corn production has dramatically increased in SD, becoming the highest produced grain commodity in the state. Cropland utilized for corn production has increased about 57% from 1984 [1.38 million hectares (M ha)] to 2012 (2.43 M ha), respectively (USDA-NASS, 2012). In 2012, corn production accounted for approximately 36% of the 7.1 M ha of cropland in SD, followed by soybeans (*Glycine max*) (1.82 M ha), wheat (*Triticum aestivum*) (0.99 M ha), and sunflower (*Helianthus annuus*) (0.24 M ha), which accounted for close to 26, 14, and 3% of the total cropland in SD, respectively (USDA-NASS, 2012). The vast majority (92%) of the corn production hectares is located east of the Missouri River **(Figure 1-1**) (USDA-NASS, 2012).

Agricultural practices used in SD corn production have changed dramatically since the 1960's. High soil disturbance tillage practices, such as using a moldboard plow histrionically has declined due to the development the chisel plow and no-till systems. The no-till corn production hectares have increased from approximately 330,250 ha in

Figure 1-1. Major corn producing regions in South Dakota (accounts for approximately 92% of total corn production cropland) [Data obtained from the USDA-NASS [(United States Department of Agriculture: National Agricultural Statistics Service) accessed in 2013]

1. Central Region
   - 38,3400 ha
2. East Central Region
   - 53,6760 ha
3. Southeastern Region
   - 53,6760 ha
4. North Central Region
   - 48,5640 ha
5. Northeastern Region
   - 48,5640 ha



2001 to close to 633,900 ha in 2005 (Horowitz et al., 2010). The dramatic shifts to no-till systems in corn production have led to increased amounts of soil surface residue remaining after harvest. Therefore, in SD, the baling of corn stalk (stover) surface residue remaining after grain harvest has recently become a common practice to remove excess soil surface corn residue and to provide an alternative resource for livestock feed and bedding (Carlson et al., 2010). Baling of corn stover increased from about 16% in 2007 to nearly 60% in 2009 (Mamani-Pati et al., 2010). The baling of corn stalk residue often results in minimal amounts of soil surface residue, which could potentially increase soil erosion, surface runoff, and decrease soil organic matter.

The ability to sustain or potentially increase corn grain and stover productivity is difficult due to abiotic and biotic stressors. Various parameters including climate change, weed pressure, plant pathogens, and insects can have detrimental impacts on corn germination, emergence (e.g. plant populations), growth (e.g. plant height), development (e.g. biomass production), grain quality (e.g. seed quality), and overall yield potential. Weed pressure is a common problem throughout the corn growing season, negatively impacting corn growth and development by resource independent mechanisms such as down regulating critical physiological pathways (Horvath et al., 2006) that slow down growth and development and resource dependent mechanisms when weeds out compete corn for critical limited resources.

Weed Pressure Impacts on Corn.

During early developmental stages in corn [within the critical weed-free period (CWFP)], weed presence can detrimentally impact corn productivity by altering critical physiological pathways when nutrient resources (e.g. water and nitrogen) are sufficient enough for both corn and weed growth. For instance, Moriles et al. (2012) reported that the presence of velvetleaf (*Abutilon theophrasti*) and canola (*Brassica napus* L.) from corn emergence to the vegetative 8-leaf corn growth stage (V8) down-regulated ontologies associated with photosynthesis, energy conversion and signaling, whereas at V11 Horvath et al. (2006) observed repressed genes associated with photosynthesis, carbon dioxide (CO_2) assimilation, cell growth and division, corn responses to oxidative stress (e.g. physiological processes like disease resistance and abiotic stress), and down-regulated genes involved in protein degradation/stabilization processes and auxin-regulation in corn at the V11 corn growth stage, respectively.

In addition to the negative impacts of weed presence on critical physiological pathways, weeds also negatively impact corn by direct or indirect competition for critical limited nutrients. The competition ensuing from weed pressure throughout corn growth and development is denoted as interspecific competition. Interspecific competition is broadly defined as the reduction in fecundity (e.g. reproduction), survivorship, growth, and development of one species (e.g. corn) resulting from resource exploitation or interference by individuals of a second species (e.g. weeds). The resources critically limited in supply include: photosynthetically active radiation (e.g. sunlight), soil moisture, soil mineral nutrients [e.g. macronutrients including nitrogen (N) and micronutrients], and field area (e.g. space) (Hellwig et al., 2002; Gower et al., 2003; Hamill et al., 2004; Moeching et al., 2003; Dalley et al., 2006; Walker et al., 1988; Clay et al., 2009; Chikoye et al., 2008; Tharp et al., 2004; Page et al., 2010). Weed interference, often, results in reduced corn emergence (plant population), growth (e.g.

plant height), physiological development (e.g. photosynthesis, photosynthate accumulations, and maturity), and productivity (e.g. ear length, kernels per row, and seed weight) (Beckett et al., 1988).

Weeds ability to compete with corn is influenced by weed density, distribution, and species diversity (Vangessel et al., 1995). For instance, high weed densities, distributions (e.g. dense cover), and the diversity of species (e.g. broadleaves and grasses) can lead to greater weed leaf area indexes (LAI) and reduce photosynthetically active radiation available by shading of corn, and ultimately leads to reductions in corn photosynthetic rates and total amount of available photosynthates (Cox et al., 2006; Scholes et al., 1995; Walker et al., 1988). For instance, Moriles et al. (2012) reported that the presence of velvetleaf and canola from corn emergence to corn growth V8 stage, down-regulated genes associated with photosynthesis. This down regulation could account for a portion of the reductions in corn leaf area and biomass observed at this time. Furthermore, many weeds have well-developed fibrous root systems, which enable them to preemptively scavenge for available soil moisture and mineral nutrients, reducing the total amounts available for corn during critical growth and developmental stages (Cathcart and Swanton., 2004; Horvarth et al., 2006). Furthermore, weeds have the extraordinary ability to rapidly germinate and grow, which enables them to deplete vacant spaces and crowd out corn within a given area (Cathcart and Swanton, 2004). Consequently, the physiological and environmental advantages weeds have when grown in association and with the vegetative growth stages of corn reduce the overall production potential of corn.

The reduction in corn yield, directly resulting from early season weed pressure, has been extensively documented. For instance, in Ontario, Canada, Bosnic and Swanton (1997) reported corn yield losses of 26 and 35% from early-emerging (1- to 3- leaf corn growth stage) barnyardgrass (*Echinochloa crus-galli*), respectively, at a density of about 100 plants m^{-1} established within 12.5 cm on either side of the corn row. Wilson and Westra (1991) reported that wild proso millet (*Panicum miliaceum*) planted immediately after corn planting, reduced corn yields between 13 and 22%, at a density of 10 plants m^{-1}. Similarly, in Aurora, SD, Clay et al. (2005) illustrated that barnyardgrass, redroot pigweed (*Amaranthus retroflexus* L.) and velvetleaf (*Abutilon theophrasti* L.), emerging prior to corn (pre-corn emergence), at corn emergence, or at the V-1 corn growth stage (vegetative one-leaf corn growth stage), reduced corn yield by 30, 14, and 9%, respectively. It was also observed that corn yield was reduced by 44 and 50% by common lambsquarters (*Chenopodium album* L.) and green foxtail (*Setarias viridis* L.) at weed densities of 30- and 50 plants m^{-2}, respectively (Cox et al., 2006). Palmer amaranth (*Amaranthus palmeri*), at densities of 0.5 and 8 m^{-1}, reduced corn yield from 11 to 91% when emerging with corn, respectively, but was less competitive if emerging post-corn emergence up to V-7 corn growth stage, reducing yield from 7 to 35% (Massinga et al., 2001).

The negative responses and detrimental impacts of corn to interspecific competition involving weeds, however, is not the only means in which weeds can reduce the overall productivity of corn. Surface and/or buried weed residue can produce toxic allelochemicals that reduce corn growth and development (Drost and Doll, 1980; Johnson III and Coble, 1986). For example, in Greece, Vasilakoglou et al. (2005) reported that

Johnsongrass (*Cynodon dactylon* L.) extracts inhibited corn germination, fresh weight, and root length by 16, 47, and 59%, respectively. In addition, in North Carolina (NC), Johnson III and Coble (1986) reported that soil-incorporated fall panicum (*Panicum dichotomiflorum*) at a residue concentration level of 0.5% weight per weight (w/w) resulted in 17.8 and 19.9% reductions in corn germination and dry matter biomass, respectively. Similarly, in Wisconsin, Drost and Doll (1980) reported that yellow nutsedge (*Cyperus esculentus*) foliage residues, at 0.5 and 0.675% w/w residue concentration levels, reduced corn shoot dry weights by 19 and 17%, while yellow nutsedge tuber residue, at a 0.675% w/w concentration level, reduced corn root and shoot dry matter by 46 and 45%, respectively. It was also observed that giant foxtail (*Setaria faberi*) root exudates inhibited corn growth (Bell and Koepee, 1972). Barley (*Hordeum distichum* L.) seedlings were reduced by antagonistic responses to purple nutsedge (*Cyperus rotundas* L.) extracts (Friedman and Horowitz, 1971), and alfalfa (*Medicago sativa* L.) seedling germination and development were inhibited by soil-incorporated quackgrass (*Agrophyron repens* L.) residue (Kommendahl et al., 1959).

The extent of reductions in corn physiological growth and development via weed pressure ultimately depends on several factors. These factors include the weed biotypes and species (e.g. physiological traits), time of weed seedling emergence (e.g. pre- or post-corn emergence), abundance of weed seedlings (e.g. density of weed numbers), and length of time that weeds are present and interfering with corn during critical growth and developmental stages (Dalley et al., 2006). Therefore, to reduce the negative impacts on corn productivity by weed pressure, the incorporation of a quality weed management program that takes into consideration the previously stated weed impact factors is crucial in the ability to maintain or potentially increase corn productivity.

Conventional Weed Control Strategies.

In corn production systems, the three most commonly utilized approaches for weed suppression and control are chemical (herbicide) application, crop rotation, and tillage. Weed control by herbicide application and tillage practices are utilized on a short term (e.g. in-season) basis, whereas crop rotation involves a greater period of time (e.g. years). In addition, corn producers also utilize a combination of these control practices like: herbicide and crop rotation, crop rotation and tillage, or crop rotation, tillage, and herbicide application.

Reicosky and Allmaras (2003) broadly defined tillage as the sequence of mechanical operations that involves disrupting the soil profile and burial of surface residue for the primary purpose of forming a quality seedbed for crop planting. The mechanical control of weeds through tillage can be performed prior to corn planting (e.g. pre-plant) and pre- and post-corn emergence via inter-row cultivation and/or rotary hoe. Tillage controls and suppresses weeds primarily by uprooting, disarticulating, and burying emerged weed seedlings (Shrestha et al, 2006; Kayode and Ademiluyi 2004). Furthermore, tillage also manages weed pressures by minimizing weed seed germination via mechanically moving and burying weed seeds below the germination zone, and by altering the level of environmental dynamics (e.g. soil temperature, soil moisture, and available oxygen) essential for weed seed germination, growth, and development (Shrestha et al., 2006; Leon and Owen, 2006). For instance, in Wisconsin, Buhler and

Mester (1991) reported from taking 25-cm-diameter cores to a depth of 20 cm, that in the upper one centimeter (cm) of the soil profile, only 15% and 25% of green and giant foxtail emerged under the conventional tillage (moldboard plowed and disked twice) and chisel plow (chisel plowed and disked once) treatments, compared to more than 40% in no-tillage. Similarly, Pareja et al. (1985) reported that 28% of weed seeds were located in the top 5-cm of the soil profile for conventional tillage treatments (fall moldboard plow followed by spring disking and harrowing), compared to 85% in the reduced tillage treatments (slot-planting in the row of the previous crop without any tillage practices). It was also observed that total biomass, weed populations, and average weed covers for the perennial weeds Canada thistle (*Cirsium arvense* L.), field bindweed (*Convolvulus arvensis* L.), common plaintain (*Plantago major* L.), quackgrass (*Elymus repens* L.), tuberous sweetpea (*Lathrus tuberosus* L.), and dandelion (*Taraxacum officinale*) were lower in the conventional tillage (plowed) (21.4%) than in the no-tillage (37.5%), respectively (Lehozky et al., 2009).

The age of modern day herbicide usage started with the commercialization of 2,4-D [(2,4-dichlorophenoxy)-acetic acid] in the 1950's. Today, about 15 different herbicide mode-of-actions are used in corn. Herbicide applications, similar to tillage, can be applied at several times throughout the corn growing season (e.g. pre-plant, pre- and post-corn emergence) to suppress and control weeds. Herbicides are chemicals that inhibit or interrupt normal plant growth and development, and are commonly classified according to time of application (e.g. pre-plant, pre-plant incorporated, pre- and post-emergence), selectivity (e.g. nonselective or selective), translocation in plants (e.g. systemic or contact), and mode-of-action. Pre-plant herbicides are soil applied herbicides (which some require incorporation into the soil through tillage) are applied prior to corn planting. Pre-emergence herbicides are applied post-corn planting but prior to crop and weed emergence, and require adequate precipitation for activation. Pre-plant and pre-emergence herbicides control weeds either by direct contact with weed seeds or seedlings or by being taken up into the plants. Post-emergence herbicides are applied post-corn emergence, and injure susceptible weeds that come into contact with the herbicide. In association with some post-emergence herbicides, genetically modified crop species which are genetically tolerant or resistant to the applied post-emergence herbicide mode-of-action are used. Herbicides can provide exceptional control and suppression of weeds. For instance, in Missouri, Monnig and Bradley (2008) reported that fall applied and 45 days pre-plant applied simazine, glyphosate [*N*-(phosphonomethyl)glycine), and rimsulfuron+thifensulfuron controlled approximately 90% of all winter annuals in no-till corn. In Oregon and Idaho, Felix and Newberry (2012), reported a 99% control at 8 and 24 days after treatment (DAT) of large crabgrass (*Digitaria sanquinalis* L.), barnyardgrass, common lambsquarters, and redroot pigweed in furrow-irrigated corn with pre-plant incorporated *S*-metolachlor or EPTC followed by a post-emergence application of halosulfuron and dicamba+glyphosate, and glyphosate alone treatments. It was also observed that weed seed density in the weed seedbank was significantly reduced by glyphosate and glufosinate herbicide treatments (Simard et al., 2011).

Crop rotation is broadly defined as the farming system of growing a series of different crops in systematic and recurring sequence on the same cropland area in sequential seasons instead of growing the same crop continuously (monoculture). Crop rotation helps diversify the cropping system with commodities of different life cycles, seasonal growth patterns, and planting and harvesting dates. The diversification within a crop rotation reduces weed establishment, thus, reducing weed reproductive cycle, and the number of weed seeds in the seedbank. Crop rotations also maintain soil fertility, which helps crops outgrow present weeds by improving the overall health and production potential of the crop, thereby increasing the crops ability to compete with weeds. However, the overall success of crop rotation systems ultimately depends on the crop sequence chosen so that it creates varying patterns of resource competition, allelopathic interference, soil disturbance, and mechanical damage, to provide an unstable environment and prevent the proliferation of specific weed species (Liebman and Dyck, 1993). For instance, in Ontario, Canada, Murphy et al. (2006) reported that a six-year no-till plus corn-soybean-winter wheat rotation, decreased the mean weed seed density from approximately 41000 weed seeds per cubic meter (m^{-3}) in 1994 to 8000 weed seeds m^{-3} in 1999. It was also observed that rotations consisting of hay-hay-corn-soybean-wheat/hay-hay and hay-hay-corn-soybeans-wheat/hay, effectively suppressed smooth pigweed (*Amaranthus hybridus*) populations and reduced the weed seedbank (Murphy et al., 2006).

The conventional practices for weed management have been shown to successfully control and suppress weeds. However, all three of these weed management practices have problems associated with them.

Problems with Conventional Weed Control Strategies.

Tillage degrades soil structure, water infiltration and movement, biological activity, surface residue and organic matter (Liu et al., 2006). The level of soil degradation by tillage is dependent on the tillage practice (e.g. moldboard plow>chisel plow>mulch till) (EPA, 2012). Reductions in soil surface plant residue decreases soil carbon and nitrogen levels, and water holding capacity, and increases the potential for soil erosion and soil surface crusting (Ghidey and Alberts, 1998; Golabi et al., 1995; Rassmussen and Collins, 1991). It has been observed that tillage decreased water infiltration by 11 and 49% (Truman et al., 2003), water storage and precipitation storage efficiency by 12 and 16% (Tanaka and Anderson, 1997), surface residue by about 49% (Buman et al., 2004), soil organic carbon by 92% in the top 6-cm of soil, and had 1.8 and 8.7 times more soil loss than no-till (Truman et al., 2003). Consequently, the increase in soil erosion associated with some tillage practices cause environmental and soil degradation which are deleterious to long-term crop production.

Crop rotations may be wide-ranging and be comprised of crops that are unprofitable [e.g. planting of alfalfa by a producer who does not have livestock or buckwheat (*Fagopyrum esculentum*) that has a low commodity price and a very limited market] or deplete soil moisture content and availability. Also, some short crop rotations (e.g. corn-soybean), can result in a decrease of soil organic matter and residual nitrogen and deteriorate soil physical properties such as increase bulk density, decrease water infiltration and organic matter content, and foster a heavy reliance on high synthetic fertilizer application rates to maintain or increase yield (Bullock, 1992; Karlen et al., 2006; Stanger and Lauer, 2008). For instance, corn-soybean rotations has been shown to decrease organic matter content by 8% (Karlen et al., 2006), NO_3-N content by 31% (Riedell et al., 2009), and increase bulk density by 7% (Karlen et al., 2006), when compared to more extensive crop rotations. In addition, Stanger and Lauer (2008) reported that grain yield trends consistently decreased and were substantially lower in corn-soybean rotations compared to 5-yr crop rotations when no nitrogen was applied. The market for alternative crops (e.g. alfalfa) are limited and producers may not have the equipment necessary to harvest these crops (Powers, 1987). Therefore, there is potential for a decrease in total production and an increased need for livestock to make long-term crop rotations comprised of alternative crops feasible (Powers, 1987).

Herbicides account for approximately 82% of the total pesticides used in the United States, of which about 60% are used in the "Corn Belt" region (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin) (EPA, 2011; USGS, 1998). In 2006, South Dakota producers applied herbicides to close to 99% of their corn and soybean hectares (USDA-NASS, 2012). The high percentage of hectares being treated with herbicides have increased concern about environmental issues involving herbicide residues leaching into and contaminating surface and/or groundwater, negatively impacting water quality, and leading to toxic effects on humans and/or aquatic life (USGS, 2006; USGS, 1998; Wyse, 1992; Goodman, 1987).

Herbicides used for agricultural practices are recognized as a leading source of non-point water contamination of surface and groundwater (USGS, 2006). A nation-wide survey from 1992-2001 by the National Water-Quality Assessment (NAWQA) Program of the United States Geological Survey (USGS) reported that in 97% of agricultural, 97% of urban, and 94% of mixed-land-use watersheds had at least one pesticide identified in the stream water (USGS, 2006). In the "Corn Belt" regions of the Midwest, water samples were collected from 149 sites in 122 river basins throughout

May and June in 1989-1990 and analyzed for pesticides. Detectable concentrations of alachlor (2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)-acetamide), atrazine (6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine), metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)-acetamide), metribuzin (4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5-(4*H*)-one), propazine (6-chloro-*N*,*N*'-bis-(1-methylethyl)-1,3,5-triazine-2,4-diamine), prometon (6-methoxy-*N*,*N*'-bis-(1-methylethyl)-1,3,5-triazine-2,4-diamine), and simazine (6-chloro-*N*,*N*'-diethyl-1,3,5-triazine-2,4-diamine) were detected in 23 to 98% of the samples (Thurman et al., 1991).

In the last two decades, close to 143 pesticides and 21 pesticides transformation products have been identified in ground waters of more than 43 states, with atrazine, simazine, alachlor, and metolachlor being the most frequently identified pesticides (USGS, 2007). Pesticides are more commonly located in surface water or shallow ground water below agricultural and urban areas than deeper wells. This is directly associated with the increase surface applications of herbicides in agricultural practices (USGS, 2006). Furthermore, some pesticide contamination levels in ground and surface waters exceed the maximum contaminant levels (MCL) or health advisory levels (HAL) for drinking water (Thurman et al., 1991; USGS, 1998).

The occurrences and impacts of surface and ground water contaminations from agricultural herbicides by soil surface runoff and/or leaching have recently declined due to the introduction of transgenic herbicide-resistant crops (e.g. glyphosate-resistant corn) and which led to the adoption of conservation tillage systems (e.g. no-till) (Givens et al., 2009; Cerdeira and Duke, 2006). Survey results reported by Givens et al. (2009)

indicated that after the introduction of glyphosate-resistant crops, 25% of conventional farmers transitioned to no-till and 31% to reduced-till systems. The transitions to conservation tillage systems and adoption of glyphosate-resistant crops, has resulted in a dramatic increase in glyphosate use from about 2 million (M) kg acid equivalent (ae) in 2000 to about 23.6 M kg ae in 2010 (USDA-NASS, 2010). The increase in glyphosate applications has reduced the applications of some persistent, residual herbicides (Shipitalo et al., 2008). For example, in 1990, about 16.3, 26.4, and 16.3 M kg active ingredient (ai) of alachlor, atrazine, and metolachlor were applied in the U.S., however, in 2010, application amounts of each chemical were reduced to close to 0.2, 23.2, and 9.9 M kg ai, respectively, resulting in reductions of about 98, 12, and 39%, respectively (USDA-NASS, 2010). Although glyphosate applications have increased, the chemical is considered more environmentally benign. Glyphosate is strongly absorbed by the soil, rapidly degraded by soil microbes, does not leach, and dissipates at a greater rate than most herbicides (Wauchope et al., 2002).

The over use of some herbicides has had negative impacts in agricultural systems, more specifically, the progression of herbicide-resistant weed biotypes. The first reported incidence of weed resistance in the United States was in the 1960's with atrazine-resistant common groundsel (*Senecio vulgaris*) (Ryan, 1970). Since then, more atrazine-resistant weed biotypes have been reported, followed by other resistant-weed biotypes to different herbicide families (e.g. ACCase and ALS inhibitors) in the 1980's. Reports of herbicide-resistant and multi-herbicide-resistant weed biotypes have increased from 183 in 42 countries in 1997 to 393 (124 dicots and 87 monocots) in 61 countries and 680,000 fields in 2012 **(Table 1-1)** (Heap, 1997; Weed Science, 2012). In the United

Table 1-1. Herbicide-resistant weed biotypes reported in 2012 (Data obtained from Weed Science International Survey of Herbicide Resistant Weeds accessed on 2013).

Country	**Total**	**Country**	**Total**	**Country**	**Total**
Argentina	9	*Greece*	9	*Saudi Arabia*	1
Australia	61	*Guatemala*	1	*Slovenia*	1
Austria	2	*Honduras*	1	*South Africa*	14
Belgium	18	*Hungary*	1	*South Korea*	12
Bolivia	7	*India*	3	*Spain*	33
Brazil	27	*Indonesia*	1	*Sri Lanka*	2
Bulgaria	4	*Iran*	11	*Sweden*	2
Canada	58	*Ireland*	1	*Switzerland*	14
Chile	16	*Israel*	27	*Taiwan*	1
China	34	*Italy*	29	*Thailand*	5
Colombia	6	*Japan*	18	*The Netherlands*	7
Costa Rica	5	*Kenya*	1	*Tunisia*	1
Cyprus	1	*Malaysia*	17	*Turkey*	15
Czech Republic	16	*Mexico*	5	*United Kingdom*	24
Denmark	8	*New Zealand*	10	*USA*	141
Ecuador	1	*Nicaragua*	1	*Venezuela*	9
Egypt	1	*Norway*	5	*Yugoslavia*	6
El Salvador	1	*Panama*	1	*Poland*	14
Ethiopia	1	*Paraguay*	2	*Portugal*	3
Fiji	1	*Philippines*	3		
France	34	*Germany*	26		

States alone, herbicide-resistant weed biotypes have increased from 49 resistant biotypes in 1997 to 141 resistant biotypes in 2012 (Heap, 1997; Weed Science, 2012). Target-site resistance (e.g. monogenic) attributed to high rates of herbicide applications and "creeping-resistance" (e.g. polygenic) attributed to reduced herbicide rates are two mechanisms that aid in the evolution of herbicide-resistance weed-biotypes (Owen and Zelaya, 2005). Furthermore, the spread and increase of herbicide-resistant weed biotypes is also due to weeds ability to produce vast number of seeds. For instance, a single redroot pigweed plant can produce 500,000 seeds per plant, therefore, if the redroot pigweed is an herbicide-resistant biotype, it has great potential to spread and negatively impact more cropland (Green, 2007). The spread of herbicide-resistant weeds, therefore, can increase cost of production, limit the types of crop commodities that can be grown, and lower yields and possibly land values (Green, 2007).

Herbicide-resistant weed biotypes have been identified for several herbicide mode-of-actions (**Table 1-2)**. About 50%, of herbicide-resistant weed biotypes are identified within the photosystem II and ALS inhibitor herbicide groups (Weed Science, 2012). Photosystem II inhibitors inhibit photosynthesis by binding to the chloroplast and blocking electron transport at plastiquinone (PQ), stopping the electron flow, the production of ATP and $NADPH_2$, and carbon dioxide (CO_2) fixation (Shumway and Scott, 2012; Hiraki et al., 2004). In past years, photosystem II inhibitor-resistant weed biotypes have infested over three million hectares, primarily in corn production systems in the United States and corn and orchard production systems in Europe, making them the most worldwide herbicide-resistance problem (Heap, 1997). Furthermore, as of 2012, there are approximately 69 identified photosystem II inhibitor-resistant weed biotypes

Table 1-2. Total herbicide-resistant weeds worldwide with associated herbicide group in 2012 (Data obtained from Weed Science International Resistant Weeds accessed on 2013).

Herbicide Group	**HRAC Group**	**Site of Action**	**Total**	**Herbicide Group**	**HRAC Group**	**Site of Action**	**Total**
ALS inhibitors	B	Inhibition of acetolactate synthase ALS	127	*Nitriles and Others*	C3	Inhibition of photosynthesis at photosystem II	4
Photosystem II inhibitors	C1	Inhibition of photosynthesis at photosystem II	69	*Chloroacetamides and Others*	K3	Inhibition of cell division (Inhibition of very long chain fatty acids)	4
ACCase inhibitors	A	Inhibition of acetyl CoA carboxylase	42	*Carotenoid Biosynthesis Inhibitors*	F1	Bleaching: Inhibition of carotenoid biosynthesis at the phytoene desaturase step (PDS)	3
Synthetic Auxins	O	Synthetic auxins	30	*Glutamine Synthase Inhibitors*	H	Inhibition of glutamine synthetase	2
Bipyridiliums	D	Photosystem-I-electron diversion	28	*Arylaminopropionic Acids*	Z	Unknown	2
Glycines	G	Inhibition of EPSP synthase	24	*Unknown*	Z	Unknown	2
Ureas and Amides	C2	Inhibition of photosynthesis at photosystem II	22	*4-HPPD Inhibitors*	F2	Bleaching: Inhibition of 4-hydroxyphenyl-pyruvate-dioxygenase (4-HPPD)	1
Dinitroanilines and Others	K1	Microtubule assembly inhibition	11	*Mitosis Inhibitors*	K2	Inhibition of mitosis / microtubule polymerization inhibitor	1
Thiocarbamates and Others	N	Inhibition of lipid synthesis - not ACCase inhibition	8	*Cellulose Inhibitors*	L	Inhibition of cell wall (cellulose) synthesis	1
PPO inhibitors	E	Inhibition of protoporphyrinogen oxidase	6	*Organoarsenicals*	Z	Unknown	1
Triazoles, Ureas, Isoxazolidiones	F3	Bleaching: Inhibition of carotenoid biosynthesis (unknown target)	5				

worldwide (Weed Science, 2012). ALS inhibitors inhibit acetolactate synthase (ALS) and the synthesis of branched-chain amino acids (isoleucine, leucine, and valine) (Shumway and Scott, 2012; Zhou et al., 2007). Within the branched-chain amino acid biosynthesis pathway, the ALS enzyme catalyzes the following two reactions: two pyruvate molecules are condensed to form 2-acetolactate for valine and leucine biosynthesis, while 2-acetohydroxybutyrate is synthesized from pyruvate and 2-ketobutyrate for isoleucine (Zhou et al., 2007). ALS-inhibiting herbicides are extensively utilized because of their high selectivity in over 12 different crop species. Today, there are over 50 different ALS-inhibiting herbicides in five different chemical classes (sulfonylureas, imidazolinones, triazolopyrimidines, pryimidinylthiobenzoates, and sulfonlyamino-carbonyl-triazolinones) have been commericialized (Green, 2007). In addition, in 1994, 17% of the global herbicide sales were for ALS-inhibiting herbicides, which were greater than any other herbicide group (Heap, 1997). Therefore, with the widespread usage and ease that weeds have become resistant to them, ALS-inhibiting herbicide-resistant weed biotypes have increased from 33 biotypes in 1994 to 127 biotypes in 2012, which is a greater annual rate than any other herbicide mode of action in the past 10 years (Weed Science, 2012).

The development and usage of transgenic crops that provide resistance to specific herbicidal compounds have increased the development of herbicide-resistant weed biotypes. For example, glyphosate is a non-selective, broad spectrum, systemic herbicide that rapidly binds to the soil, thus resistant to leaching, rapidly biodegrades, and has extremely low toxicity to animals and aquatic life (Pline-Srnie, 2006; Nandula et al., 2005). In addition, glyphosate was considered a low risk herbicide for the development of herbicide-resistant weed biotypes because of its mode-of-action, chemical structure, limited metabolism in plants, and lack of residual activity (Heap, 1997). Following its introduction and commercialization in 1974, glyphosate was primarily used in short, intense selection events as a non-selective burndown weed control on emerged plants prior to crop seeding with few glyphosate-resistant weed biotypes being identified. However, the introduction of transgenic crops in 1996 (e.g. glyphsate-resistant crops) caused a dramatic change in the use of glyphosate (Powles, 2008) and increased resistant weed biotypes.

In 2012, approximately 88 and 93% of corn and soybeans planted in the United States consisted of glyphosate-resistant varieties (USDA-NASS, 2012). The adoption of glyphosate-resistant crops has resulted in a severe reduction in the use of selective herbicides to a heavy reliance on the non-selective glyphosate for primary weed control. Consequently, this has resulted in a strong selection intensity favoring glyphosate-resistant weed biotypes (Powles, 2008). As of today, there are a total of 24 glyphosate-resistant weed species, compared to only 10 in 2005, respectively (Weed Science, 2012). This substantial increase is a direct result of the high adaption of glyphosate-resistant crops and the increased use of glyphosate (Nandula et al., 2005).

The rapid changes in weed communities and the level of selection pressures and evolved herbicide-resistant weed biotypes show that the current implementations of agrochemicals for long term weed management and production are not sustainable (Owen and Zelaya, 2005; Green, 2007). In addition, the concerns about contamination of water resources and pesticide residues in food due to agricultural chemical applications, and soil erosion and depletion of natural resources due to tillage have prompted research into an alternative weed management strategy for to maintain sustainable production systems (Lu et al., 2000).

Alternative Weed Management Strategies.

The research and development into viable alternative weed management strategies that are effective at managing weeds, maintaining crop performance and quality, reducing soil erosion and dependency on agrochemicals, and conserving soil resources are critical for maintaining sustainable agricultural systems. In addition, the alternative weed management strategies must be economically feasible and, for wide-spread adoption, should be easily implemented into current production and management practices. Research into using cover crops as an alternative weed management strategy has been successful in some crop rotations in some areas (Fisk et al., 2001), however, further research is still needed to quantify if cover crops can be successfully used for weed management in South Dakota to reduce or eliminate the use of chemical control within the alternative weed management plan.

Cover Crops.

Cover crops can be defined as crops primarily grown during periods in which the field is fallow (Dabney et al., 2001). Cover crops often have been integrated and established into cropping systems in the fall and/or spring and consist of legumes or brassica, grass or other species **(Table 1-3).** Cover crops have shown to play an important role in sustainable agriculture because of their ability to reduce soil erosion and nitrate leaching and by increase soil water infiltration rate, soil organic matter content, and nutrient availability, and break disease cycles (Barberi and Mazzoncini, 2001;

Table 1-3. Common legume and non-legume cover crop species (Obtained from SARE 2007: Managing Cover Crops Profitably, 3rd Ed. accessed on 2013)

Legume Cover Crops			Non-Legume Cover Crops		
Common Name	**Scientific Name**	**Growing Season**	**Common Name**	**Scientific Name**	**Growing Season**
Crimson Clover	*Trifolium incarnatum*	Annual	Annual Ryegrass	*Lolium multiflorum*	Annual
Hairy Vetch	*Vicia villosa*	Annual	Barley	*Hordeum vulgare*	Annual
Field Peas	*Pisum sativum subsp. arvense*	Annual	Oats	*Avena sativa*	Annual
Subteranean Clover	*Trifolium subterraneum*	Annual	Rye	*Secale cereale*	Annual
	Trifolium yanninicum	Annual	Winter Wheat	*Triticum aestivum*	Annual
	Trifolium brachycalcycinum	Annual	Buckwheat	*Fagopyrum esculentum*	Annual
Cowpea	*Vigna unguiculata*	Annual	Sorghum-sudan	*Sorghum bicolor var. sudanese*	Annual
Berseem Clover	*Trifolium alexandrinum*	Annual	White Mustard	*Brassica hirta*	Annual
Burr Medic	*Medicago polymorpha*	Annual	Brown Mustard	*Brassica juncea*	Annual
Barrel Medic	*Medicago truncatula*	Annual	Rapeseed	*Brassica napus*	Annual
Black Medic	*Medicago lupulina*	Perennial		*Brassica rapa*	Biennial
Red Clover	*Trifolium pratense*	Perennial	Forage Radish	*Raphanus sativus*	Annual
White Sweetclover	*Melilotus officinalis*	Biennial	Turnips	*Brassica rapa rapa*	Annual
Yellow Sweetclover	*Melilotus alba*	Biennial			
White Clover	*Trifolium repens*	Perennial			
Woollypod Vetch	*Vicia villosa ssp. Dasycarpa*	Annual			
Lentil	Lens culinaris	Annual			

Sarrantonio and Gallandt, 2003; Fageria et al., 2005; Hartwig and Ammon, 2002; Dabney et al., 2001; Lu et al., 2000; Teasdale et al. 2007). An additional positive feature associated with utilizing cover crops into cropping systems is their ability to suppress weeds.

Cover crop suppress weeds as living plants by smothering growth of establishing or established weeds or by creating an environment that interferes or competes with weed emergence and establishment by depriving weeds of essential growth elements (e.g. light, mineral nutrients, water) and space. Cover crops also suppress weeds as surface plant residue (e.g. mulch) after cover crop senescence by eliminating or altering environmental signals for weed germination (e.g. light or alternating temperatures), creating physical obstructions that hinders weed emergence following germination, or by releasing phytotoxic (e.g. allelopathic) compounds that impede germination and growth of weeds (Teasdale et al., 2007; Moonen and Barberi, 2004; Fageria et al., 2005; Sarrantonio and Gallandt, 2003; Dabney et al., 2001; Hartwig and Ammon, 2002; Lu et al., 2000).

Several alternative weed management systems utilizing cover crops for weed suppression have been researched. For instance, Fisk et al. (2001) reported that fall-seeded Santiago burr medic (*Medicago polymorpha*), barrel medic (*Medicago truncatula*), red clover (*Trifolium pratense*), and berseem clover (*Trifolium alexandrinum*) reduced winter annual weed densities by 41, 68, 78, and 68% and winter annual weed dry weights by 72, 78, 78, and 80%, respectively. Similar results were noted by De Haan et al. (1994), who reported that yellow mustard (*Brassica compestriss*) seeded at 2120 seeds m^{-2} and at a height of 10-cm reduced weed dry weight by approximately 82%. It was also observed that a cover crop mixture containing alsike clover (*Trifolium hybridum* L.), balansa clover (*Trifolium michelianum*), berseem clover (*Trifolium alexandrinum*), crimson clover (*Trifolium incarnatum*), Persian clover (*Trifolium resupinatum*), red clover (*Trifolium pratense*), and white clover (*Trifolium repens*) reduced brown mustard (*Brassica juncea*) biomass between 29 and 57% (Ross et al., 2001). However, the degree of weed suppression via cover crops greatly depends on the quantity of cover crop biomass that is produced. For instance, Teasdale and Daughtry (1991) presented a model that showed that weeds were not suppressed until soil coverage by cover crop residue had reached 42% and that 97% coverage was required to reduce weed density by 75%, respectively. Similar results were reported by Teasdale and Mohler (2000), showing that hairy vetch (*Vicia villosa*) and crimson clover mulches had to reach a total of 200 g m^{-2} before declines in velvetleaf biomass were significant.

The integration of cover crops into corn cropping systems has shown to be successful as an alternative weed management source, but cover crops also have problems associated to them. Some cover crops species have been shown to reduce corn yields by immobilizing and/or delaying N release (Vos, 1999; Snapp et al., 2005; De Bruin et al., 2005; Smeltekop et al., 2002), delaying or prolonging soil warming (Teasdale et al., 2007; Lu et al., 2000), depleting stored soil moisture (Williams III et al., 2000), and altering soil water use patterns (Reddy and Koger, 2004; Unger and Vigil, 1998), and by releasing phytotoxins (Fageria et al., 2005). In addition, some cover crops are overly vigorous and must be treated with a herbicide to eliminate the detrimental impacts on corn productivity (Snapp et al., 2005; DeHaan et al., 1994). For example, rye (*Secale cereal*) has great winter hardiness and growth in the early spring; therefore it could be used as a cover crop in corn for weed suppression. However, rye has been shown to delay corn maturation and decrease corn yields by immobilizing N, decreasing soil temperature and water content if not controlled or desiccated at the correct time by herbicide applications or tillage treatments (Raimbault et al., 1990; Vaughan and Evanylo, 1998). In addition, Vos (1999) reported that medic over-seeded in a broadcast application at 50 kg ha^{-1} into corn at corn planting, reduced yields by approximately 22% compared to the control mainly due to N immobilization (Smeltekop et al., 2002).

The ability of cover crops to suppress weeds without adversely affecting corn productivity is directly related to the cover crop species selected, timing of sowing and establishment, and quantity of cover crop biomass that is produced (Barberi and Mazzoncini, 2001; Vos, 1999; Teasdale et al., 2007; Teasdale and Mohler, 2000; Teasdale and Daughtry, 1991; Swanton and Weise, 1991). Furthermore, cover crops used for weed suppression should ideally reduce soil erosion (Buhler et al., 1998; Raimbault et al., 1990; Eadie et al., 1992), reduce dependency on herbicide applications and tillage practices (Johnson et al., 1993; De Haan et al., 1994), increase water infiltration and retention (Tollenaar et al., 1993; Vaughan and Evanylo, 1998; Galloway and Weston, 1996), provide N to subsequent crops (Reddy and Koger, 2004; Hartwig and Ammon, 2002; Wagger, 1989), reduce environmental contaminations from herbicide and fertilizer surface runoff and leaching (De Bruin et al., 2005; Unger and Vigil, 1998), improve soil quality through organic matter enrichment (Sarrantonio and Gallandt, 2003; Fageria et al., 2005), and reduce economic and production costs (Snapp et al., 2005). Cover crops can also decrease soil compaction (Galloway and Weston, 1996), improve soil nutrient cycling (Sarrantonio and Gallandt, 2003), fix atmospheric N (Unger and

Vigil, 1998; Hartwig and Ammon, 2002), provide habitat for wildlife (Lu et al., 2000), and can be used as a forage or renewable energy resource (Tollenaar et al., 1993).

In South Dakota, the implementation and establishment of cover crops as an alternative weed control strategy in corn is difficult due to environmental niches (e.g. cold fall temperatures and dry soil conditions) and the dominant corn-soybean crop rotation which shortens the period of time for cover crop establishment (SARE, 2007). Interseeding of a cover crop into standing corn after the critical weed-free period could provide a greater length of time for cover crop growth which may provide a more rapid and consistent establishment of cover crops in corn fields in South Dakota (Hively and Cox, 2001). Smeltekop et al. (2002) showed that annual snail medic broadcast interseeded into corn, directly after corn planting, produced an average of about 604 kg biomass ha^{-1} with no added nitrogen, and about 912 kg biomass ha^{-1} when 134 kg N ha^{-1} was applied. Also, Vos (1999) reported that broadcast interseeded annual medic produced an average of approximately 640 kg biomass ha^{-1} when planted two weeks prior to corn planting. However, caution must be taken as these medic cover crops seeded at or before corn planting competed with the corn and reduced yields. A cover crop that does not grow until or after the critical weed free period (e.g. interseeded after corn planting) may help with this problem.

Interseeding of a cover crop into standing corn has been shown to be a successful method for establishing cover crops. For instance, in Ontario, Canada, Eadie et al. (1992) reported that winter rye and spring barley produced 169.6 and 174.6 g m^{-2} of dry matter in the fall when broadcast interseeded approximately 31 days after corn (DAP) planting. It was also observed in Michigan (MI) that chickling vetch (*Lathyrus sativus* L.) and red clover were successfully established in corn when broadcast interseeded at V5-V7 corn growth stages (Baributsa et al., 2008). However, interseeding of a cover crop at planting can adversely impact corn yields. For example, in Iowa, Schaller and Larson (1955) reported that a cover crop mixture of rye, alfalfa, red clover, and timothy (*Phleum pratense*) interseeded at corn planting had a 65% lower corn yield compared to being planted on June 24th following the third cultivation practice. Similarly, Nordquist and Wicks (1974) reported corn yield losses ranged from 1000 to 3000 kg ha^{-1} when alfalfa was interseeded at corn planting. In contrast, cover crops interseeded 28 days after corn planting (Jeranyama et al., 1998), between V4 and V6 corn growth stages showed no yield reductions (Baributsa et al., 2008), or seeded to emerge in the middle of the vegetation period of the main crop (Brandsaeter and Netland, 1999).

Weed suppression by cover crop integration and establishment via interseeding into standing corn is dependent on the species of cover crop. A smother plant is a specialized cover crop species that has potential to suppress weeds when interseeded into standing corn without adversely impacting corn yield (De Haan et al., 1997). Interseeded smother plants could provide a living mulch during corn growth which may potentially inhibit weed germination and establishment of weeds indirectly by reducing light transmittance and soil temperature and directly by competing with weeds for essential growth resources (e.g. soil nutrients and water) (Severino and Christoffoleti, 2004). Therefore, interseeded smother plants could provide a nonchemical means of weed suppression (De Haan et al., 1997) while assisting in improving soil quality (e.g. increased infiltration), fertility, and reducing soil wind and water erosion (Brainard et al., 2004; Abdin et al., 1998). De Haan et al. (1994) stated that an ideal smother plant variety for the north central region of the United States (e.g. South Dakota) would consist of the following criteria: rapid seedling emergence under cool weather conditions, horizontal leaf angle, two- by three-cm mature leaf size, 25 cm rooting depth, a maximum height of 10 cm, short life cycle, non-dormant seed, and a seed production potential of at least 500 kg seeds ha^{-1}. In addition, smother plants incorporated into corn by interseeding should also be shade tolerant. Crimson clover, lentil (*Lens culinaris*), and winter wheat cover crop species correlate well with the stated criteria for quality smother plants for the North Central regions.

Crimson Clover.

Crimson clover is a legume native to Europe where it is primarily cultivated as a forage or green manuring crop (Hannaway and Myers, 2004). In 1818, crimson clover was introduced to the U.S. and by 1855 crimson clover seed was widely distributed by the U.S. Patent Office. A rapid increase in crimson clover occurred in 1942 due to the development of reseeding or volunteering varieties, the additional benefit of crimson clover to possibly provide substantial amounts of nitrogen, its rapid stand establishment and vigorous growth, and its value for winter grazing (Knight and Hollowell, 1973). Furthermore, in the southern regions of the U.S., crimson clover is primarily used as a winter forage legume that is overseeded into perennial and warm-season grasses because of its excellent seedling vigor, early forage production, and early maturation time (Smith et al., 2008; Butler et al., 2002). In recent years, researchers have begun to successfully use crimson clover as a cover crop in corn rotations, orchards, berry fields and vineyards as a living mulch because of its shade tolerance and reseeding potential (Anderson, 2010).

Crimson clover is an annual that can grow up to 76 cm tall, has light-green colored pubescent foliage, and a root system consisting of a central taproot supported by many fibrous branch roots (Sattell et al., 1998). The normal seeding rate ranges between 16.8 and 33.6 kg ha^{-1}, depending on application (SARE, 2007). Crimson clover can produce approximately 336 kg seeds ha^{-1}, which have a hardseededness [def: where seeds do not imbibe water or oxygen from the soil (Cabrera et al., 1995)] ranging from 30-75%, respectively. Crimson clover seeds can germinate in cool conditions and rapidly grow in the fall (Brink, 1990). Knight and Hollowell (1973) stated that crimson clover seeds withstood and germinated at temperature of -12°C, respectively. Crimson clover begins flowering when the day length exceeds 12 hours (Butler et al., 2002), is determinant, with growth terminating following the development of a pointed, conical flower head that is commonly composed of 75-125 florets (Knights and Hollowell, 1973).

Crimson clover cover crops have been shown to provide several benefits to agricultural production such as increasing soil N supply for subsequent crops, reducing soil runoff and erosion, improving soil physical and chemical properties, improving water use efficiency, conserving leachable plant nutrients, and providing weed suppression (Decker et al., 1994). For instance, crimson clover was shown to contain between 93 and 133 kg N ha^{-1} (Rannells and Wagger, 1992), increased grass weed control by 46 to 61% (Yenish et al., 1996) and reduced soil surface water runoff between 18 and 23% and sediment runoff by 89% (Stearman and Wells, 1997). Crimson clover can accumulate approximately 5466 kg ha^{-1} of dry matter (Dyck and Liebman, 1994) which will provide additional surface cover, organic matter, help retain soil moisture, and can suppress weeds (through release of toxic allelochemicals from decomposing plant material).

Lentil.

Lentil is one of the oldest legumes that originated in Near East more than 10,000 years ago. Lentil has been widely adapted cause of its ability to grow in dry soils, cold climates and harsh conditions. In 1916 lentils were introduced to the U.S and Canada in 1969 (Erskine et al., 2009). The majority of lentil production areas in North America are located in Saskatchewan, Alberta, Manitoba, Washington, and Idaho (Nielsen, 2001). Lentils are primarily utilized in the semiarid regions of the Canadian Prairies to lengthen the wheat-fallow crop rotations. Recently, lentil cultivation has progressed as an accelerated rate in the Great Plains of the U.S. due to climate warming and the crop's tolerance to dry conditions and adaptive ability to harsh environments (Cutforth et al., 2007; Rao et al., 2005).

Lentil plant height can range between 30.5- to 52 cm and has compound leaves with upper leaves having tendrils while lower leaves are mucronate (Oplinger et al., 1990). Lentil has a shallow root system that penetrates to approximately 0.6 m into the soil profile (Vandenberg and Risula, 2010). The normal seeding rate ranges between 33.6 and 112 kg ha^{-1}, depending on application (SARE, 2007). Lentils have been shown to produce about 654 kg seeds ha^{-1} (Nielsen, 2001). Lentil seeds have the ability to germinate and emerge in cool soil temperatures. Cutforth et al. (2007) state that lentil seeds can germinate at base temperatures near 0°C and can withstand moderate frost temperatures ranging from -2 to -18°C. Furthermore, lentil requires few growing degree-days to reach anthesis (540 degree-days at a base of 5°C (DD_5)) and to attain full maturity (1060 DD_5) (Cutforth et al., 2007). In addition, lentil has been shown to produce about 3510 kg ha^{-1} of biomass in the semiarid climates of Oregon (Pikul Jr. et al., 2004).

Lentil cover crops have been shown to benefit agricultural production systems by providing N (Rao et al., 2005), improving water use efficiency, reducing greenhouse gas emissions, suppressing weeds (Chen et al., 2012), and reducing soil erosion by providing surface residue (Krupinsky et al., 2007). For instance, lentils have been shown to accumulate 129 kg N ha^{-1} from N_2 fixation (Kessel, 1994), extract water from a depth of only 80 cm and had an average extractable soil water of 90 mm (Zhang et al., 2000), and reduced soil erosion from 18 to 58% (Raya et al., 2006). Lentils, therefore, may have great potential for growing as a main or cover crop in the Great Plains due to limited water use, drought tolerance, and cold germination and growth requirements (Cutforth et al., 2007).

Winter Wheat.

Winter wheat has thought to have been developed as a crop in the Middle East around 9000 years ago. Winter wheat was first introduced into the U.S. around 1600's (Australian Government, 2008). Presently, the U.S. is now the major wheat-producing country next to China and ranks third among U.S. grain commodities. Winter wheat accounts for approximately 40% of the total wheat produced in the U.S. (USDA, 2012). Winter wheat is primarily used for produce food for humans and animal feed (Beuerlein, 2001). However, recently winter wheat has been utilized as a cover crop due to its ability to provide the benefits of other cereal cover crops and as an alternative grazing feed source (SARE, 2007).

Winter wheat can grow up to 1.2 m tall and has flat narrow leaves that are between 20-38 cm long and 1.3 cm wide (Duke, 1983). Winter wheat has two distinct types of roots which are commonly classified as seminal (e.g. primary) and nodal (e.g. adventitious) roots (Nakamoto and Oyanagi, 1994). Seminal roots develop in the embryonic hypocotyl of the germinating seed while nodal roots emerge from the base of the apical culm and tillers. The root system of winter wheat generally has a horizontal spread of 20-60 cm and a vertical depth of approximately 30 cm (Reynolds et al., 2001). The normal seeding rate ranges from 67.2 to 168 kg ha^{-1}, depending on application (SARE, 2007). Winter wheat seed production in the U.S. has been shown to be approximately 2100 kg ha^{-1} (Duke, 1983). Winter wheat germinates in cool soil temperatures. Lindstrom et al., (1976) stated that winter wheat has potential to germinate at temperatures ranging from 3.5 to 5.5°C. Furthermore, winter wheat fall biomass production has been shown to range between 971 to 1650 kg ha^{-1}, respectively (MacKown and Carver, 2005).

When utilized as a cover crop, winter wheat has been shown to provide many benefits to agricultural production such as erosion control, nutrient scavenging and weed suppression. For instance, winter wheat was shown to have an N concentration and content level close to 17.7 g N kg^{-1} (McVay et al., 1989) and reduce weed pressure between 14 and 52% while producing an average biomass of 1600 kg ha^{-1} (Reeves et al., 2005). The biomass produced can potentially aid in reducing soil erosion and increase soil organic matter.

These findings suggest that crimson clover, lentil, and winter wheat sown into a corn crop in South Dakota should readily germinate and grow through the fall because each of these plant varieties having the ability to germinate under cool soil temperatures, have early maturation potentials and vigorous growth capabilities. Establishment prior to corn harvest is needed because of very short or non-existent growth periods after corn grain harvest. These plants should be able to grow as corn senesces, providing cover and forage late in the fall after corn grain is harvested and corn stover is baled.

Research Objectives.

Research was conducted in 2010-2012 at Andover and at Trail City and Aurora, SD in 2011-2012. The objective of this experiment was to examine the broadcast and drill seed placements, time of sowing, and field position of an interseeded cover crop mixture consisting of crimson clover, lentil, and winter wheat and the cover crops ability to control or suppress late-emerging weeds in corn, and provide a fall surface ground cover. The specific objectives of this experiment were to determine if interseeding crimson clover, lentil, and winter wheat into corn at the V3 and V5 growth stages would:

1. provide a suitable environment for cover crop establishment and growth;
2. suppress late-emerging broadleaf and grass weeds, and
3. be present after corn grain harvest to provide soil surface residue

CHAPTER TWO

MATERIALS AND METHODS

Experimental Locations and Descriptions.

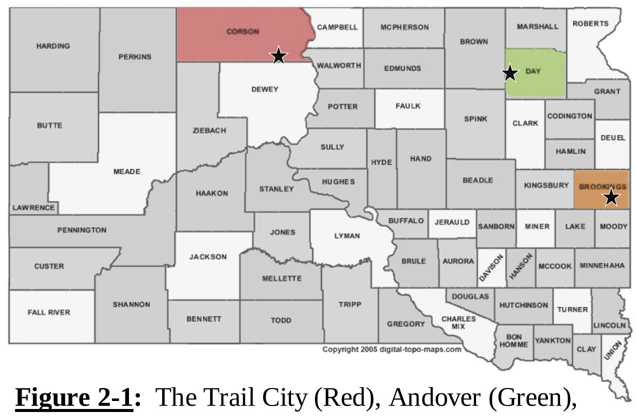


Figure 2-1: The Trail City (Red), Andover (Green), and Aurora (Orange) field experiment locations.

Field experiments were conducted from 2010 to 2012 on dryland cropland hectares at three separate geographic locations in South Dakota (SD). The field experiments were located in Day County near Andover (Andover), Corson County near Trail City (Trail City), and at the Aurora Experimental Farm in Brookings County near Aurora (Aurora) **(Figure 2-1)**. In 2010, a single field experiment was conducted at the Andover location, whereas in 2011 and 2012 three field experiments were conducted at Andover, Trail City, and Aurora. Furthermore, at the Andover and Trail City field experimental locations, two research sites were selected, one on a summit (SMT) position (uppermost section of the field (e.g. top of a hill) and a second on a toeslope (TSP) position (lowermost section of the field (e.g. bottom of a hill), whereas, at the Aurora field experimental locations, a single research site was selected on a flat-plain (e.g. level ground) **(Table 2-1).**

The farming systems and crop rotation sequences utilized at the Andover and Trail City research sites were: full no-tillage wheat (*Triticum aestivum*)-corn (*Zea mays* L.) crop rotation. At the Aurora research sites, the farming system and crop rotation

Table 2-1. Andover, Trail City, and Aurora research sites, field positions, and plot locations.

Geographical Location	Research Period	Field Location	Field Position	Research Plot Location
Andover	2010	44°22'29"N, 97°58'46"W	Summit	45°22'30"N, 97°58'47"W
			Toeslope	45°22'31"N, 97°58'46"W
	2011	45°27'41"N, 97°57'49"W	Summit	45°22'43"N, 97°57'46"W
			Toeslope	45°22'38"N, 97°57'46"W
	2012	45°22'47"N, 97°57'49"W	Summit	45°22'42"N, 97°56'27"W
			Toeslope	45°22'53"N, 97°56'28"W
Trail City	2011	45°33'19"N, 100°49'42"W	Summit	45°33'51"N, 100°49'43"W
			Toeslope	45°33'43"N, 100°49'43"W
	2012	45°33'19"N, 100°50'25"W	Summit	45°33'28"N, 100°49'58"W
			Toeslope	45°33'28"N, 100°49'58"W
Aurora	2011	44°18'20"N, 96°40'12"W	Flat-plain	44°18'20"N, 96°40'12"W
	2012	44°18'18"N, 96°40'24"W	Flat-plain	44°18'18"N, 96°40'24"W

sequence utilized each year was: conventional tillage [fall chisel-plow after soybean (*Glycine max*) harvest] plus a spring cultivation (seedbed preparation for corn planting), which resulted in less than 15% soil surface residue remaining at corn planting, with a corn following soybean crop rotation.

The Andover and Trail City research sites were selected and plots were established in late-August to early-September immediately following wheat harvest. Furthermore, in late-April to early-May, the Aurora research sites were selected and plots were established after spring cultivation of the soybean stubble and prior to corn planting **(Table 2-2)**.

Experimental Design and Plot Dimensions.

The experimental design incorporated into the Andover, Trail City, and Aurora research plots was a randomized split-block split-plot experimental design. The variables used within the experimental design were: cover crop as the main treatments (plot), and three cover crop interseeding methods [none (NoCC), broadcast (BRD), and drill (DRL)] at vegetative five-leaf (V5) (Andover, Trail City, and Aurora each experimental year) (subplots) **(Figures 2-2 and 2-3)**. In addition, cover crops were interseeded with both methods at Aurora at the vegetative three-leaf (V3) corn growth stage. Therefore, the sub-subplots at Andover and Trial City were BRDV5 and DRLV5, whereas at Aurora, the sub-subplots were BRDV5, DRLV5, BRDV3, and DRLV3. Four replications were used at each research site and field position.

Table 2-2. Andover, Trail City, and Aurora research site soil texture and types [Data obtained from Web Soil Survey (USDA-NRCS) accessed in 2013].

Research Site Location	Experimental Year	Soil Description	Soil Content			
			Sand	**Silt**	**Clay**	**Organic Matter**
			(%)			
	2010	Forman-Aastad Loams, 1 to 6 percent slopes (fine-loamy, mixed, frigid, Udic Argiborolls)	36	36	28	2.69
Andover	2011	Forman-Buse-Aastad loams, 1 to 6 percent slopes (fine-loamy, mixed, frigid Udic Argiborolls)	33	38	29	2.69
	2012	Kranzburg-Brookings silt loams, 0 to 2 percent slopes (fine-silty, mixed, frigid Udic Haploborolls)	8	67	25	3.84
Trail City	2011 and 2012	Reeder loam, 2 to 6 percent slopes (fine-loamy, mixed, frigid Typic Argiborolls)	37	28	25	2.29
Aurora	2011 and 2012	Brandt silty clay loam, 0 to 2 percent slopes (fine-silty, mixed, frigid Udic Haploborrols)	7	63	30	3.38

Figure 2-2. Andover (A) and Trail City (B) experimental design (block, plot, subplot and sub-subplot design and dimensions).

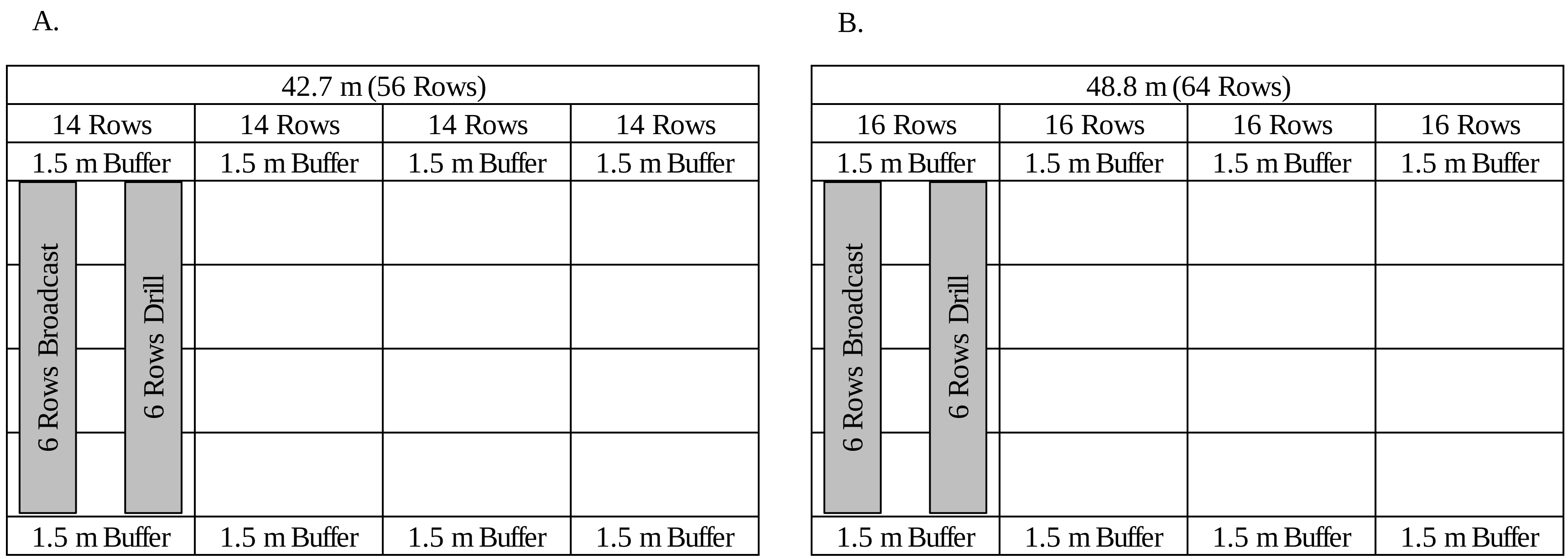
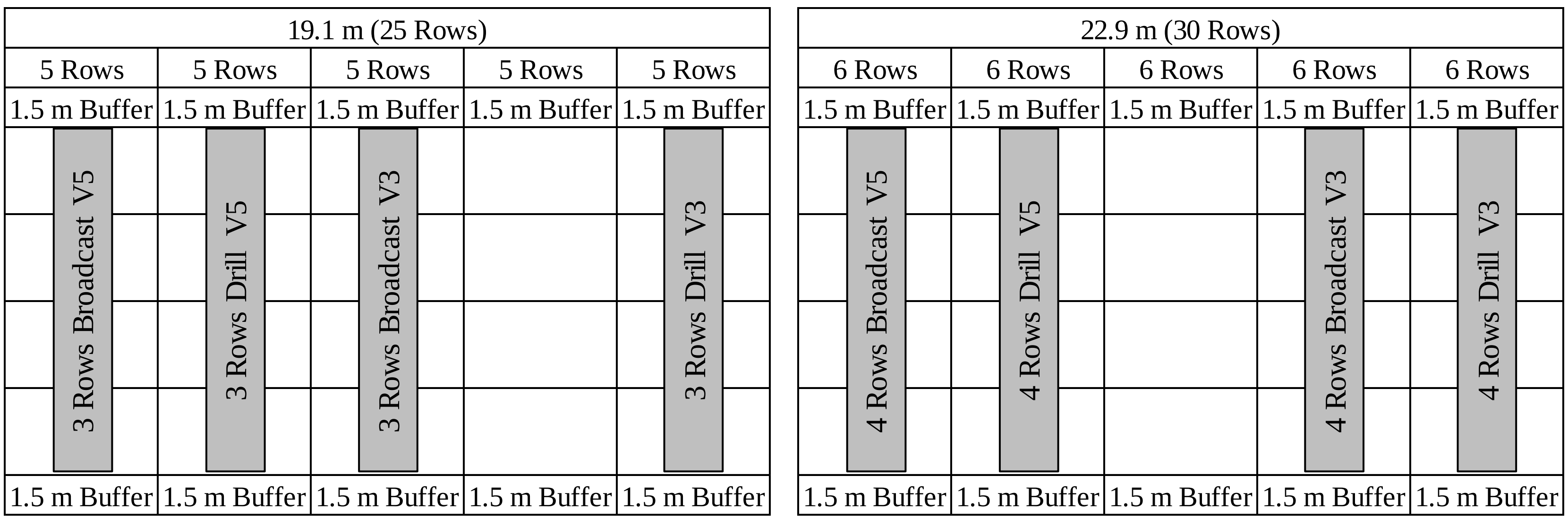


Figure 2-3. Aurora 2011 (A) and 2012 (B) experimental design (block, plot, subplot, and sub-subplot design and dimensions).

A. B.



The plot dimensions at the Andover and Trail City research sites were: 56 to 64 corn rows wide [42.7 to 48.8 meters (m)] by 27.4 m long (block), 14 to 16 corn rows wide (10.7 to 12.2 m) by 27.4 m long (plot), and 6 corn rows wide (4.6 m) by 27.4 m long (subplots) **(Figure 2-2).** The plots dimensions at the Aurora research sites in 2011 and 2012 were: 25 to 36 corn rows wide (19.1 to 22.9 m) by 27.4 m long (block), 5 to 6 corn rows wide (3.8 to 4.6 m) by 27.4 m long (plot), and 3 (2011) to 4 (2012) corn rows wide (2.3 to 3.1 m) by 27.4 m long (subplots) **(Figure 2-3).** The corn row width at all sites was 76 cm.

Corn Planting.

At the Andover research sites, Mycogen 2J463 (96 day corn maturity), Stine 9204 (89 day corn maturity), and Mycogen 2J339 (92 day corn maturity) corn varieties were seeded directly into wheat stubble on April 21, 2010, May 11, 2011, and May 3, 2012, respectively, with a 18.3 m corn planter at populations close to 74100, 76570, and 71605 seeds ha^{-1}. At the Trail City research sites, REA 3V375 (89 day corn maturity) corn variety was seeded directly into wheat stubble with a Kinze 2700 planter on May 16, 2011 and May 6, 2012 with a population of approximately 61750 seeds ha^{-1}. At Aurora, DKC48-12 (98 day corn maturity) corn variety was planted on May 4, 2011 and May 15, 2012 with a John Deere 7000 four-row corn planter at a population of approximately 79040 seeds ha^{-1}, respectively.

Herbicide Applications.

Herbicides were applied pre-corn (PRE) and post-corn (POST) emergence (prior-to cover crop interseeding) at the Andover and Trail City research sites. At Aurora, a single POST herbicide application was made each experimental year prior to cover cover crop planting at the research sites. Herbicides were applied with a 30.5 m sprayer (Andover), a 27.4 m (Trail City), and a 3.1 m sprayer (Aurora).

At Andover, the PRE herbicides were applied on May 6, 2010, May 17, 2011, and April 20, 2012. The herbicides and rates applied PRE in 2010 and 2011 were: 1.7 kg a.i. ha^{-1} of Atrazine 4L (1-chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine) plus 1.1 kg a.e. ha^{-1} of Roundup Weathermax [N-(phosphonomethyl)-glycine in the form of its potassium salt]. In 2012, the PRE herbicide and rate applied was 1.2 kg a.e. ha^{-1} of Durango [N-(phosphonomethyl)-glycine, isopropylamine salt]. Furthermore, POST herbicides were applied on May 31, 2010, June 21, 2010, May 25, 2011, and May 23, 2012, respectively. In 2010 (two applications) and 2011 (single application), the POST herbicide and rate applied was 1.1 kg a.e. ha^{-1} of Roundup Weathermax. In 2012, the herbicides and rates applied on May 23, 2012 were 1.1 kg a.e. ha^{-1} of Roundup Powermax plus 1.7 kg a.i. ha^{-1} Aatrex 4L (2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine).

At Trail City, a PRE burndown herbicide was applied on May 23, 2011 and May 15, 2012 and a POST herbicide was applied when corn was approximately 30.5 cm tall. The herbicide and rate applied for both PRE (burdown) and POST was 0.77 kg a.e. ha^{-1} RT3 [N-(phosphonomethyl)-glycine in the form of its potassium salt].

In 2011 and 2012 a single POST herbicide application was made to the research sites at Aurora immediately before the V3 cover crop interseeding on June 1, 2011 and

June 3, 2012. The POST herbicide and rate applied each year was 1.1 kg a.e. ha^{-1} of Roundup Weathermax.

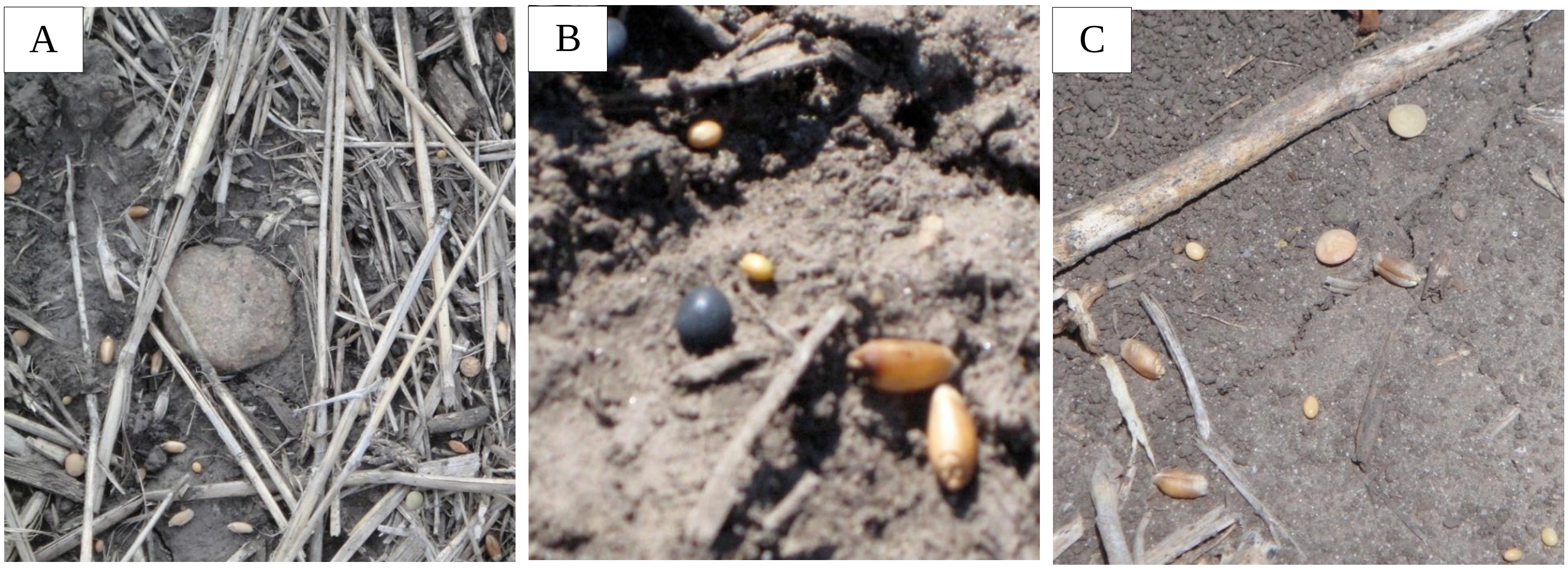
Cover Crop V3 and V5 Interseeding.

At Andover, Trail City, and Aurora, crimson clover (*Trifolium incarnatum*), lentil (*Lens culinaris*), and winter wheat (*Triticum aestivum*) cover crops were BRD and DRL interseeded into standing corn at the V5 corn growth stage on June 22, 2010, June 28, 2011, and June 12, 2012 at Andover, June 30, 2011 and June 20, 2012 at Trail City, and on June 20, 2011 and June 18, 2012 at Aurora into the subplot areas within the experimental design. Furthermore, at Aurora, additional subplots were established where cover crops were BRD and DRL interseeded at V3 corn growth stage on June 3, 2011 and June 8, 2012, respectively. The selected cover crop species were interseeded as a mixture ‘cover crop cocktail’ at the selected rates of: 5.4 kg ha^{-1} (crimson clover), 9.8 kg ha^{-1} (lentil), and 8.9 kg ha^{-1} (winter wheat).

The BRD interseedings were completed by walking down the center of 6 (Andover and Trail City) and 3 or 4 (Aurora) sub-subplot corn rows and uniformly distributing the cover crop mixture by hand **(Figure 2-4)**. The DRL interseedings were completed by using a single-row push drill (calibrated prior to cover crop interseeding) to plant the cover crop mixture in the center of 6 (Andover and Trail City) and 3 or 4 (Aurora) sub-

<u>Figure 2-5</u>: The single-row push drill used for drill cover crop interseeding procedure.

Figure 2-4. Interseeded cover crops at Andover (A.), Trail City (B.), and Aurora (C.) by surface broadcasting.



subplot rows at a depth close to 1.3 cm, respectively **(Figure 2-5 and Figure 2-6)**.

Midseason Interseeded Cover Crop Growth Examination.

The interseeded cover crops at Aurora, Andover, and Trail City research sites were visually examined in mid-July. Visual estimations were made on the percentage of cover crop growth and row coverage achieved by the interseeded cover crops **(Figure 2-7)**.

Cover Crop and Weed Biomass Harvest.

Cover crop and weed biomass harvests were completed prior to corn grain harvest at the Andover, Trail City, and Aurora research sites each year **(Figure 2-8**). The cover crop and weed biomass at Andover and Trail City were harvested on: September 30, 2010, August 22, 2011, and August 22, 2012 (Andover), and September 14, 2011 (Trail City). In 2012 at Trail City, cover crop and weed biomass were not collected due to severe drought resulting in no cover crop or weed growth. At Aurora, the cover crop and weed biomass were harvested on September 22, 2011 and August 29, 2012, respectively.

The cover crop and weed biomass were harvested by placing a PVC square (1/10th m^2) randomly in the center of an interseeded corn row (or in the center of a row of a control plot) on the soil surface. The living cover crop and weed biomass within the PVC square was clipped at the soil surface with scissors, separated by cover crop and weed broadleaves and grasses, then placed into properly labeled paper bags. Twelve random samples were collected within each subplot (BRD and DRL). The collected biomass samples were weighed to obtain fresh weight, and were dried at 30°C until constant weight, and dry weight was measured. The cover crop and weed biomass weights

Figure 2-6. Drill interseeded cover crops at Andover (A.), Trail City (B.), and Aurora (C.).

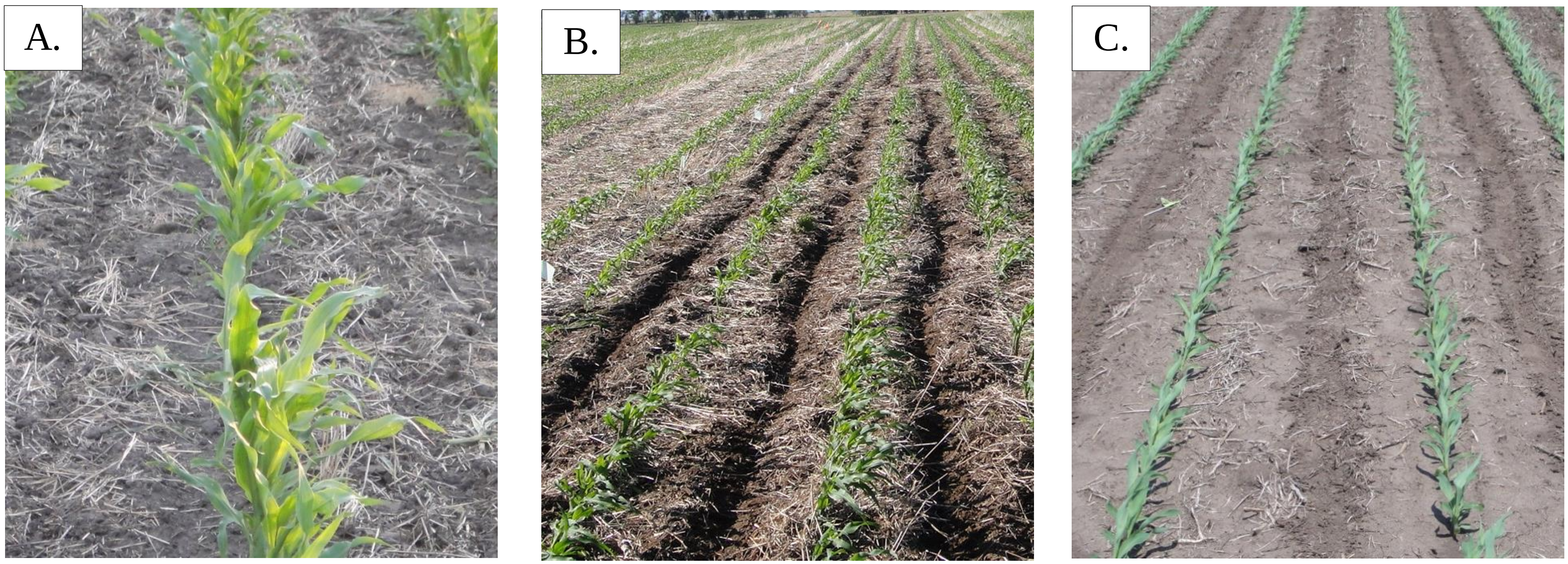


Figure 2-7. Mid-season drilled cover crops 15 days after planting (DAP) at Andover (A.), 10 DAP at Aurora (B.), and 14 DAP at Trail City (C.).

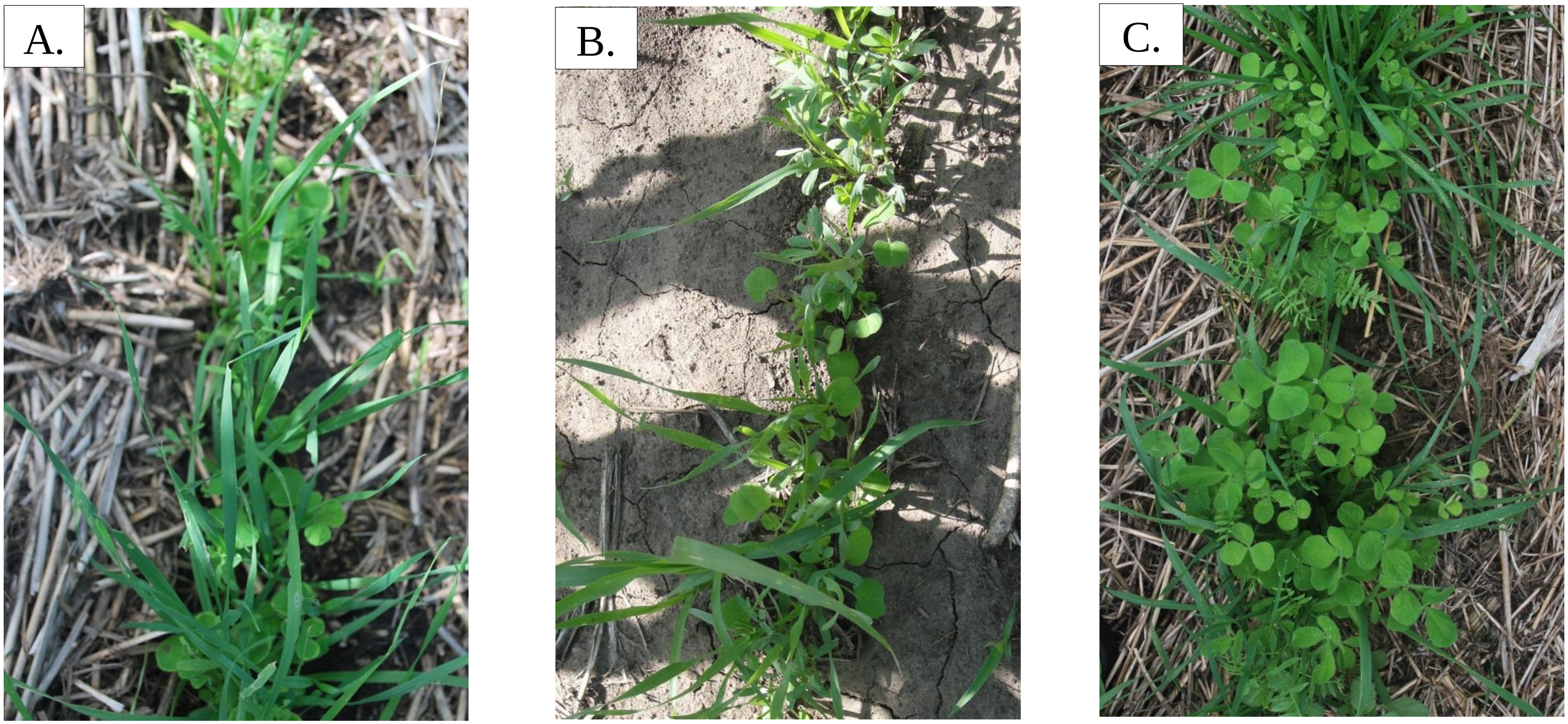
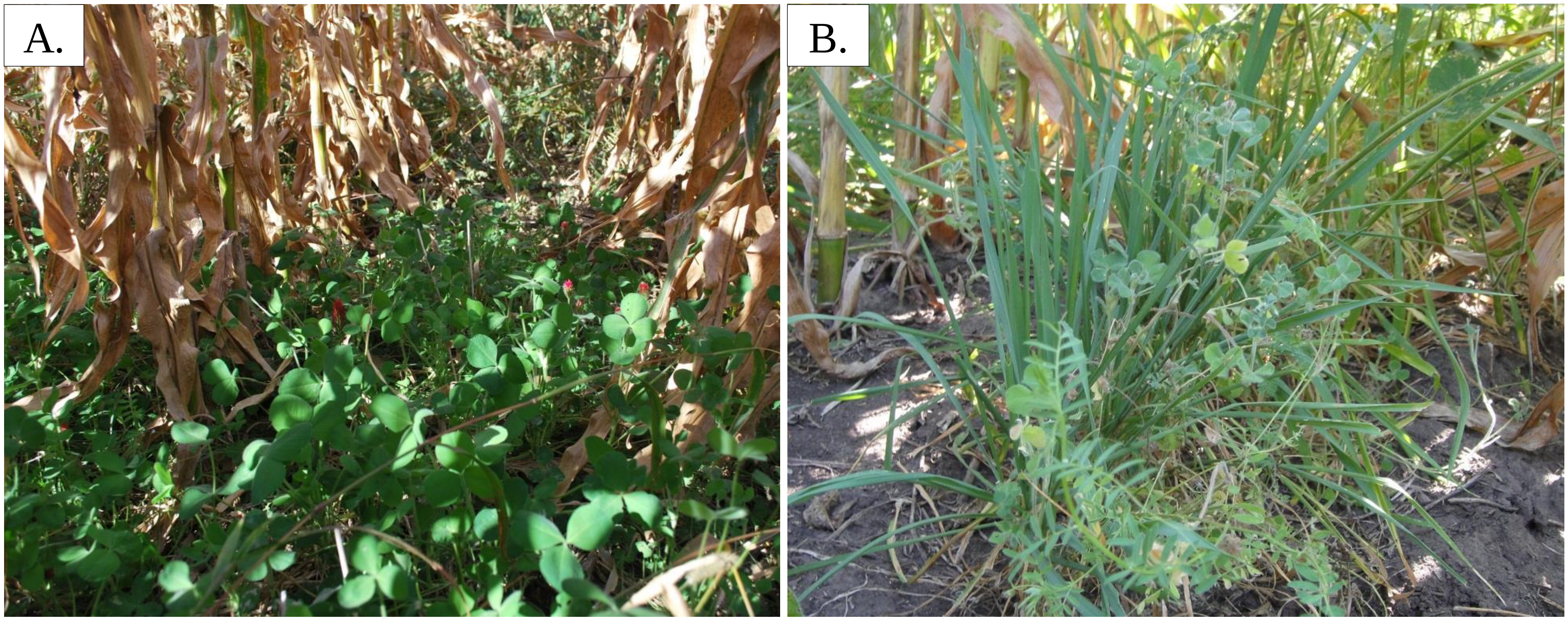


Figure 2-8. Broadcasted cover crops at Andover (A.) and drilled cover crops at Aurora (B.) at cover crop and weed biomass harvest.



recorded were adjusted to provide the amount of broadleaf and grass cover crop and weed biomass on a kg ha^{-1} basis.

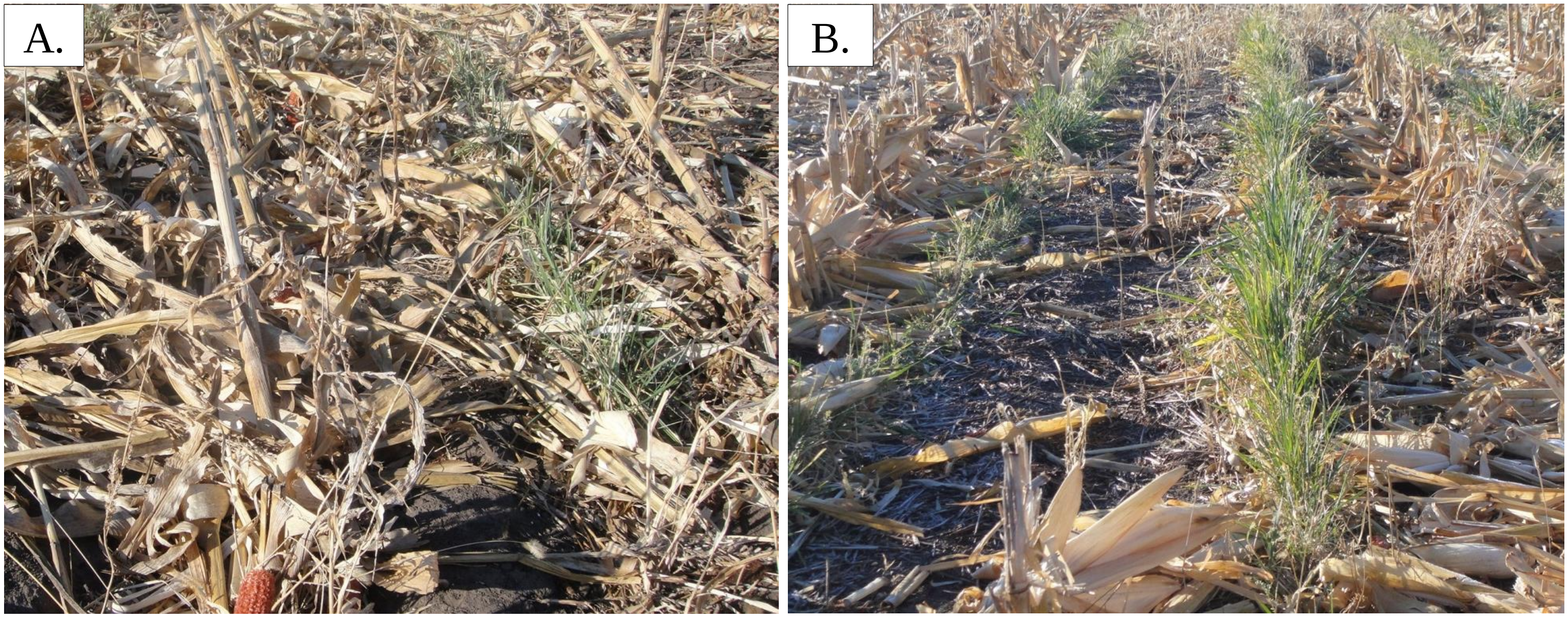
Corn Grain Harvest.

Corn grain harvests were completed following cover crop and weed biomass harvests at the Andover, Trail City, and Aurora research sites. At Andover and Trial City, corn grain was harvested on September 28 to October 1, 2010, October 13 to October 18, 2011, and September 21 to September 23, 2012 (Andover), and on October 5 to October 6, 2011 (Trail City). At Aurora, corn grain was harvested on September 29, 2011 and October 17, 2012. Corn grain was hand-picked on 12 (3.1 m long) sections marked within the three center corn rows of each sub-subplot. Samples were then weighed, sub-sampled to 25 ears, weighed again, and dried at 30°C until constant moisture. The sub-samples were then shucked, to separate the corn grain from cobs, and individually weighed. The grain weights were adjusted to 15% moisture content and grain weight and yield on a kg ha^{-1} basis was calculated.

Interseeded Cover Crop Fall Observation.

In the fall (late-September to early-October), after corn grain harvest, visual examinations were made of the cover crop interseeded sub-subplots. Examinations were made to see if any cover crops remained or if regrowth occurred after corn grain harvest. If there was living cover crop mulch, visual estimations were made on the percentage of corn row cover **(Figure 2-9)**.

Figure 2-9. Drill interseeded cover crop growth during fall season examination Aurora (A.) and Andover (B.).



Statistical Analysis.

Analysis of Variance was performed on the broadleaf and grass weed cover crop and weed biomass and corn yield data that was collected at each field research site each experimental year. The significant differences and mean separations were determined using LSD values at $P< 0.10$. All data analyses and interactions were performed and completed by using PROC GLM Procedure of SAS 9.2. This procedure provided outputs similar to PROC MIXED Procedure of SAS 9.2.

CHAPTER THREE

RESEARCH RESULTS

Significant differences in precipitation amounts and average temperatures occurred among the 2010, 2011, and 2012 growing seasons and research locations. In addition, differences in water availability were noted between the summit and toeslope locations at the Andover and Trail City locations. These differences influenced interseeded cover crop and weed biomass accumulations and corn grain yield. Therefore, the data are presented by the geographical location (Andover, Trail City, and Aurora), research site [summit (SMT) and toeslope (TSP)] (Andover and Trail City only), and experimental year.

Andover Weather Conditions.

2010 Research Site.

Climate conditions during the 2010 growing season (April through August) was warmer and drier than the 30-year averages **(Table 3-1)**. Although the total annual (January through December) precipitation accumulation was slightly above the 30-year average, the precipitation accumulation from April through August was about 13% below the 30-year average. The precipitation amounts in April, May, July, and August were 33%, 29%, 7%, and 28% below the 30-year averages, respectively. Precipitation in June was 15% above 30-year average. In April, the average temperature was about 37% above the 30-year average, whereas May and August were about 10% above the 30-year averages.

Table 3-1. Andover average monthly temperature and total precipitation amounts, and growing degree days (GDD) for 2010 to 2012 and the 30-year average [Data obtained from the NOAA (National Oceanic and Atmospheric Administration) recording station 5.8 km from research sites].

	2010			2011			2012			1980-2010		
Month	**Temp. (C°)**	**Precip. (cm)**	**GDD (C°)**	**Temp. (C°)**	**Precip. (cm)**	**GDD (C°)**	**Temp. (C°)**	**Precip. (cm)**	**GDD (C°)**	**Temp. (C°)**	**Precip. (cm)**	**GDD (C°)**
January	-12.2	1.4	-	-14.4	5.7	-	-5.6	1.8	-	-10.7	1.2	-
February	-11.6	1.4	-	-11.0	3.7	-	-4.1	2.4	-	-7.8	1.4	-
March	2.3	4.3	-	-5.0	3.9	-	7.1	1.3	-	-1.0	3.2	-
April**	10.8	3.5	106.9	5.9	6.4	42.8	9.5	10.4	91.4	6.8	5.2	53.6
May**	13.8	5.6	164.4	12.6	8.6	141.7	16.0	4.5	202.8	14.1	8.0	158.3
June**	19.5	11.9	287.5	18.8	11.0	266.9	21.3	4.6	340.0	19.1	10.2	273.9
July**	22.6	7.9	384.7	24.6	13.5	439.2	25.2	4.3	434.7	22.0	8.6	371.9
August**	23.5	4.8	404.4	21.7	4.3	356.1	20.7	1.7	325.8	21.2	6.7	346.4
September	14.7	11.2	162.5	15.5	2.2	199.4	18.2	0.2	232.8	15.6	7.1	189.2
October	10.6	4.6	120.0	10.8	2.5	130.6	7.4	6.7	68.6	8.1	5.1	67.8
November	0.3	0.4	-	2.7	0.4	-	0.8	0.8	-	-0.9	2.1	-
December	-11.4	2.8	-	-2.8	0.9	-	-7.8	1.1	-	-8.4	1.4	-

**Significant growing season months

2011 Research Site.

The 2011 growing season climate conditions were wetter (April through July) and warmer (April through August) than the 30-year averages **(Table 3-1)**. The total annual precipitation accumulation was slightly above the 30-year average, whereas the precipitation amount from April through August was 12% above the 30-year average, and varied from 7% (May and June) to 36% (July) above the 30-year averages. August was dry, with rainfall 36% below the 30-year average. In April, the average temperature was approximately 13.8% above 30-year average, whereas May was about 10% above 30-year average, respectively. In June and August, the average temperatures were slightly above the 30-year averages, whereas July was 11% above the 30-year average.

2012 Research Site.

The 2012 climate conditions during May through August were very dry (44% to 74.3% below the monthly 30-year averages) and very warm (ranging from 10.3% to 28.1% warmer than the monthly 30-year averages) **(Table 3-1)**. The precipitation accumulation and average temperature during the growing season (April through August) were 34% below and 10.3% above the 30-year averages. The precipitation amount in April was 49.9% above the 30-year average, whereas May, June, July, and August were 44%, 54.5%, 49.9%, and 74.3% below the monthly 30-year averages, respectively. In addition, in April, May, June, and July, the average temperatures were 28.1%, 12.2%, 10.2%, and 12.8% above the 30-year averages. In August, the average temperature was slightly below the 30-year average.

Andover Research Site Weather Condition Comparisons.

The 2011 growing season was wetter than 2010 and 2012. In 2011, the precipitation accumulation during April through August was 9.8% and 10.1% greater than 2010 and 2012, respectively. Furthermore, the 2012 growing season was drier than 2010 and 2011. The average temperature during April through August was 7.4% and 14% greater than 2010 and 2011, respectively.

Andover Cover Crop Data.

The cover crop mixture was interseeded into standing corn at the V5 growth stage 62 (2010), 48 (2011), and 40 (2012) days after corn planting (DACP) into dry soil conditions. Precipitation amounts 14 days prior-to and after the cover crop interseeding dates were approximately 9.4 and 4.3 cm (2010), 9.2 and 6.3 cm (2011), and 2.4 and 3 cm (2012). In 2010 and 2011, all three cover crop species had emerged 9 (2010) and 14 (2011) days after interseeding (DAI) in both the broadcast (BRD) and drill (DRL) treatments. In 2012, 16 DAI, all three cover crop species had emerged in the DRL treatment only.

Cover crop biomass was harvested on September 30, 2010 (100 DAI), August 22, 2011 (55 DAI), and August 22, 2012 (71 DAI) and only crimson clover and winter wheat were present. Differences were noticed in the crimson clover, winter wheat, and total cover crop biomass when comparisons were made among research years **(Table 3-2a)** and when the research years were examined individually **(Table 3-2b)**.

In 2010, at the summit (SMT) and toeslope (TSP) sites, the crimson clover biomass in the BRD and DRL treatments accounted for 93% and 80% (SMT) and 100%

Table 3-2a. Source of variation and P-values from PROC GLM procedure on crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010-2012.

		SMT			TSP		
Source of Variation	DF	CC	WW	TC	CC	WW	TC
Interseeding Technique (IT)	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Year (Y)	2	<0.0001	0.5902	<0.0001	0.0020	<0.0001	<0.0001
IT x Y	4	<0.0001	0.2626	0.0013	0.0064	<0.0001	<0.0001

Table 3-2b. Source of variation and P-values from PROC GLM procedure on crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass at the 2010, 2011, and 2012 research sites at Andover, SD.

		2010			2011			2012		
Source of Variation	DF	CC	WW	TC	CC	WW	TC	CC	WW	TC
Interseeding Technique (IT)	2	<0.0001	0.2233	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Field Position (FP)	1	0.0002	0.1008	<0.0001	<0.0001	<0.0001	<0.0001	0.1357	0.0112	0.0051
IT x FP	2	0.0248	0.2847	0.0175	<0.0001	<0.0001	<0.0001	0.1096	0.0019	0.0005

and 97% (TSP) of the total cover crop biomass, respectively **(Table 3-3a)**. In 2011, dissimilar to 2010 where crimson clover was the dominant species, the winter wheat biomass at the SMT and TSP sites accounted for 54.7% and 85.7% (SMT) and 86.7% and 84.6% (TSP) of the total cover crop biomass **(Table 3-3a)**. Similar to 2011, in 2012 winter wheat was the dominant cover crop species, with biomass in the DRL treatment accounting for 80% and 76.5% of the total cover crop biomass, respectively **(Table 3-3a)**.

There were several differences noted in the total cover crop and individual cover crop species biomass from 2010 through 2012 at the SMT and TSP sites **(Table 3-3b)**. Crimson clover grew very well at the SMT site in 2010 and averaged 79.4 kg ha^{-1} over all treatments, whereas in 2011 and 2012 at the SMT sites the stands were very poor and had on average 94.4% less crimson clover biomass than 2010. In addition, at the TSP sites in 2010 and 2011, crimson clover grew very well and averaged 20.8 and 15.6 kg ha^{-1} over all treatments, whereas in 2012 stands were poor and had on average 83.8% less crimson clover biomass than 2010 and 2011, respectively **(Table 3-3b)**. Furthermore, the winter wheat biomass was similar across all years and treatments at the SMT sites, whereas, at the TSP sites, the winter wheat grew very well in 2011 and averaged 86.5 kg ha^{-1} over all treatments and had on average 94.3% more winter wheat biomass than 2010 and 2012, respectively **(Table 3-3b)**. In addition, at the SMT and TSP sites, because crimson clover at the 2010 SMT site and winter wheat at the 2011 TSP site made up the majority of the total biomass when averaged over all treatments, the total cover crop biomass showed the same trends **(Table 3-3b)**.

Table 3-3a. Comparisons between the crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass harvested on September 30, 2010, August 22, 2011, and August 22, 2012 in the broadcast (BRD) and drill (DRL) interseeding treatments at Andover, SD.

Interseeding Treatment	2010						2011						2012					
	SMT			TSP			SMT			TSP			SMT			TSP		
	CC	WW	TC	CC	WW	TC	CC	WW	TC	CC	WW	TC	CC	WW	TC	CC	WW	TC
	(kg ha^{-1})						**(kg ha^{-1})**						**(kg ha^{-1})**					
BRD	120.6	8.8	129.4	23	0	22.5	3.9	4.8	8.7	1.6	10.2	11.8	0	0	0	0	0	0
DRL	117.5	30	147.5	40	1.3	41.3	8.8	53	62	45	249.2	294.6	14.4	57.7	72.1	8.8	28.5	37.3
LSD (0.10	NS	NS	NS	NS	NS	NS	3.9	13	13	11	53.9	58.5	3.9	12	14.1	3.3	9.7	8.9

Table 3-3b. Comparisons between the crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass harvested on September 30, 2010, August 22, 2011, and August 22, 2012 averaged over all treatments at the SMT and TSP research sites at Andover.

	SMT			TSP		
Research Site	CC	WW	TC	CC	WW	TC
	(kg ha^{-1})			**(kg ha^{-1})**		
2010	79.4	12.9	92.3	20.8	0.4	21.3
2011	4.2	19.2	23.4	15.6	86.5	102.1
2012	4.8	19.2	24	2.9	9.5	12.4
LSD (0.10)	19.2	NS	22.9	10.6	18	20.9

The DRL treatment, when averaged over all years, produced more biomass by species and total than the BRD treatment, with exceptions to crimson clover at the SMT site **(Table 3-4)**. The cover crop biomass in the DRL treatments were 51% to 90% greater at the SMT sites and 75% to 90% greater at the TSP sites than the BRD treatments. Similar results were noted also at the 2011 and 2012 SMT and TSP research sites when examined individually **(Table 3-3a)**. Furthermore, the SMT sites two out of the three research years had produced more biomass than the TSP sites.

In 2010, at the SMT site, the crimson clover biomass in the interseeding treatments (BRD and DRL) was about 94.6% greater than 2011 and 2012, respectively. In addition, at the TSP site, the crimson clover biomass in the 2010 BRD treatment was approximately 96.4% greater than the BRD treatments in 2011 and 2012, whereas the cover crop biomass in the DRL treatment in 2011 was 12% and 80% greater than 2010 and 2012 DRL treatments, respectively. Winter wheat biomass was similar across all years and interseeding methods at the SMT sites, whereas at the TSP site in 2011, the BRD and DRL treatments had on average 97% more winter wheat biomass than 2010 and 2012.

The total cover crop biomass averaged over the interseeding treatments at the 2010 SMT site had 93.3% and 58.3% more biomass than 2011 and 2012, respectively. Also in 2010, at the TSP site, the BRD and DRL treatments had 48% and 100% more total cover crop biomass than those in 2011 and 2012. In addition, the DRL treatment in 2011 had on average 86.7% more total cover crop biomass than DRL treatments in 2010 and 2012, respectively.

Table 3-4. Comparisons between the crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass harvested on September 30, 2010, August 22, 2011, and August 22, 2012 averaged over all years at the summit (SMT) and toeslope (TSP) research sites at Andover, SD.

	SMT			TSP		
Research Site	CC	WW	TC	CC	WW	TC
	(kg ha^{-1})			**(kg ha^{-1})**		
BRD	41.5	4.5	46	8	3.4	11.4
DRL	46.9	46.8	93.7	31.4	93	124.4
LSD (0.10)	NS	11.7	22.9	8.5	18	20.9

Andover Weed Data.

The grass and broadleaf weed biomass were harvested on September 30, 2010, August 22, 2011, and August 22, 2012. The most prominent grass and broadleaf weed species each year were: yellow foxtail (*Setaria pumila*), green foxtail (*Setaria viridis*), barnyardgrass (*Echninochloa crus-galli*), kochia (*Kochia scoparia*), redroot pigweed (*Amaranthus retroflexus*), common lambsquarters (*Chenopodium album*), and eastern black nightshade (*Solanum ptychanthum*) (2010 only). Differences were noticed in the grass weed, broadleaf weed, and total weed biomass when comparisons were made between each research year **(Table 3-5a)** and when the research years were examined individually **(Table 3-5b)**.

In 2010, at the SMT site, the broadleaf weed biomass in the BRD and DRL treatments accounted for 55.9% and 53.6% of the total weed biomass, whereas at the TSP site, the grass weed biomass in the interseeding treatments accounted for about 98.9% of the total weed biomass **(Table 3-6a)**. Similar to the 2010 TSP site, the grass weed biomass in the BRD and DRL treatments at the SMT and TSP sites in 2011 and 2012 on average accounted for 95.1% of the total weed biomass **(Table 3-6a)**.

There were differences noticed in the total weed and individual weed biotypes biomass from 2010 through 2012 at the SMT and TSP sites **(Table 3-6b)**. In 2010, the SMT and TSP research sites had a high weed infestation by which the grass weed, broadleaf weed, and total weed biomass averaged over all treatments were between 62.2% and 99.6% greater than 2011 and 2012, respectively. Furthermore, when averaged over all years, the BRD and DRL treatments reduced the grass weed biomass at the SMT

Table 3-5a. Source of variation and P-values from PROC GLM procedure on grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010-2012.

		SMT			TSP		
Source of Variation	DF	GW	BW	TW	GW	BW	TW
Interseeding Technique (IT)	2	0.0003	0.5156	0.2375	0.0356	0.2771	0.0307
Year (Y)	2	<0.0001	0.1100	<0.0001	0.0003	0.0732	0.0002
IT x Y	4	0.0003	0.7257	0.4727	0.2756	0.2612	0.2334

Table 3-5b. Source of variation and P-values from PROC GLM procedure on grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass at the 2010, 2011, and 2012 research sites at Andover, SD.

		2010			2011			2012		
Source of Variation	DF	GW	BW	TW	GW	BW	TW	GW	BW	TW
Interseeding Technique (IT)	2	0.0017	0.622	0.0500	0.0403	0.3455	0.3480	0.1068	0.3719	0.1098
Field Position (FP)	1	0.4511	0.1534	0.8495	0.5067	<0.0001	<0.0001	0.9531	0.3200	0.9648
IT x FP	2	0.9594	0.5276	0.9210	0.2242	0.9798	0.8580	0.7782	0.3719	0.7688

Table 3-6a. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass harvested on September 30, 2010, August 22, 2011, and August 22, 2012 in the broadcast (BRD) and drill (DRL) interseeding treatments at Andover, SD.

Interseeding Method	2010						2011						2012					
	SMT			TSP			SMT			TSP			SMT			TSP		
	GW	BW	TW	GW	BW	TW	GW	BW	TW	GW	BW	TW	GW	BW	TW	GW	BW	TW
	(kg ha^{-1})						**(kg ha^{-1})**						**(kg ha^{-1})**					
BRD	160	203	363	261	0	261	54	0	54	190	0	190	13	0	13	40	0	40
DRL	119	138	257	229	5	234	41	19	60	46	1	47	20	0	20	0	0	0
Control	604	10	614	643	18	661	51	0	51	192	0	192	79	0	79	77	0	77
LSD (0.10)	228	NS	NS	392	NS	391	NS	9.2	NS	127	NS	127	NS	NS	NS	59	NS	59

Table 3-6b. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass harvested on September 30, 2010, August 22, 2011, and August 22, 2012 averaged over all treatments at the SMT and TSP research sites at Andover.

Research Site	SMT			TSP		
	GW	BW	TW	GW	BW	TW
	(kg ha^{-1})			**(kg ha^{-1})**		
2010	294.2	116.7	410.9	377.5	7.5	385
2011	48.8	6.3	55.1	142.6	0.2	142.8
2012	37.4	0.4	37.8	39	0	39
LSD (0.10)	81.9	102.4	135.3	136.8	6.1	136.6

and TSP sites by 69% and 75% (SMT) and 46% and 69% (TSP), respectively **(Table 3-7)**. However, although the BRD and DRL treatments influenced the grass weed biomass at the SMT and TSP sites when averaged over all the research years, reductions were only noticed in 2010 (SMT and TSP site) and at the TSP sites in 2011 and 2012 when the research sites were examined individually **(Table 3-6a)**.

Andover Corn Grain Yield Data.

The corn grain was harvested on September 28 to October 1, 2010, October 13 to October 18, 2011, and September 21 to September 23, 2012. There were differences noticed when comparing research years **(Table 3-8a)** and when individually examining each year **(Table 3-8b)**. In 2010, the corn grain yield at the SMT site, averaged over all treatments, was close to 31% and 40% greater than 2011 and 2012, whereas at the TSP site, the 2010 and 2011 corn grain yields were similar and about 43.7% greater than 2012, respectively **(Table 3-9)**. Furthermore, when averaged over all treatments, the grain yield in 2011 and the TSP site was 30% greater than the SMT site, whereas, in 2010, the SMT was 6% greater than the TSP site, respectively. The interseeding methods (BRD and DRL) and the no cover crop (control) treatment were similar across all years **(Table 3-10a and Table 3-10b)**.

Andover Fall Ground Cover Observations.

In mid-October to early-November, observations were made in the fall to see if any of the interseeded cover crops were present. In 2010 and 2011 it was observed that crimson clover and winter wheat both remained in the DRL treatments, with winter wheat being the most prominent. However, there was no growth or regrowth in the BRD

Table 3-7. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass harvested on September 30, 2010, August 22, 2011, and August 22, 2012 averaged over all years in the broadcast (BRD), drill (DRL), and no cover crop (control) treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD.

	SMT			TSP		
Treatments	GW	BW	TW	GW	BW	TW
		(kg ha^{-1})			**(kg ha^{-1})**	
BRD	75.8	45.8	121.6	163.6	0	163.6
DRL	60	74.2	134.2	91.6	1.9	93.5
Control	244.6	3.3	247.9	303.9	5.8	309.7
LSD (0.10)	81.9	NS	NS	136.8	NS	139.6

Table 3-8a. Source of variation and P-values from PROC GLM procedure on corn grain yield (CY) at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010-2012.

		SMT	TSP
Source of Variation	DF	CY	CY
Interseeding Technique (IT)	2	0.6567	0.9722
Year (Y)	2	<0.0001	<0.0001
IT x Y	4	0.5960	0.9209

Table 3-8b. Source of variation and P-values from PROC GLM procedure on corn grain yield (CY) at the 2010, 2011, and 2012 research sites at Andover, SD.

		2010	2011	2012
Source of Variation	DF	CY	CY	CY
Interseeding Technique (IT)	2	0.2604	0.6145	0.8910
Field Position (FP)	1	0.5005	<0.0001	0.0636
IT x FP	2	0.9335	0.6908	0.9380

Table 3-9. Comparisons between the corn grain yield (CY) harvested on September 28 to October 1, 2010, October 13 to October 18, 2011, and September 21 to September 23, 2012 averaged over all treatments at the summit (SMT) and toeslope (TSP) research sites.

	SMT	TSP	
Research Year	CY	CY	LSD (0.10)
	(kg ha^{-1})	**(kg ha^{-1})**	
2010	13185	13404	NS
2011	8980	12850	957
2012	7854	7387	414
LSD (0.10)	766	571	-

Table 3-10a. Comparisons between the corn grain yield (CY) harvested on September 28 to October 1, 2010, October 13 to October 18, 2011, and September 21 to September 23, 2012 in the broadcast (BRD), drill (DRL), and no cover crop (control) treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD.

	SMT	TSP
Research Year	CY	CY
	(kg ha^{-1})	**(kg ha^{-1})**
BRD	9939	11241
DRL	9836	11167
Control	10244	11241
LSD (0.10)	NS	NS

Table 3-10b. Comparisons between the corn grain yield (CY) harvested on September 28 to October 1, 2010, October 13 to October 18, 2011, and September 21 to September 23, 2012 in the broadcast (BRD), drill (DRL), and no cover crop (control) treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD.

	SMT			TSP		
Interseeding Method	2010	2011	2012	2010	2011	2012
	(kg ha^{-1})			**(kg ha^{-1})**		
BRD	13520	8452	7845	13596	12708	7419
DRL	12742	8797	7968	13112	12982	7406
Control	13263	9692	7748	13505	12861	7336
LSD (0.10)	NS	NS	NS	NS	NS	NS

treatments or in the BRD and DRL treatments in 2012. In addition, the inter-row ground cover remaining after corn grain harvest in the DRL treatments were visually estimated to be from 15% to 45% respectively.

Trail City Weather Conditions.

2011 Research Site.

Climate conditions during the 2011 growing season were cooler and wetter than the 30-year averages **(Table 3-11)**. The total annual precipitation was 16% above the 30-year average, whereas the precipitation amount from April through August was approximately 28% above the 30-year average. In April, May, June, and August the precipitation amounts were 37%, 13%, 47%, and 35% above the 30-year averages, respectively. Precipitation in July was 19% below the 30-year average. In April and May, the average temperatures were about 28% and 18% below the 30-year average. In June the average temperature was slightly below the 30-year average, whereas the average temperatures in July and August were slightly greater than the 30-year average, respectively.

2012 Research Site.

The 2012 growing season climate conditions were drier and warmer than the 30-year averages **(Table 3-11)**. Although the total annual (January through December) precipitation was 21% below the 30-year average, the precipitation accumulation from April through August was slightly below the 30-year average. In April, May and July, the precipitation amounts were 47%, 2%, and 7% above the 30-year averages, whereas

Table 3-11. Trail City average monthly temperature and total precipitation amounts and growing degree days (GDD) for 2011 to 2012 and the 30-year average [Data obtained from the NOAA (National Oceanic and Atmospheric Administration) recording station 11.4 km from research sites].

	2011			2012			1980-2010		
Month	**Temp.**	**Precip.**	**GDD**	**Temp.**	**Precip.**	**GDD**	**Temp.**	**Precip.**	**GDD**
	(C°)	**(cm)**	**(C°)**	**(C°)**	**(cm)**	**(C°)**	**(C°)**	**(cm)**	**(C°)**
January	-11.5	2.4	-	-4.1	0.9	-	-7.8	1.1	-
February	-10.4	1.7	-	-4.6	2.3	-	-5.4	1.5	-
March	-4.6	4.3	-	8.4	1.2	-	0.2	2.9	-
April**	5.5	6.8	46.1	9.8	8.1	117.5	7.7	4.3	73.3
May**	11.4	8.3	122.2	14.1	7.4	180.3	13.8	7.2	166.1
June**	18.8	15.7	268.1	20.6	4.7	317.5	18.9	8.4	268.3
July**	24.1	5.4	406.4	25.8	7.5	428.3	22.7	6.7	390.6
August**	22.5	6.7	363.3	21.4	2.3	335.3	22.0	4.3	370.0
September	16.2	1.0	221.9	16.8	0.1	251.4	16.2	3.7	213.9
October	10.6	2.4	128.3	7.4	0.8	80.3	8.5	4.0	81.7
November	0.8	0.0	-	0.3	1.0	-	-0.2	1.5	-
December	-3.3	0.6	-	-6.5	0.9	-	-6.8	1.2	-

**Significant growing season months.

June and August were 45% and 47% below the 30-year averages, respectively. From April through August, the average temperatures ranged from slight to 37% above the 30-year averages.

Trail City Research Site Weather Condition Comparisons.

The 2011 growing season was wetter and cooler than 2012. In 2011, the precipitation accumulation during the growing season (April through August) was 31% greater than 2012. In addition, the average temperature during the 2011 growing season was 10% cooler than 2012.

Trail City Cover Crop Data.

The cover crop mixture was interseeded into standing corn at the V5 growth stage 45 (2011) and 24 (2012) DACP into dry soil conditions. Precipitation amounts 14 days prior-to and after the cover crop interseeding dates were approximately 13 and 1.9 cm (2011) and 4.6 and 1.4 cm (2012). In 2011, all three cover crop species had emerged at the V12 corn growth stage in both the BRD and DRL treatments, whereas, in 2012 no cover crop species had emerged in the interseeding treatments. Therefore, only cover crop data from 2011 will be discussed.

When the cover crop biomass was harvested on September 14, 2011 (76 DAI), only crimson clover and winter wheat were present. There were several differences noticed in the total and individual cover crop species when comparisons were made between sites **(Table 3-12a)**. In addition, there were also differences noticed in the interseeding methods (BRD vs DRL).

Table 3-12a. Source of variation and P-values from PROC GLM procedure on crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass at Trail City, SD in 2011.

Source of Variation	Cover Crop		
	CC	WW	TC
Interseeding Technique (IT)	<0.0001	<0.0001	<0.0001
Field Position (FP)	<0.0001	0.9967	<0.0001
IT x FP	0.0002	1.0000	0.0002

Table 3-12b. Comparisons between the crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass harvested on September 14, 2011 in the broadcast (BRD) and drill (DRL) interseeding methods at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD.

Interseeding Methods	SMT			TSP		
	CC	WW	TC	CC	WW	TC
	(kg ha^{-1})			**(kg ha^{-1})**		
BRD	1.2	0	1.2	118.6	0	118.6
DRL	26.9	15.5	42.4	306.6	15.4	322.1
LSD (0.10)	19.8	5.2	17.9	105.6	11.3	107.8

In 2011, at the SMT and TSP research sites, the crimson clover biomass in the BRD and DRL treatments accounted for 100% and 63.4% (SMT) and 100% and 95.2% (TSP) of the total cover crop biomass, respectively **(Table 3-12b)**. Furthermore, there were differences noticed in the interseeding methods (BRD vs DRL) in the total cover crop and individual cover crop species biomass. When averaged over the SMT and TSP sites, the DRL treatment had about 64%, 100%, and 67% greater crimson clover, winter wheat, and total cover crop biomass than the BRD treatment.

The crimson clover grew very well in the BRD and DRL treatments at the TSP site, and was on average 95% greater than the SMT site. Because crimson clover made up the majority of the total biomass in the BRD and DRL treatments at the TSP site, the total cover crop biomass showed the same trends. In addition, the winter wheat biomass in the interseeding treatments at the SMT and TSP sites were similar.

Trail City Weed Data.

The grass and broadleaf weed biomass were harvested on September 30, 2011. The most prominent grass and broadleaf weed species were: yellow and green foxtail, barnyardgrass, kochia, redroot pigweed, common lambsquarters, and turnips *(Brassica rapa rapa*) (TSP site only). The turnips at the TSP site were regrowth from the fall cover crop mixture that was drill seeded immediately after wheat harvest in 2010. Differences were noticed in the interseeding method (BRD vs DRL) and field position (SMT vs TSP) **(Table 3-13a)**.

In 2011, at the SMT site, the broadleaf weed biomass in the BRD and DRL treatments accounted for 74.3% and 95.5% of the total weed biomass. Similar to the

Table 3-13a. Source of variation and P-values from PROC GLM procedure on grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass at Trail City, SD in 2011.

		Weed Biomass		
Source of Variation	DF	GW	BW	TW
Interseeding Technique (IT)	2	0.0403	0.3455	0.3480
Field Position (FP)	1	0.5067	<0.0001	<0.0001
IT x FP	2	0.2242	0.9798	0.8580

Table 3-13b. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass harvested on September 14, 2011 in the broadcast (BRD) and drill (DRL) interseeding methods and the no cover crop (control) treatments at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD.

	SMT			TSP		
Treatment	GW	BW	TW	GW	BW	TW
	(kg ha^{-1})			**(kg ha^{-1})**		
BRD	33.5	97	130.5	9.5	265.7	275.2
DRL	2.3	49.1	51.4	27.4	202.9	230.3
Control	41.5	51.9	93.4	67.1	265.7	332.8
LSD (0.10)	NS	44.6	60.3	38.5	NS	NS

SMT site, the broadleaf weed biomass in the interseeding treatments at the TSP site accounted for on average 92.3% of the total weed biomass, respectively **(Table 3-13b)**. Furthermore, when averaged over all treatments, the TSP site had close to 71.2% more broadleaf weed biomass than the SMT site, whereas the grass weed biomass were similar between sites **(Table 3-14a**). In addition, because the broadleaf weed biomass made up the majority of the total weed biomass at the TSP and SMT sites, total weed biomass followed the same trends.

When averaged over the SMT and TSP sites, the BRD and DRL treatments had an influence on the grass weed biomass **(Table 3-14b**). In the control (no interseeded cover crop) the grass weed biomass averaged 54.3 kg ha^{-1} over all treatments which was 60.4% and 72.6% greater than the BRD and DRL treatments, respectively. However, although the interseeding methods had reduced the grass weed biomass when averaged over both sites (SMT and TSP), the reduction in grass weed biomass was only noticed at the TSP site **(Table 3-13b)**.

Trail City Corn Yield Data.

The corn grain was harvested on October 5 to October 6, 2011. Differences were noticed between the research sites and interseeding methods **(Table 3-15a)**. The corn grain yield at the TSP site was 42.4% greater than the SMT site when averaged over all treatments **(Table 3-15b)**. In addition, when averaged over the SMT and TSP sites, the corn grain yield in the BRD and DRL treatments were similar to the control **(Table 3-16a)**. In addition, when the sites were individually examined, the corn grain yield in the BRD and DRL treatments were similar to the control **(Table 3-16b)**.

Table 3-14a. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass harvested on September 14, 2011 averaged over all treatments at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD.

Field Position	GW	BW	TW
		(kg ha^{-1})	
SMT	25.8	66	91.8
TSP	34.7	229.2	263.9
LSD (0.10)	NS	54.8	60.7

Table 3-14b. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass harvested on September 14, 2011 at the summit (SMT) and toeslope (TSP) research sites averaged over the broadcast (BRD), drill (DRL), and control (no cover crop) treatments at Trail City, SD.

Treatment	GW	BW	TW
		(kg ha^{-1})	
BRD	21.5	181.4	202.9
DRL	14.9	126	140.9
Control	54.3	135.5	189.8
LSD (0.10)	27.2	NS	NS

Table 3-15a. Source of variation and P-values from PROC GLM procedure on corn grain yield (CY) at Trail City, SD in 2011.

Source of Variation	DF	CY
Interseeding Technique (IT)	1	0.1543
Field Position (FP)	2	<0.0001
IT x FP	2	0.4353

Table 3-15b. Comparisons between the corn grain yields harvested on October 5 to October 6, 2011 averaged over all treatments at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD.

Research Site	CY
	(kg ha^{-1})
SMT	5464.8
TSP	9483.7
LSD (0.10)	524.5

Table 3-16a. Comparisons between the corn grain yield (CY) harvested on October 5 to October 6, 2011 averaged over the broadcast (BRD), drill (DRL), and no cover crop (control) treatments from the summit (SMT) and toeslope (TSP) research sites at Trail City, SD.

Treatment	CY
	(kg ha^{-1})
BRD	7774.3
DRL	7598.1
Control	7050.3
LSD (0.10)	NS

Table 3-16b. Comparisons between the corn grain yield (CY) harvested on October 5 to October 6, 2011 in the broadcast (BRD), drill (DRL), and no cover crop (control) treatments at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD.

	SMT	TSP
Research Year	CY	CY
	(kg ha^{-1})	**(kg ha^{-1})**
BRD	5760.8	9787.9
DRL	5346.6	9849.6
Control	5287	8813.6
LSD (0.10)	NS	NS

Trail City Fall Ground Cover Observations.

In mid-October to early-November, observations were made in the fall to see if any of the interseeded cover crops were present. In 2011, at both the SMT and TSP research sites, it was visually observed that none of the interseeding cover crops were present in the BRD or DRL treatments.

Aurora Weather Conditions.

2011 Research Site.

Climate conditions during the 2011 growing season (April through August) was wetter and warmer than the 30-year averages **(Table 3-17)**. Although the annual (January through December) precipitation was slightly below the 30-year average, the precipitation accumulation from April through August was about 19% above the 30-year average. The precipitation accumulations in April and May were 19% and 52% above the 30-year averages, whereas, in June and July, the precipitation amounts were about 7% below and 33% above the 30-year averages. Precipitation in August was 51% below the 30-year average. In April, May, and June the average temperature ranged from slight to 16% below the 30-year averages. In July and August, the average temperature ranged from slight to 13% above the 30-year averages, respectively.

2012 Research Site.

The 2012 growing season (April through August) climate conditions were drier and warmer than the 30-year averages **(Table 3-17)**. The total annual precipitation was 18% below the 30-year average, whereas, from April through August it was slightly

Table 3-17. Aurora average monthly temperature and total precipitation amounts and growing degree days (GDD) for 2009 to 2012 and the 30-year average [Data obtained from the NOAA (National Oceanic and Atmospheric Administration) recording station 7.2 km from research sites].

	2011			2012			1980-2010		
Month	**Temp.**	**Precip.**	**GDD**	**Temp.**	**Precip.**	**GDD**	**Temp.**	**Precip.**	**GDD**
	(C°)	**(cm)**	**(C°)**	**(C°)**	**(cm)**	**(C°)**	**(C°)**	**(cm)**	**(C°)**
January	-13.9	3.4	-	-6.4	1.3	-	-10.6	0.9	-
February	-11.0	2.6	-	-4.8	1.6	-	-7.8	1.0	-
March	-4.2	2.1	-	6.5	1.4	-	-1.1	2.9	-
April**	5.6	6.7	34.4	9.2	7.0	92.2	6.7	5.4	47.2
May**	12.5	15.7	136.4	15.4	17.6	191.1	13.4	7.5	147.8
June**	18.5	10.1	254.2	20.5	4.0	317.2	18.7	10.9	261.9
July**	24.4	12.4	431.1	25.1	3.6	439.4	21.3	8.3	351.1
August**	20.5	3.9	321.7	19.8	6.3	303.6	20.1	7.8	314.7
September	14.4	0.4	189.4	15.3	0.2	215.3	15.0	8.1	181.1
October	10.2	1.3	131.7	6.2	2.7	66.9	7.6	5.2	66.9
November	0.8	0.3	-	0.5	0.9	-	-0.7	2.4	-
December	-3.8	0.6	-	-7.7	4.2	-	-8.5	1.2	-

**Significant growing season months

below the 30-year average. In April and May, the precipitation amounts were 23% and 57% above the 30-year averages, respectively. In June through August, the precipitation accumulations were approximately 63%, 57%, and 19% below the 30-year averages. In April through July, the average temperatures were 28%, 13%, 9%, and 15% above the 30-year averages, respectively. In August, the average temperature was slightly below the 30-year average.

Aurora Weather Condition Comparisons.

In 2011, the annual precipitation amount was approximately 15% greater than 2012. In addition, the precipitation accumulation from April through August in 2011 was 49 cm which was 21% greater than 2012, respectively. Furthermore, the average temperature from April through August in 2012 was approximately 9% greater than 2011.

Aurora Cover Crop Data.

The cover crop mixture was interseeded into standing corn at the V3 and V5 corn growth stages 30 and 47 DACP (2011) and 24 and 34 DACP (2012) into dry soil conditions. Precipitation amounts 14-days prior-to and after the cover crop V3 interseeding dates were about 10.8 and 2.1 cm (2011) and 5 and 3.9 cm (2012), whereas the after the V5 interseeding dates the precipitation amounts were 2.1 and 10.7 cm (2011) and zero and 4 cm (2012), respectively. In 2011, all three cover crop species had emerged 53 (V3) and 36 (V5) DAI in both the BRD and DRL treatments. In 2012, all three cover crop species had emerged 18 (V3) and 8 (V5) DAI in the DRL treatment only. The broadcast seed was seen to have washed into alleyways due to a 4 cm downpour, which some seeds germinated, but where killed due to severely dry topsoil conditions.

When the cover crop biomass were harvested on September 22, 2011 [111 (V3) and 94 (V5) DAI] and August 29, 2012 [81 (V3) and 71 (V5) DAI] only crimson clover and winter wheat were present. There were differences noticed in the crimson clover biomass, winter wheat biomass, and total cover crop biomass when comparisons were made between the 2011 and 2012 research years. In addition, differences were noticed in the total and individual cover crop species when the research years were examined individually **(Table 3-18a)**.

In 2011, the crimson clover biomass accounted for on average 94% of the total cover crop in both BRD treatments the DRL V3 treatment (all were lower than the seeding rate), whereas, winter wheat accounted for 89% of the total biomass in the DRL V5 treatment, respectively. In 2012, the winter wheat biomass accounted for approximately 52% and 76% of the total biomass in the DRL V3 and V5 treatments **(Table 3-18b)**. Furthermore, when the total and individual cover crop species biomass in the interseeding treatments were averaged over both years, the crimson clover and total biomass in 2012 were 73.3% and 54.1% greater than 2011, respectively **(Table 3-19a)**.

At Aurora, the DRL treatments always resulted in a greater cover crop biomass than the BRD treatments when averaged over both years **(Table 3-19b)**. In 2011, the BRD V3 and BRD V5 treatments had 100% more crimson clover biomass than 2012, whereas the crimson clover biomass in the DRL V3 and DRL V5 treatments were 96.3 % and 66.5% greater in 2012 than 2011, respectively. The crimson clover biomass

Table 3-18a. Source of variation and P-values from PROC GLM procedure on crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass at Aurora, SD from 2011 to 2012.

Source of Variation	CC	WW	TC
Interseeding Technique (IT)	<0.0001	<0.0001	<0.0001
Year (Y)	<0.0001	0.2196	0.0204
IT x Y	<0.0001	0.4264	0.0059

Table 3-18b. Comparisons between the crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass harvested on September 22, 2011 and August 29, 2012 in the broadcast (BRD) and drill (DRL) interseeding methods at Aurora, SD.

	2011			2012		
Treatment	CC	WW	TC	CC	WW	TC
	(kg ha^{-1})			**(kg ha^{-1})**		
BRD V3	4.1	0.4	4.5	0	0	0
BRD V5	1.2	0.1	1.3	0	0	0
DRL V3	1	0	1	27.1	28.8	55.9
DRL V5	5.4	44.5	49.8	16.1	51.4	67.5
LSD (0.10)	3	NS	20.3	2.8	NS	21

Table 3-19a. Comparisons between the crimson clover (CC), winter wheat (WW), and total cover crop biomass (TC) harvested on September 22, 2011 and August 29, 2012 averaged over the interseeding treatments at Aurora, SD from 2011 to 2012.

Research Year	CC	WW	TC
	(kg ha^{-1})		
2011	2.3	9	11.3
2012	8.6	16	24.6
LSD (0.10	1.3	NS	9.4

Table 3-19b. Comparisons between the crimson clover (CC), winter wheat (WW), and total cover crop (TC) biomass harvested on September 22, 2011 and August 29, 2012 averaged in the broadcast (BRD) and drill (DRL) interseeding treatments at Aurora, SD.

Treatment	CC	WW	TC
	(kg ha^{-1})		
BRD V3	1.8	0.2	2
BRD V5	0.5	0.1	0.6
DRL V3	15.9	16.5	32.4
DRL V5	11.5	48.4	59.9
LSD (0.10)	2.1	14.8	14.7

accumulated in the 2011 BRD V3 and BRD V5 treatments, however, was greater than 2012, but were below the initial seeding rate. Similar results were noticed in the total cover crop biomass accumulations in both the BRD and DRL V3 and V5, treatments. In addition, the winter wheat biomass was similar between treatments and years.

Aurora Weed Data.

The grass and broadleaf weed biomass were harvested on September 22, 2011 and August 29, 2012. The most prominent grass and broadleaf weed species were: yellow foxtail, green foxtail, barnyardgrass, kochia, redroot pigweed, common lambsquarters, and soybeans (*Glycine max*) (2011 only). There were differences noticed in the total and grass weed biomass when comparisons were made between research years and when examined individually **(Table 3-20a)**.

In 2011, the grass weed biomass in the BRD and DRL V3 and V5 treatment accounted for approximately 66.3% (BRD V3), 90.9% (BRD V5), 91.1% (DRL V3), and 49.9% (DRL V5) of the total weed biomass **(Table 3-20b)**. In 2012, the grass weed biomass made up 100% of the total weed biomass in all treatments. Furthermore, in 2012, the grass weed and total weed biomass were 50% and 38.5% greater than 2011, whereas the broadleaf biomass was 100% greater in 2011 than 2012 **(Table 3-21a)**.

The interseeding methods all had a reduced grass weed and total weed biomass when averaged over both years when compared to the control **(Table 3-21b)**. For instance, the BRD treatments had reduced grass weed biomass by 49.1% (BRD V3) and 47.7% (BRD V5), whereas the DRL treatments had reduced it by 76.3% (DRL V3) and 75.2% (DRL V5), respectively. Because the grass weed biomass accounted for the

Table 3-20a. Source of variation and P-values from PROC GLM procedure on grass weed (GW), broadleaf weed (BW), and weed (TW) biomass at Aurora, SD from 2011 to 2012.

Source of Variation	DF	GW	BW	TW
Interseeding Technique (IT)	4	<0.0001	0.4156	<0.0001
Year (Y)	1	0.0002	0.0004	0.0045
IT x Y	4	<0.0001	0.2661	<0.0001

Table 3-20b. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass harvested on September 22, 2011 and August 29, 2012 in the broadcast (BRD) and drill (DRL) interseeding methods at Aurora, SD.

	2011			2012		
Treatment	GW	BW	TW	GW	BW	TW
	(kg ha^{-1})			**(kg ha^{-1})**		
BRD V3	66.8	33.9	100.7	208.3	0	208.3
BRD V5	203.9	20.5	224.4	111.9	0	111.9
DRL V3	62.6	6.1	68.7	73	0	73
DRL V5	38.5	38.7	77.2	96.9	0	96.9
Control	92.1	7.3	99.4	438.1	0	438.1
LSD (0.10)	56.6	NS	69.2	100.1	NS	100.1

Table 3-21a. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed biomass (TW) harvested on September 22, 2011 and August 29, 2012 averaged over the interseeding treatments at Aurora, SD.

Research Year	GW	BW	TW
	(kg ha^{-1})		
2011	92.8	21.3	114.1
2012	185.6	0	185.6
LSD (0.10	39.6	9.6	41

Table 3-21b. Comparisons between the grass weed (GW), broadleaf weed (BW), and total weed (TW) biomass harvested on September 22, 2011 and August 29, 2012 averaged in the broadcast (BRD) and drill (DRL) interseeding treatments at Aurora, SD.

Treatment	GW	BW	TW
	(kg ha^{-1})		
BRD V3	147.6	15.5	162.1
BRD V5	151.3	8.8	160.1
DRL V3	68.6	2.6	71.2
DRL V5	71.8	16.6	88.4
Control	289.8	3.1	292.9
LSD (0.10)	62	NS	64.2

majority of the weed biomass, the total weed biomass had the same trend. Furthermore, when comparing the interseeding methods between years, in 2011, the BRD V3, DRL V3 and V5 all had grass weed and total weed than 2012.

Aurora Corn Grain Yield.

The corn grain yield was harvested on September 29, 2011 and October 17, 2012. There were differences noticed when comparing research years and within the interseeding treatments **(Table 3-22a)**. In 2012, the corn grain yield was 6.1% greater than 2011, respectively **(Table 3-22b)**. Furthermore, when averaged over both years, the interseeding treatments had no impacts on corn grain yield, with exceptions to the DRL V3 treatment **(Table 3-23a)**. The corn grain yield in the DRL V3 treatment had close to 10.2% and 8% less corn grain yield than the BRD V3 and the no cover crop control. However, when examining the years individually, the interseeding methods were similar to the control, with the only difference being between the DRL V3 and BRD V3 treatments in 2012 **(Table 3-23b)**.

Aurora Fall Ground Cover Observations.

In mid-October to early-November, observations were made in the fall to see if any of the interseeded cover crops were present. In 2011 and 2012, it was observed that no cover crops had regrown or emerged in either of the interseeding treatments. Therefore, there was no ground cover provided by the interseeded cover crops.

Table 3-22a. Source of variation and P-values from PROC GLM procedure on corn grain yield (CY) at Aurora, SD from 2011 to 2012.

Source of Variation	DF	CY
Interseeding Technique (IT)	4	0.0589
Year (Y)	1	0.0167
IT x Y	4	0.9026

Table 3-22b. Comparisons between the corn grain yields harvested on September 29, 2011 and October 17, 2012 averaged over all treatments at Aurora, SD.

Research Site	CY
	(kg ha^{-1})
2011	9050.2
2012	9633.2
LSD (0.10)	398.1

Table 3-23a. Comparisons between the corn grain yield (CY) harvested on September 29, 2011 and October 17, 2012 averaged over the broadcast (BRD), drill (DRL), and no cover crop (control) treatments at Aurora, SD.

Treatment	CY
	(kg ha^{-1})
BRD V3	9875.1
BRD V5	9235.6
DRL V3	8870
DRL V5	9083.8
Control	9643.9
LSD (0.10)	629.5

Table 3-23b. Comparisons between the corn grain yield (CY) harvested on September 29, 2011 and October 17, 2012 in the broadcast (BRD), drill (DRL), and no cover crop (control) treatments at Aurora, SD.

	2011	2012
Treatment	CY	CY
	(kg ha^{-1})	**(kg ha^{-1})**
BRD V3	9231.6	10266.2
BRD V5	8989.6	9381.9
DRL V3	8809.7	9073.8
DRL V5	8936.4	9559.2
Control	9333.7	9885
LSD (0.10)	NS	927.8

Andover, Trail City, and Aurora Research Site Comparisons.

Cover Crop Biomass.

At Trail City, the crimson clover biomass in the BRD and DRL treatments was 21.4 and 49.9 times greater (BRD) and about 83.8% and 96.8% more than at Andover and Aurora, respectively. However, the winter wheat biomass in the BRD and DRL treatments at Andover were greater, averaging about 100% and 98.7% greater in the BRD and about 9.7 and 3.4 times greater in the DRL than Trail City and Aurora. Similar to the crimson clover biomass, at Trail City, the BRD and DRL treatments averaged about 5.9 and 46.1 times greater in the BRD and 1.1 and 3.7 times greater in the DRL total cover crop biomass than Andover and Aurora, respectively. In addition, at all three locations, the DRL interseeding treatments always had a greater total and individual species biomass than the BRD.

Weed Biomass

Grass weeds were the most prolific weed species at all three research sites. The BRD and DRL interseeding methods reduced the grass weed biomass at all three locations. However, due to limited cover crop growth in the BRD treatments and the inconsistency of the grass weed reductions in the DRL treatments, the reductions in grass weed biomass were inconsistent. Furthermore, reductions were noticed in the total weed biomass, however this is a direct result grass weed biomass accounting for the majority of the total weed biomass. In addition, the interseeding methods had no influence on broadleaf weed biomass at either location.

Corn Grain Yield.

At the three locations, the BRD and DRL treatments did not impact the corn grain yield, with exceptions to the DRL V3 treatment at Aurora in 2012. This reduction could have been a result of the early planting or the high cover crop growth which may have directly competed with corn for critical limited nutrients. This is feasible since there was no yield reduction in 2011, which had a total cover crop biomass of about 1 kg ha^{-1}.

Fall Ground Cover Observations.

At the research locations, cover crops were only noticed at Andover in 2010, 2011, and 2012 in the DRL treatments, which had an inter-row ground cover ranging from 10 to 30%. This is most likely to the increased precipitation amounts that the Andover research sites had received after the corn grain harvest.

DISCUSSION

The results from these experiments indicated that the establishment of interseeded cover crops into standing corn at the V5 corn growth stage and the response of corn and weeds to the broadcast and drill interseeded cover crops varied from location to location and year to year. The outcomes indicated that cover crops can at times be established into standing corn, provide a limited suppression of late-emerging grass weeds, and provide ground cover in the fall. However, they may be difficult to establish due to growing season weather conditions, interseeding method, field position, and pre-emergence corn herbicide choice.

In this experiment, the cover crop mixture [crimson clover (*Trifolium incarnatum*), winter wheat (*Triticum aestivum*), and lentil (*Lens culinaris*)] was drill and broadcast interseeded into standing corn at the V5 corn growth stage. All cover crop species emerged but at the end of the growing season only crimson clover and winter wheat remained. The early desiccation and disappearance of lentil may be due to the lentil being very sensitive to competition from seedling establishment to early flowering stage (Fesehaie, 1994; Oplinger et al., 1990). For instance, Rahman et al. (2009) reported that lentil growth was reduced by 28% up to 46% when lentil was intercropped compared to sole cropping.

Drilling seeds always resulted in greater total cover crop biomass (104.4 kg ha^{-1}) which was 76.5% great biomass in the broadcast treatment. The lower level of cover crop biomass in the broadcast interseeding treatment may be due to less than uniform seed distribution, poor seed-to-soil contact and seeding depth, and the below adequate available moisture required by the broadcasted cover crops seeds for rapid germination and emergence (Jasa, 2011). In addition, the greater total cover crop establishment in the drill treatments led to fall ground covers ranging from 15% to 55%, while there was zero in the broadcast treatments. Furthermore, the total cover crop biomass on the toeslope field positions averaged 70.7 kg ha^{-1} over all research sites and was about 45.5% greater than the summit field positions. This may be a result of the toeslope position having more or maintaining a greater moisture content level. For instance, Hanna et al. (1982) reported that the toeslope position contained on average 4 cm more of available water when compared to the summit position.

In this experiment, the broadcast and drill interseeded cover crops had no impact on the broadleaf weed biomass since very little broadleaf weeds were present throughout the growing seasons at each experimental location, but did impact the grass weed biomass. The drill treatment averaged over all research sites had approximately 38.2% less grass weed biomass than the broadcast treatment. In addition, reductions in the grass weed biomass ranging from 64% to 100% were observed in the drilled cover crops when compared to the control. Similar results were noticed by Buhler et al. (1990) who reported that caliph medic (*Medicago truncatula*), santiago medic (*Medicago polymorpha*), sava medic (*Medicago scutellata*), berseem clover (*Trifolium alexandrinum*), and yellow mustard (*Brasicca compestriss*) interseeded and incorporated directly after corn and soybean planting had suppressed weeds from 19% to 90%. Also, Carruthers et al. (1997) reported that annual ryegrass (*Lolium multiflorum*), perennial ryegrass (*Lolium perenne*), and red clover (*Trifolium pratense*) interseeded after corn planting had reduced the dicot weed density and biomass between corn rows by 73% to

100% when compared to the weedy control. The reductions noticed by the drill interseeded cover crops and not the broadcast interseeded cover crops may be due to the increased vegetation cover in the drill treatment which may have had the ability to out compete and reduce the amount of photosynthetically active radiation absorbed by the grass weeds.

The drill and broadcast interseeded cover crops had no impacts on corn grain yield throughout the experiment. This is in agreement with Abdin et al. (1998), who reported no effects on corn grain yield due to interseeded cover crops of fall rye (*Secale cereal* L.), hairy vetch (*Vicia villosa*), a mixture of red clover (*Trifolium pratense* L.) and ryegrass (*Lolium multiflorum*), a mixture of white clover (*Trifolium repens* L.) and ryegrass, subterranean clover (*Trifolium subterraneum* L.), yellow sweetclover (*Mililotus officinalis*), black medic (*Medicago lupulina* L.), Persian clover (*Trifolium resupinatum* L.), strawberry clover (*Trifolium fragiferum* L.), alfalfa (*Medicago sativa* L.), and berseem clover (*Trifolium alexandrinum* L.) into standing corn when corn was approximately 11 and 30 cm tall. Similar results were observed by Wall et al. (1991), who reported that red clover did not reduce corn yields when drill interseeded into standing corn at the vegetative four-leaf (V4) corn growth stage, respectively. However, the cover crops drill interseeded at the V3 corn growth stage did reduce corn yield one out of two years. This could be a result of greater weed biomass or direct competition with corn for the critical limited soil nutrients and moisture, and photosynthetically active radiation.

Therefore, the results from this experiment shows that a drilled and broadcast cover crop into standing corn at the V5 corn growth stage is feasible, can provide ground cover, and suppress late-emerging grass weeds without adversely impacting corn grain yield. However, to become an agronomically viable alternative cropping system, further research will have to be conducted to identify cover crop genotypes that are less susceptible to competition when interseeded as a mixture, more resistant to drought, and have a greater shade tolerance. Also, further research needs to be conducted to identify if a cover crop genotype is interseeded as a monoculture (e.g. not as a mixture) would establish better, provide greater ground cover, and be present after the corn growing season. In addition, further research into interseeded stages and techniques should be examined to identify the best corn growth stages and ease of interseeding that would provide the greatest cover crop biomass without negatively impacting corn grain yield.

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APPENDIX

Table 3-3a PROC GLM Procedure for the crimson clover, winter wheat, and total cover crop biomass in the broadcast and drill treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010 to 2012.

2010 Andover SMT Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	151287	75643	7.88	0.0012
Error	45	432145	9603		
Corrected Total	47	583433			

2010 Andover SMT Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	7616	3808	1.4	0.257
Error	45	122375	2719		
Corrected Total	47	129991			

2010 Andover SMT Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	207054	103527	8.09	0.001
Error	45	576105	12802		
Corrected Total	47	783159			

2010 Andover TSP Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	12866	6433	4.26	0.0202
Error	45	67900	1508		
Corrected Total	47	80766			

2010 Andover TSP Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	16	8	1	0.3759
Error	45	375	8		
Corrected Total	47	391			

2010 Andover TSP Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	13650	6825	4.55	0.0158
Error	45	67475	1499		
Corrected Total	47	81125			

Table 3-3a continued

2011 Andover SMT Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	618	309	7.31	0.0018
Error	45	1903	42		
Corrected Total	47	2521			

2011 Andover SMT Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	27208	13604	30.92	<.0001
Error	45	19798	439		
Corrected Total	47	47007			

2011 Andover SMT Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	35434	17717	38.71	<.0001
Error	45	20597	457		
Corrected Total	47	56032			

2011 Andover TSP Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	21219	10609	30.48	<.0001
Error	45	15663	348		
Corrected Total	47	36883			

2011 Andover TSP Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	636399	318199	38.57	<.0001
Error	45	371289	8250		
Corrected Total	47	1007689			

2011 Andover TSP Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	890028	445014	45.85	<.0001
Error	45	436769	9705		
Corrected Total	47	1326798			

Table 3-3a continued

2012 Andover SMT Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2215	1107	24.68	<.0001
Error	45	2019	44		
Corrected Total	47	4235			

2012 Andover SMT Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	35512	17756	42.91	<.0001
Error	45	18622	413		
Corrected Total	47	54135			

2012 Andover SMT Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	55468	27734	49.51	<.0001
Error	45	25205	560		
Corrected Total	47	80674			

2012 Andover TSP Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	812	406	12.99	<.0001
Error	45	1405	31		
Corrected Total	47	2217			

2012 Andover TSP Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	8648	4324	16.3	<.0001
Error	45	11940	265		
Corrected Total	47	20589			

2012 Andover TSP Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	14760	7380	32.3	<.0001
Error	45	10282	228		
Corrected Total	47	25043			

Table 3-3b PROC GLM Procedure for crimson clover, winter wheat, and total cover crop biomass averaged over all treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010 to 2012.

SMT Crimson Clover Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	63233	31616	9.79	0.0001
Research Year	2	179308	89654	27.76	<.0001
CvrCrpTrt*Research Year	4	90887	22721	7.03	<.0001

SMT Winter Wheat Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	64008	32004	26.87	<.0001
Research Year	2	1261	630	0.53	0.5902
CvrCrpTrt*Research Year	4	6329	1582	1.33	0.2626

SMT Total Cover Crop Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	210734	105367	22.87	<.0001
Research Year	2	150500	75250	16.33	<.0001
CvrCrpTrt*Research Year	4	87223	21805	4.73	0.0013

TSP Crimson Clover Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	25484	12742	20.24	<.0001
Research Year	2	8166	4083	6.49	0.002
CvrCrpTrt*Research Year	4	9413	2353	3.74	0.0064

TSP Winter Wheat Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	266872	133436	46.96	<.0001
Research Year	2	214528	107264	37.75	<.0001
CvrCrpTrt*Research Year	4	378192	94548	33.27	<.0001

TSP Total Cover Crop Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	453442	226721	59.49	<.0001
Research Year	2	234555	117277	30.77	<.0001
CvrCrpTrt*Research Year	4	464997	116249	30.5	<.0001

Table 3-4 PROC GLM Procedure for crimson clover, winter wheat, and total cover crop biomass averaged over all years in the broadcast and drill treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010 to 2012.

SMT Crimson Clover Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	63233	31616	9.79	0.0001
Research Year	2	179308	89654	27.76	<.0001
CvrCrpTrt*Research Year	4	90887	22721	7.03	<.0001

SMT Winter Wheat Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	64008	32004	26.87	<.0001
Research Year	2	1261	630	0.53	0.5902
CvrCrpTrt*Research Year	4	6329	1582	1.33	0.2626

SMT Total Cover Crop Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	210734	105367	22.87	<.0001
Research Year	2	150500	75250	16.33	<.0001
CvrCrpTrt*Research Year	4	87223	21805	4.73	0.0013

TSP Crimson Clover Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	25484	12742	20.24	<.0001
Research Year	2	8166	4083	6.49	0.002
CvrCrpTrt*Research Year	4	9413	2353	3.74	0.0064

TSP Winter Wheat Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	266872	133436	46.96	<.0001
Research Year	2	214528	107264	37.75	<.0001
CvrCrpTrt*Research Year	4	378192	94548	33.27	<.0001

TSP Total Cover Crop Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	453442	226721	59.49	<.0001
Research Year	2	234555	117277	30.77	<.0001
CvrCrpTrt*Research Year	4	464997	116249	30.5	<.0001

Table 3-6a PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass in the broadcast, drill, and control treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010 to 2012.

2010 Andover SMT Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2313816	1156908	7.87	0.0012
Error	45	6614150	146981		
Corrected Total	47	8927966			

2010 Andover SMT Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	306866	153433	0.56	0.5763
Error	45	12374200	274982		
Corrected Total	47	12681066			

2010 Andover SMT Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	992716	496358	1.1	0.3413
Error	45	20287250	450827		
Corrected Total	47	21279966			

2010 Andover TSP Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1693850	846925	1.95	0.1545
Error	45	19575450	435010		
Corrected Total	47	21269300			

2010 Andover TSP Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2600	1300	1.32	0.2771
Error	45	44300	984		
Corrected Total	47	46900			

2010 Andover TSP Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1821050	910525	2.1	0.1346
Error	45	19535350	434118		
Corrected Total	47	21356400			

Table 3-6a continued

2011 Andover SMT Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1526	763	0.19	0.8248
Error	45	177638	3947		
Corrected Total	47	179165			

2011 Andover SMT Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3820	1910	8	0.0011
Error	45	10738	238		
Corrected Total	47	14558			

2011 Andover SMT Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	608	304	0.07	0.9307
Error	45	190167	4225		
Corrected Total	47	190775			

2011 Andover TSP Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	223612	111806	2.43	0.0992
Error	45	2067886	45953		
Corrected Total	47	2291499			

2011 Andover TSP Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3	2	1	0.3759
Error	45	86	2		
Corrected Total	47	90			

2011 Andover TSP Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	221763	110881	2.41	0.1011
Error	45	2068395	45964		
Corrected Total	47	2290158			

Table 3-6a continued

2012 Andover SMT Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	41461	20730	0.82	0.4455
Error	45	1133095	25179		
Corrected Total	47	1174556			

2012 Andover SMT Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0	0	.	.
Error	45	0	0		
Corrected Total	47	0			

2012 Andover SMT Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	40819	20409	0.81	0.4509
Error	45	1132661	25170		
Corrected Total	47	1173480			

2012 Andover TSP Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	47964	23982	2.41	0.1014
Error	45	447997	9955		
Corrected Total	47	495962			

2012 Andover TSP Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0	0	.	.
Error	45	0	0		
Corrected Total	47	0			

2012 Andover TSP Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	47964	23982	2.41	0.1014
Error	45	447997	9955		
Corrected Total	47	495962			

Table 3-6b PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass averaged over all treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010 to 2012.

SMT Grass Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	1005726	502863	8.57	0.0003
Research Year	2	2019905	1009952	17.2	<.0001
CvrCrpTrt*Research Year	4	1351077	337769	5.75	0.0003

SMT Broadleaf Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	122154	61077	0.67	0.5156
Research Year	2	411708	205854	2.24	0.11
CvrCrpTrt*Research Year	4	188547	47136	0.51	0.7257

SMT Total Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	465184	232592	1.45	0.2375
Research Year	2	4255441	2127720	13.29	<.0001
CvrCrpTrt*Research Year	4	568960	142240	0.89	0.4727

TSP Grass Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	1118588	559294	3.42	0.0356
Research Year	2	2888066	1444033	8.82	0.0003
CvrCrpTrt*Research Year	4	846838	211709	1.29	0.2756

TSP Broadleaf Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	851	425	1.3	0.2771
Research Year	2	1753	876	2.67	0.0732
CvrCrpTrt*Research Year	4	1751	437	1.33	0.2612

TSP Total Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	1168263	584131	3.58	0.0307
Research Year	2	3026605	1513302	9.26	0.0002
CvrCrpTrt*Research Year	4	922514	230628	1.41	0.2334

Table 3-7 PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass averaged over all years in the broadcast, drill, and control treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010 to 2012.

SMT Grass Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	1005726	502863	8.57	0.0003
Research Year	2	2019905	1009952	17.2	<.0001
CvrCrpTrt*Research Year	4	1351077	337769	5.75	0.0003

SMT Broadleaf Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	122154	61077	0.67	0.5156
Research Year	2	411708	205854	2.24	0.11
CvrCrpTrt*Research Year	4	188547	47136	0.51	0.7257

SMT Total Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	465184	232592	1.45	0.2375
Research Year	2	4255441	2127720	13.29	<.0001
CvrCrpTrt*Research Year	4	568960	142240	0.89	0.4727

TSP Grass Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	1118588	559294	3.42	0.0356
Research Year	2	2888066	1444033	8.82	0.0003
CvrCrpTrt*Research Year	4	846838	211709	1.29	0.2756

TSP Broadleaf Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	851	425	1.3	0.2771
Research Year	2	1753	876	2.67	0.0732
CvrCrpTrt*Research Year	4	1751	437	1.33	0.2612

TSP Total Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	2	1168263	584131	3.58	0.0307
Research Year	2	3026605	1513302	9.26	0.0002
CvrCrpTrt*Research Year	4	922514	230628	1.41	0.2334

Table 3-9 PROC GLM Procedure for corn grain yield averaged over all treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010 to 2012.

SMT Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Research Year	2	757975765	378987882	73.88	<.0001
CvrCrpTrt	2	4328291	2164145	0.42	0.6567
CvrCrpTrt*Research Year	4	14281470	3570367	0.7	0.596

TSP Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Research Year	2	1061948537	530974269	186.48	<.0001
CvrCrpTrt	2	160527	80264	0.03	0.9722
CvrCrpTrt*Research Year	4	2623645	655911	0.23	0.9209

Table 3-10a PROC GLM Procedure for corn grain yields averaged over all years in the broadcast, drill, and control treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010-2012.

SMT Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Research Year	2	757975765	378987882	73.88	<.0001
CvrCrpTrt	2	4328291	2164145	0.42	0.6567
CvrCrpTrt*Research Year	4	14281470	3570367	0.7	0.596

TSP Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Research Year	2	1061948537	530974269	186.48	<.0001
CvrCrpTrt	2	160527	80264	0.03	0.9722
CvrCrpTrt*Research Year	4	2623645	655911	0.23	0.9209

Table 3-10b PROC GLM Procedures for corn grain yield in the broadcast, drill, and control treatments at the summit (SMT) and toeslope (TSP) research sites at Andover, SD from 2010 to 2012.

2010 Andover SMT Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rate	3	8542115	2847371	1.15	0.3406
CvrCrpTrt	2	5119364	2559682	1.03	0.3649

2010 Andover TSP Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rate	3	4431235	1477078	0.57	0.6411
CvrCrpTrt	2	2113831	1056915	0.4	0.67

2011 Andover SMT Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rate	3	36299582	12099860	1.03	0.3891
CvrCrpTrt	2	13101817	6550908	0.56	0.5768

2011 Andover TSP Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitogen Rate	3	20763000	6921000	1.75	0.1710
CvrCrpTrt	2	605860	302930	0.08	0.9263

2012 Andover SMT Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rates	3	6419967	2139989	2.05	0.1209
CvrCrpTrt	2	388580	194290	0.19	0.8300

2012 Andover TSP Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rates	3	4571241	1523747	0.81	0.4952
CvrCrpTrt	2	64480	32240	0.02	0.983

Table 3-12b PROC GLM Procedure for crimson clover, winter wheat, and total cover crop biomass in the broadcast and drill treatments at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD in 2011.

SMT Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2554	1277	16.69	<.0001
Error	45	3444	76		
Corrected Total	47	5999			

SMT Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	7416	3708	3.33	0.045
Error	45	50169	1114		
Corrected Total	47	57586			

SMT Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	18670	9335	10.29	0.0002
Error	45	40840	907		
Corrected Total	47	59511			

TSP Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	765013	382506	12.1	<.0001
Error	45	1422471	31610		
Corrected Total	47	2187484			

TSP Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2542	1271	3.54	0.0375
Error	45	16177	359		
Corrected Total	47	18719			

TSP Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	849009	424504	12.89	<.0001
Error	45	1481816	32929		
Corrected Total	47	2330825			

Table 3-13b PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass in the broadcast, drill, and control treatments at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD in 2011.

SMT Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	13712	6856	1.57	0.2198
Error	45	196877	4375		
Corrected Total	47	210589			

SMT Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	23115	11557	2.05	0.1411
Error	45	254222	5649		
Corrected Total	47	277337			

SMT Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	50133	25066	2.43	0.0994
Error	45	463951	10310		
Corrected Total	47	514085			

TSP Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	27839	13919	3.32	0.0452
Error	45	188737	4194		
Corrected Total	47	216577			

TSP Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	34012	17006	0.37	0.6957
Error	45	2091808	46484		
Corrected Total	47	2125820			

TSP Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	27946	13973	0.26	0.7718
Error	45	2413008	53622		
Corrected Total	47	2440954			

Table 3-14a PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass averaged over all treatments at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD in 2011

Grass Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Field Position	2	28525	14262	3.33	0.0403
CvrCrpTrt	1	1904	1904	0.44	0.5067
CvrCrpTrt*Field Position	2	13026	6513	1.52	0.2242

Broadleaf Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Field Position	2	56063	28031	1.08	0.3455
CvrCrpTrt	1	639287	639287	24.52	<.0001
CvrCrpTrt*Field Position	2	1064	532	0.02	0.9798

Total Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Field Position	2	68275	34137	1.07	0.348
CvrCrpTrt	1	710979	710979	22.24	<.0001
CvrCrpTrt*Field Position	2	9805	4902	0.15	0.858

Table 3-14b PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass averaged over the summit and toeslope research sites in the broadcast, drill, and control treatments at Trail City, SD in 2011.

Grass Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Field Position	2	28525	14262	3.33	0.0403
CvrCrpTrt	1	1904	1904	0.44	0.5067
CvrCrpTrt*Field Position	2	13026	6513	1.52	0.2242

Broadleaf Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Field Position	2	56063	28031	1.08	0.3455
CvrCrpTrt	1	639287	639287	24.52	<.0001
CvrCrpTrt*Field Position	2	1064	532	0.02	0.9798

Total Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Field Position	2	68275	34137	1.07	0.348
CvrCrpTrt	1	710979	710979	22.24	<.0001
CvrCrpTrt*Field Position	2	9805	4902	0.15	0.858

Table 3-15b PROC GLM Procedure for corn grain yield averaged over all treatments at the summit and toeslope research sites at Trail City, SD in 2011.

Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Field Position	1	387632550	387632550	162.2	<.0001
CvrCrpTrt	2	9123976	4561988	1.91	0.1543
CvrCrpTrt*Field Position	2	3814049	1907024	0.80	0.4535

Table 3-16a PROC GLM Procedure for corn grain yield averaged over the summit and toeslope research sites in the broadcast, drill, and control treatments at Trail City, SD in 2011.

Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Field Position	1	387632550	387632550	162.2	<.0001
CvrCrpTrt	2	9123976	4561988	1.91	0.1543
CvrCrpTrt*Field Position	2	3814049	1907024	0.80	0.4535

Table 3-16b PROC GLM Procedure for corn grain yield in the broadcast, drill, and control treatments at the summit (SMT) and toeslope (TSP) research sites at Trail City, SD in 2011.

SMT Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rates	3	40316632	13438877	16.8	<.0001
CvrCrpTrt	2	2130633	1065316	1.33	0.275

TSP Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rates	3	97044485	32348161	30.76	<.0001
CvrCrpTrt	2	10807393	5403696	5.14	0.0101

Table 3-18b PROC GLM Procedure for crimson clover, winter wheat, and total cover crop biomass in the broadcast and drill treatments at Aurora, SD from 2011 to 2012.

2011 Aurora Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	249	62	3.17	0.0205
Error	55	1082	19		
Corrected Total	59	1331			

2011 Aurora Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	18869	4717	6.52	0.0002
Error	55	39773	723		
Corrected Total	59	58643			

2011 Aurora Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	22351	5587	6.35	0.0003
Error	55	48434	880		
Corrected Total	59	70786			

2012 Aurora Crimson Clover Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	9939	2484	106.59	<.0001
Error	75	1748	23		
Corrected Total	79	1168			

2012 Aurora Winter Wheat Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	34913	8728	6.22	0.0002
Error	75	105219	1402		
Corrected Total	79	140132			

2012 Aurora Total Cover Crop Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	74172	18543	14.54	<.0001
Error	75	95661	1275		
Corrected Total	79	169833			

Table 3-19a PROC GLM Procedure for crimson clover, winter wheat, and total cover crop biomass averaged over all treatments at Aurora, SD from 2011 to 2012.

Crimson Clover Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	5970	1492	68.55	<.0001
Research Year	1	1366	1366	62.78	<.0001
CvrCrpTrt*Research Year	4	4218	1054	48.44	<.0001

Winter Wheat Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	49456	12364	11.09	<.0001
Research Year	1	1696	1696	1.52	0.2196
CvrCrpTrt*Research Year	4	4326	1081	0.97	0.4264

Total Cover Crop Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	79673	19918	17.97	<.0001
Research Year	1	6109	6109	5.51	0.0204
CvrCrpTrt*Research Year	4	16850	4212	3.8	0.0059

Table 3-19b PROC GLM Procedure for crimson clover, winter wheat, and total cover crop biomass averaged over both years in the broadcast and drill treatments at Aurora, SD from 2011 to 2012.

Crimson Clover Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	5970	1492	68.55	<.0001
Research Year	1	1366	1366	62.78	<.0001
CvrCrpTrt*Research Year	4	4218	1054	48.44	<.0001

Winter Wheat Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	49456	12364	11.09	<.0001
Research Year	1	1696	1696	1.52	0.2196
CvrCrpTrt*Research Year	4	4326	1081	0.97	0.4264

Total Cover Crop Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	79673	19918	17.97	<.0001
Research Year	1	6109	6109	5.51	0.0204
CvrCrpTrt*Research Year	4	16850	4212	3.8	0.0059

Table 3-20b PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass in the broadcast, drill, and control treatments at Aurora from 2011 to 2012.

2011 Aurora Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	202614	50653	7.39	<.0001
Error	55	377201	6858		
Corrected Total	59	579816			

2011 Aurora Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	10677	2669	0.98	0.4277
Error	55	150264	2732		
Corrected Total	59	160941			

2011 Aurora Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	191903	47975	4.67	0.0026
Error	55	564934	10271		
Corrected Total	59	756837			

2012 Aurora Grass Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1443748	360937	12.48	<.0001
Error	75	2168970	28919		
Corrected Total	79	3612719			

2012 Aurora Broadleaf Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0	0	0	0
Error	75	0	0		
Corrected Total	79	0			

2012 Aurora Total Weed Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1443748	360937	12.48	<.0001
Error	75	2168970	28919		
Corrected Total	79	3612719			

Table 3-21a PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass averaged over all treatments at Aurora, SD from 2011 to 2012.

Grass Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	901601	225400	11.51	<.0001
Research Year	1	295629	295629	15.09	0.0002
CvrCrpTrt*Research Year	4	744761	186190	9.51	<.0001

Broadleaf Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	4575	1143	0.99	0.4156
Research Year	1	15550	15550	13.45	0.0004
CvrCrpTrt*Research Year	4	6101	1525	1.32	0.2661

Total Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	855395	213848	10.17	<.0001
Research Year	1	175575	175575	8.35	0.0045
CvrCrpTrt*Research Year	4	780256	195064	9.28	<.0001

Table 3-21b PROC GLM Procedure for grass weed, broadleaf weed, and total weed biomass averaged over both years in the broadcast, drill, and control treatments at Aurora, SD from 2011 to 2012.

Grass Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	901601	225400	11.51	<.0001
Research Year	1	295629	295629	15.09	0.0002
CvrCrpTrt*Research Year	4	744761	186190	9.51	<.0001

Broadleaf Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	4575	1143	0.99	0.4156
Research Year	1	15550	15550	13.45	0.0004
CvrCrpTrt*Research Year	4	6101	1525	1.32	0.2661

Total Weed Biomass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	4	855395	213848	10.17	<.0001
Research Year	1	175575	175575	8.35	0.0045
CvrCrpTrt*Research Year	4	780256	195064	9.28	<.0001

Table 3-22b PROC GLM Procedure for corn grain yield averaged over all treatments at Aurora, SD from 2011 to 2012.

Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	1	10199002	10199002	5.9	0.0167
Research Year	4	16224378	4056094	2.35	0.0589
CvrCrpTrt*Research Year	4	1801522	450380	0.26	0.9026

Table 3-23a PROC GLM Procedure for corn grain yield averaged over both years in the broadcast, drill, and control treatments at Aurora, SD from 2011 to 2012.

Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CvrCrpTrt	1	10199002	10199002	5.9	0.0167
Research Year	4	16224378	4056094	2.35	0.0589
CvrCrpTrt*Research Year	4	1801522	450380	0.26	0.9026

Table 3-23b PROC GLM Procedure for corn grain yield in the broadcast, drill, and control treatments at the 2011 and 2012 research sites at Aurora, SD.

2011 Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rates	3	68715540	22905180	16.64	<.0001
CvrCrpTrt	4	2995961	748990	0.54	0.7039

2012 Corn Grain Yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nitrogen Rates	3	9037457	3012485	1.64	0.1923
CvrCrpTrt	4	10148267	2537066	1.38	0.2544