# REACTION OF NORTH AMERICAN OATS (*Avena sativa* **L.**) TO

# CROWN RUST

A Thesis

by

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# ABSTRACT

Crown rust, caused by the fungus *Puccinia coronata*, is a severe disease negatively impacting seed quality and yield in oat (*Avena sativa*). Host genetic resistance is the primary means for controlling this disease. The most extensive oat map contains nearly 2,500 genetic markers, many of which are restriction and amplified fragment length polymorphic (RFLP or AFLP) markers. However, the use of more abundant single nucleotide polymorphic (SNP) markers combined with diversity arrays technology (DArT) would be more advantageous for marker assisted breeding (MAB) and genome wide selection (GWS) applications due to the availability of high density genotyping technologies. The purpose of using this technology is to improve the competitiveness of oat by producing varieties with durable resistance to crown rust and desirable traits that will benefit oat growers in the U.S. Panels of winter and spring oat were evaluated for resistance to crown rust in four field environments in Texas, Louisiana, Minnesota, and North Dakota during a two-year study in 2010 and 2011. Plants representing 702 elite lines of oat were phenotyped for crown rust resistance and found to have highly diverse responses. The winter oat lines demonstrated the best crown rust resistance and are expected to yield the most QTL to be used in developing durable crown rust resistance. Heritability of crown rust resistance in this study ranged from 0.88 to 0.90 in spring and winter oats, respectively. Crown rust measurements were also found to be repeatable. Repeatability ranged from 0.56 to 0.88 at Castroville, TX in 2011 and 2010, respectively in spring oats and from 0.79 at St. Paul, MN in 2011

to 0.96 at Castroville, TX in 2010 in winter oats. Oat lines contributed by states along the *Puccinia* pathway in Texas, Louisiana, Minnesota, North Dakota, and Wisconsin on average exhibited the best crown rust resistance as compared to other areas in the country where spring and winter oat are grown. GGE biplot analysis indicated that Castroville, TX was the most representative and most ideal testing location. The above results are expected to increase knowledge of the genetic diversity of the oat germplasm, yield comprehensive genotyping and phenotyping information for North American oat breeding programs, and to promote further use of GWS and MAB for key traits regarding disease resistance in oat. Future work is to conclude the association mapping process by completing genotypic analysis.

# DEDICATION

To the Lord, for blessing me with the knowledge, strength, courage and fortitude required of any hopeful student pursuing a graduate degree.

To my supportive husband, Paul Wiget, for his unfailing love, encouragement, and patience in all of my endeavors.

To my devoted parents, Charles and Kathy Lange, for imparting within me the importance and value of pursuing an education, for always telling me that I could be anything I wanted to be, and for stressing to me that college was mandatory.

To all of my siblings, Charles, Katie, Conrad, and Chris, who don't realize how much I look up to each and every one of them. I hope I can inspire and encourage them in the same manner with which they inspire me.

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# NOMENCLATURE

| | |
|---|---|
| AFLP | Amplified fragment length polymorphism |
| AM | Association mapping |
| ANOVA | Analysis of variance |
| BR | Baton Rouge, LA |
| GWS | Genome wide selection |
| CAS | Castroville, TX |
| CI | Coefficient of infection |
| Core | Elite lines of North American oats |
| DArT | Diversity arrays technology platform |
| DS | Disease severity |
| FRG | Fargo, ND |
| G x E | Genotype-by-environment interaction |
| H | Heritability |
| IT | Infection type |
| LD | Linkage disequilibrium |
| MAB | Marker-assisted breeding |
| MR | Moderately resistant |
| MS | Moderately susceptible |
| QTL | Quantitative trait loci |
| R | Resistance |
| RFLP | Restriction fragment length polymorphisn |
| S | Susceptible |
| SNP | Single nucelotide polymorphism |
| STP | St. Paul, MN |

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# CHAPTER I

# INTRODUCTION

Crown rust, or *Puccinia coronata*, is the most severe pathogen affecting oat in North America. Crown rust negatively impacts seed quality and yield, and can reduce overall test weights. Under the most favorable crop conditions, crown rust can successfully wipe out an entire crop. Due to successful pathogen overwintering, multiple infection cycles and increased pathogen severity, it is difficult to maintain a resistant plant population which can outlast pathogen virulence for an extended period of time (Carson, 2010). Crown rust occurs nearly everywhere that oats are grown, but is most serious in humid areas. Testing in Castroville, TX and Baton Rouge, LA is ideal due to their respective locations at the forefront of the *Puccinia* pathway (Figure 1.1). From these sites, windborne rust spores are disseminated into northern parts of the United States. This pathway is consistent for all *Puccinia* species. Castroville, TX has an additional advantage over the Baton Rouge, LA location to screen for crown rust resistance since there are more races of *Puccinia* in Texas than any other state.
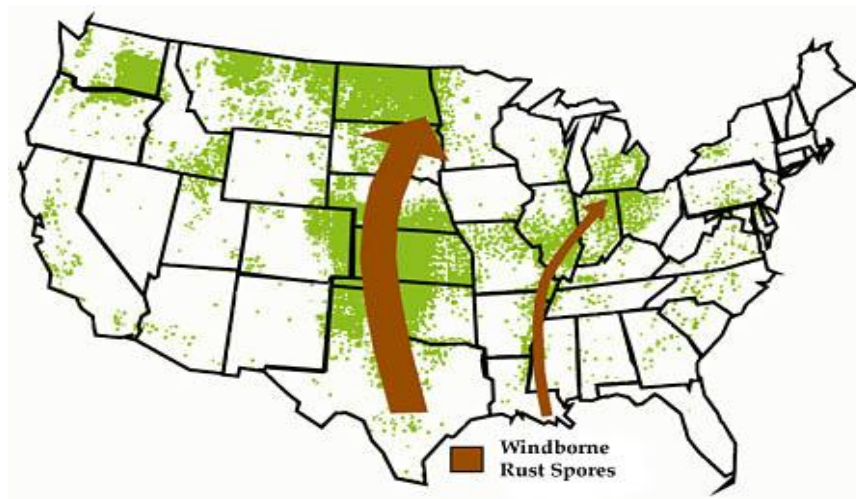
**Figure 1.1. The *Puccinia* pathway.** (Courtesy: Marty Carson, Cereal Disease Laboratory, St. Paul, MN)

Symptoms of oat crown rust include the appearance of orange to yellow pustules, called urediospores, on the leaves (Figure 1.2). These spores reproduce every 7-10 days until harvest. In an alternate phase, black resting spores, or teliospores, overwinter on straw or buckthorn, the alternate host, and can survive until germination in the spring (Wilson, 1955).

**Figure 1.2.  The symptoms of crown rust in two distinct life cycles.**

Host genetic resistance is the primary means of controlling crown rust.  Breeders rely on race-specific seedling genes which are expressed as some form of hypersensitive reaction phenotypically expressed as flecks of chlorosis on leaves in the absence of rust pustules.  Resistance genes in cultivated hexaploid oat, *A. sativa*, were deployed, resulting in such a rapid increase in corresponding virulence in the crown rust population that virulence to most of these genes became fixed in the oat populations of North America.  More recent efforts relied upon the exploitation of resistant genes in wild hexaploid oat, *A. sterilis*.  The result was another corresponding increase in rust virulence which limited the lifespan of a resistant cultivar to a maximum of five years (Carson, 2010).  Oat breeders and geneticists then attempted to utilize alternate sources of resistant genes in diploid species of oat, especially black oat, *A. strigosa*.

Introgressing resistance into hexaploid oats has become a challenge due to differences in ploidy levels and a lack of homology of chromosomes between black oat and common oat (Carson, 2008).

Molecular markers suitable for effective marker-assisted selection of quantitative trait loci (QTL) conferring partial (quantitative) resistance to crown rust in oat are currently lacking, but rapid developments in this area will help its use in oat improvement. The most extensive oat map to date contains 2500 genetic markers, most of which feature restriction fragment length polymorphism (RFLP) or amplified fragment length polymorphism (AFLP) technologies. RFLP are excellent markers, but are unsuitable for high throughput applications. AFLP lack consistent repeatability and are difficult to transfer. Diversity arrays technology (DArT) markers are also commonly used, but have an inadequate density for marker-assisted breeding and genome wide selection, as well as being rather expensive (Eckstein et al., 2008; Tinker et al., 2009). The solution is a proposed combination of DArT markers and single nucleotide polymorphsims (SNPs). SNPs allow high density, high throughput application, they are abundantly available and, unlike DArTs, do not rely on a specific technology platform. SNPs can also be directly related to sequence variation within candidate genes without losing stability (Chen et al., 2007).

As genetic and technological advancements are made, new methodology enables breeders to seek alternate methods of discovering and utilizing resistant genes. One such option is using an association mapping approach to link phenotypic traits to a specific gene or set of genes. Association mapping is a molecular plant breeding methodology

which statistically identifies significant QTL effects in a population with varying degrees of structure and relatedness according to linkage disequilibrium as a complement to QTL analysis. Using a large experimental population representing elite germplasm of the oat breeding programs in North America for association mapping would make information derived from this panel directly applicable to modern crop improvement. Additionally, studying a group of unrelated individuals provides variation permitting a variety of traits to be studied within the same population using the same genotypic data (Breseghello and Sorrells, 2006).

The objective of this study was to evaluate three panels of North American oats (winter, spring, and core) for resistance to crown rust in four field environments. These field trials will accompany data obtained from a similar screening experiment in greenhouse trials in the future. Together, these results will contribute to the mapping of loci controlling crown rust resistance using SNP assays and a complementary DArT platform. Ultimately, this will lead to the improved competitiveness of oats by yielding varieties with durable resistance to crown rust, as well as other desirable traits, to benefit oat growers in North America.

# CHAPTER II

# LITERATURE REVIEW

**Common oat (*Avena sativa* L.)**

Common oats are classified as an annual grass belonging to the genus *Avena* and are of the *sativa* species. Cultivated oat is a self-pollinating allohexaploid (n=3x=21) composed of three basic genomes, A, C and D (Rajhathy and Thomas, 1974). Domestic oat, *A. sativa*, contains 42 chromosomes, while wild tetraploids, such as *A. barbata*, have only 28 chromosomes (O'Brien, 2010).

Common oats are ranked fifth in the world's most important cereal crops, exceeded only by rice (*Oryza sativa*), wheat (*Triticum aestivum* L.), corn (*Zea mays*), and barley (*Hordeum vulgare* L.), respectively. The popularity of oats globally is increasing due to its many nutritional benefits for the human diet. Among numerated health benefits are a high content of total dietary fiber, good quality protein, and high oil content. Additionally, oats contain a higher presence of essential acids, including linoleic acid (Young and Pellett, 1994), than other cereal crops (Oliver et al., 2011).

Oats are also a rich source of the antioxidants α-tocotrienol and α-tocopherol, and avenathramides (Young and Pellett, 1994). Tocotrienols and tocophenols are commonly associated with the prevention of heart disease (Peter et al., 1997), Alzheimer's (Zandi et al., 2004), prostate cancer (Helzlsouer et al., 2000) and glaucoma (Engin et al., 2007). Avenanthramides, phytoalexins uniquely associated with oats, are shown to modulate nitric oxide production and reduce smooth muscle proliferation in the cell wall (Nie et

al., 2006; Pearce et al., 1992).  Other benefits include the lowered risks of atherosclerosis and myocardial infarctions (Liu et al., 2004; Peter et al., 1997; Ridker et al., 1989; Yue et al., 1994), and a reduction in diastolic and systolic blood pressure (el Zein et al., 2009; Gondal et al., 1996).  Oat is already consumed and enjoyed in a number of whole-grain formulations, making it an effective and desirable staple food naturally providing dietary intervention of many common and serious health risks (Jackson et al., 2008).

While the many health benefits of oat increase its popularity, oat acreage in North America is dramatically decreasing each year.  In the United States alone, the acreage of oat production dropped from 14 million in 1988 to 2 million in 2008.  The number of research groups intent on improving oats as a crop has decreased since the 1980's from 29 to 11 (Jackson et al., 2007).  At present, there are an estimated twelve publicly funded oat breeding programs in the United States and Canada (Newell et al., 2011).  These breeding programs face a number of challenges that will inhibit the preservation and improvement of oats as an economically important crop for both consumers and producers (Jackson et al., 2007).  These programs are focused on developing more promising oat varieties that feature disease resistance, increased yield, stress tolerance and reduced lodging (Oliver et al., 2011).

Oats are a versatile grain crop constituting the third most important cereal crop in the United States, behind corn and wheat.  A useful crop for pasture and reducing soil erosion, oats are suitable to a variety of crop rotations and purposes.  Oats are nutrient-rich equaling a desirable feed for horses, poultry and livestock.  In addition to grain usage, oat straw is considered the best for feed or bedding (Martin and Leonard, 1949).

Currently, oat acreage in the United States is on the decline, despite high nutritional value. Considered a grass species, oats are primarily grown as a grain or forage crop (Newell et al., 2011).

There are two primary regions for oat production in the United States. In the south, including Texas and Louisiana, winter oats are planted in the fall and harvested in the spring. In the upper Midwest region, spring oats are planted between late March and mid-May and harvested in midsummer (Carson, 2010). Oats are most suitably grown in cool, temperate regions with an average of 25 inches or more of annual precipitation or irrigation. Under heat stress, blasting or the dropping of florets can occur during flowering, indicating less heat tolerance than wheat or barley. Soil pH does not typically impact oat production; however, oats cultivated in heavy soils or phosphorous lacking soils can exhibit a reduction in yield. Oats have been broadly adapted to a diverse array of environments, but are most commonly grown in the northern central regions of the United States, primarily, Minnesota, Wisconsin, Iowa, North Dakota and South Dakota (Chapman and Carter, 1976).

Oats are susceptible to several highly damaging diseases, which account for millions of dollars of losses each year. Such diseases include fungal infections, such as crown rust, stem rust (*Puccinia graminis*), loose smut (*Ustilago nuda*), *Septoria* blight, *Fusarium* blight, root rot (*Rhizoctonia solani*), powdery mildew (*Erysiphe graminis*), and halo blight (*Pseudomonas coronafaciens*). Viruses affecting the oat population include soilborne oat mosaic virus (*Bymovirus* spp.) and barley yellow dwarf virus (*Luteovirus* spp.) (Wiese, 1987). Among these, the number one pathogen threatening oat

production is crown rust, *Puccinia coronata* f. sp. *avenae*, which is found everywhere oats are cultivated.  Crown rust is considered the most severe disease of oats in North America (Carson, 2009; Simons, 1985).  Under the most favorable crop conditions, crown rust can devastate an entire planting, resulting in total crop failure (Carson, 2008).

**Crown rust (*Puccinia coronata* f. sp. *Avenae*)**

Oat crown rust is caused by a heteroecious macrocyclic fungus, *Puccinia coronata* Corda f. sp. *Avenae*, which is regarded as the most detrimental fungal disease of oat (Simons, 1985).  Crown rust is widespread occurring wherever oats are grown (Carson, 2008; Leonard, 2002; Simons, 1985).  While distributed globally, crown rust has the most impact under conditions of heavy dew combined with moderate to high temperatures of 20-25°C.  Arid regions where cultivated and wild oats are found are usually free of crown rust infection.  Conditions considered most favorable to the oat crop are also the most favorable to crown rust, often leading to complete crop failure (Carson, 2008).  Under less than ideal conditions, crown rust can negatively impact yield and test weight, as well as increase lodging (Wiese, 1987).

Moderate to severe crown rust epidemics have been shown to reduce overall grain yield by as much as 10-40%.  The greatest yield losses generally occur when the oat yield is expected to be the highest.  Crown rust causes damage to plant leaves, specifically the flag leaf, thereby reducing photosynthesis.  In oat used for grain, the presence of rust on the flag leave inhibits the transport of photosynthesized sugars that are used in grain production.  As a result, the grain that is produced tends to be shriveled

and, therefore, has a lower feed value.  In oat used for forage, the damage caused to leaves can also limit plant growth and a reduction in forage value.  Crown rust also impacts plants beneath the soil surface by stunting root growth and leading to poor drought tolerance (Chong, 2002; Leonard, 2002; Simons, 1985).

A crown rust infection is characterized by the formation of uredinia on the upper and lower surfaces of affected leaves, and in severe conditions, leaf sheaths.  Uredinia are round to oval blister-like pustules that can be up to 5 mm long.  These pustules are composed of bodies of orange-yellow spores which become exposed via rupturing on the leaf's epidermis.  In a matter of weeks, the edges of the uredinia are blackened by the formation of brown-black teliospores.  Black telia rings are often formed around the uredinia, but the leaf's epidermis will remain intact over the rings until the leaves expire (Chong, 2002; Simons, 1985).

Life Cycle of *Puccinia coronata*
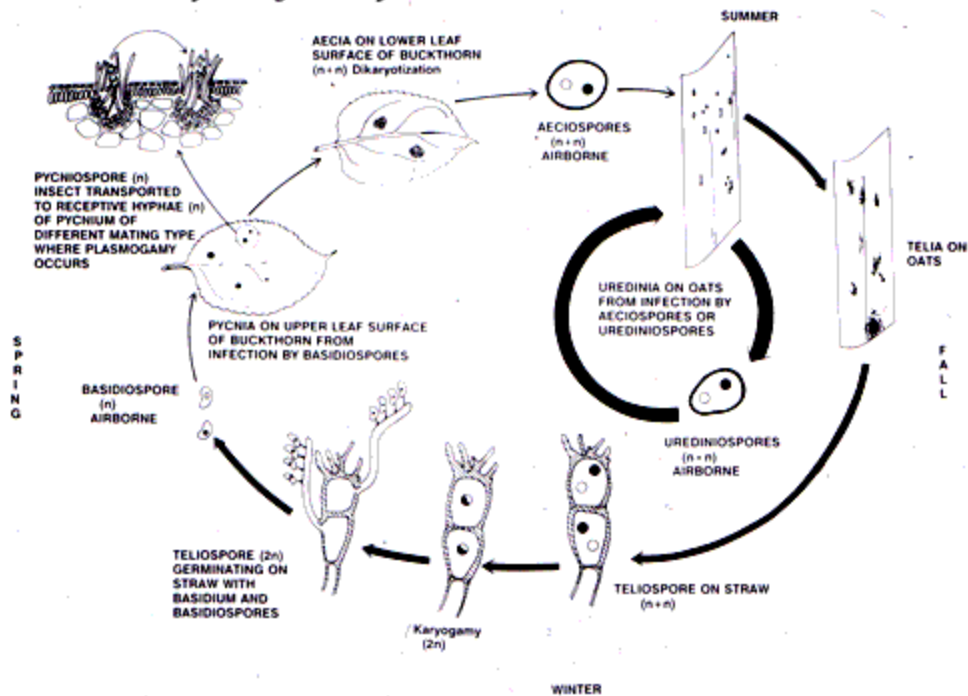
**Figure 2.1. Life cycle of oat crown rust.** (Courtesy Vickie Brewster, United States Department of Agriculture-Agricultural Research Station)

Initial infection begins on oats sown during the fall by uredinia from volunteer or wild oat plants which survived throughout the summer. This happens in moist protected habitats near streams or irrigation canals. Crown rust generally follows one of two distinct life cycles (Figure 2.1). In each cycle, the uredinia form on oats several weeks prior to the crop ripening. In the first phase of the cycle, the spores from these pustules are windborne and infect new plants, producing fresh spores every 8-10 days. Alternately, the teliospores, form on the oats, circling the blister-like pustules to overwinter on straw, post-harvest. In the spring, small spores are airborne and can infect

common buckthorn (*Rhamnus cathartica* L.), the aecial or alternate host of crown rust. The infection cycle repeats as new spores are transmitted from buckthorn to oats, where the uredinia form once more (Wiese, 1987). Common buckthorn is found in the upper Midwest of the U.S. and does not therefore serve as a host of the fungus in the southern oat regions. In these areas, wild oat (*A. fatua*) can serve as a site for overwintering (Carson, 2010). Teliospores that overwinter on the straw of buckthorn or wild oat produce basidiospores, which infect the host plants' young leaves. These infections then produce aecia, which yield aeciospores that eventually infect oat plants, repeating the cycle. Also, urediniospores and aeciospores can germinate in free water on the surfaces of leaves. The germination and infection of leaves via stomates occur at temperatures ranging from 10-25°C, but is inhibited at temperatures greater than 30°C (Chong, 2002; Simons, 1985).

Since winter oats are not durable enough in the northern parts of the U.S., crown rust does not survive the winter in the uredinial stage except in the south. Crown rust infections typically develop during the early summer in southern growing areas, such as Louisiana and Texas. Urediniospores are then disseminated to the north to infect the oats sown in the spring. This pattern follows what is referred to as the Puccinia pathway (Figure 1.1) which depicts the route of travel for most races of rust. In the upper Midwest growing regions, aeciospores from common buckthorn serve as the primary source of inocula (Chong, 2002; Chong et al., 2000; Simons, 1985). Urediniospores and aeciospores are capable of surviving a great distance during dissemination, while germination teliospores endure on the straw. When humidity is very high during the

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night or rain showers occur, the teliospores can release the basidiopsores which must rapidly infect other plants. Basidiospores are incapable of surviving airborne dissemination greater than several hundred meters from their original source (Chong et al., 2000; Simons, 1985).

While individual varieties of the crown rust fungus are limited to cultivated and wild oat or buckthorn, a number of other grass species may serve as hosts as well. In cultivated grass species, rye (*Secale cereal* L.) and barley can be slightly impacted by crown rust, although not by the same varieties which impact oat. Ryegrass (*Lolium* L.) and fescue (*Festuca* L.), common lawn and pasture grasses, can be severely infected by crown rust. A new form of crown rust has been discovered to infect smooth brome grass (*Bromus inermis*), an important pasture grass in the upper Midwest of the U.S. (Chong et al., 2000; Simons, 1985). Clearly, crown rust is a dangerous pathogen which impacts a variety of important plant species, is effectively disseminated, and extremely durable. Since this fungus is present virtually everywhere that cultivated oats are grown, it is in the best interest of oat breeders and growers to determine a method for controlling the spread of crown rust and protecting the oat population.

In the north-central United States, oat fields are commonly exposed to high external inoculum levels of a very diverse *P. coronata* population because the fields are often bordered by a highly dense buckthorn population. In the south, winter oats can also be exposed to high inoculums levels because the longer growing season permits more asexual reproductive cycles of the fungus than occur in the shorter growing region of the northern states (Carson, 2009).

**Disease management strategies and challenges**

A number of methods for controlling crown rust have been attempted, many of which are host genetic resistances which occur at the molecular level. Such methods include host genetic resistance, partial resistance, race-specific seedling genes, and multiline cultivars (Carson, 2009). Many breeders seek resistance from alternate oat sources, including diploid oat (*A. strigosa*), tetraploid oat (*A. magna*), and slender oat (*A. barbata*) and release multiline cultivars of oat derived from a method of introgression (Carson, 2010). Other breeders continue to search for additional sources of broad-spectrum and durable resistance.

Conventional methods for managing crown rust include fluctuating planting dates and eradicating the buckthorn population. In the upper Midwest where spring oat is grown, planting earlier allows the crop to mature prior to when the most severe symptoms of crown rust will develop. In colder regions, a weed management strategy targeting the common buckthorn population will delay the spread of the fungus, as well as inhibit the development of new, more virulent rust races through the use of resistant varieties maturing earlier (Wiese, 1987).

Host partial resistance is considered an alternative to the use of resistant genotypes (Luke et al., 1975; Wang et al., 1994; Wilcoxson, 1981). Resistant genotypes present qualitative resistance, but are countered by an increased selection pressure on the crown rust population. This selection pressure leads to a rapid evolution of rust races which become resistant to the host; therefore the resistant varieties are rendered ineffective and short-lived (Barbosa et al., 2006). Host partial resistance is complex as a

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result of the interaction of the following components: a reduced number of lesions, increased latent period, a smaller spore production, smaller pustule size, slow disease progression, and ultimately, a smaller rate of disease development (Parlevliet, 1987).

Host genetic resistance has become the primary method of controlling crown rust. Breeders employ this method of resistance by relying heavily on race-specific seedling genes expressing as a hypersensitive reaction. Such genes were originally found in cultivated oat (*A. sativa*). Once deployed in oat cultivars, the virulence of the crown rust population increased greatly, rendering the resistant genes ineffective. At present, the virulence of crown rust to most of these deployed genes has become fixed within the North American oat population. The lifespan of resistant cultivars resides around five years maximum, presenting a new challenge for oat breeders (Carson, 2008).

Breeding for disease resistance is regarded as the most effective and economical method for managing *P. coronata*. The discovery of crown rust resistant genes has become a high priority for oat breeders. Through the use of molecular mapping, many race-specific resistance genes have been characterized, including *Pc38*, *Pc39*, *Pc48*, *Pc68*, *Pc71*, *Pc91*, *Pc92*, and *Pc94* (Wight et al., 2003). This type of resistance is easily defeated because of selection pressure on the fungus resulting from massive and lengthy cultivation practices. The durability of these genes can be extended if multiple resistance genes are pyramided (Hittalmani et al., 2000) into oat cultivars because the likelihood of the pathogen mutating simultaneously at multiple sites for virulence is much lower than a single mutation for virulence. However, gene pyramiding is difficult due to dominance and epistatic effects of deploying multiple resistance genes.

Additionally, multiple resistance genes may exhibit similar reactions to a variety of races presenting a challenge when identifying specific rust resistance genes (Chen et al., 2007).

Originally, the *Pc* genes were introgressed from cultivated and wild hexaploid oats and deployed in new cultivars (Carson, 2010). Currently, *Pc68* is the only gene providing crown rust resistance in Canadian-grown oat cultivars, but reliance on this single gene could prove to be short-lived (Chen et al., 2007). *Pc68* has demonstrated potential for introgression into the oat germplasm while maintaining positive agronomic characteristics when combined with additional strategies for improving durability. Molecular markers will be of great assistance for further use of the *Pc68* gene and the discovery of alternate resistance genes (Kulcheski et al., 2010).

Diploid and tetraploid species of oat became the primary focus of more recent efforts to utilize the *Pc* genes. Diploid black oat (*A. strigosa*) has demonstrated well-documented resistance for a significant amount of time. Introgression of this resistance into cultivated hexaploid oat is highly difficult due to differences in ploidy levels and a deficiency in chromosome homology between *A. strigosa* and *A. sativa* (Carson, 2010). Some successes of introgression include the release of a cultivar containing *Pc94* from an *A. strigosa* accession that was effective against crown rust by the University of Wisconsin-Madison and the Agriculture Agri-Foods Canada-Winnipeg oat breeding programs (Aung et al., 1996). Another success is the oat cultivar Hi-Fi, released by North Dakota State University, a tetraploid species, *A. magna* CI 8330, with the *Pc91* resistance gene (McMullen et al., 2005). Recently the United States Department of

Agriculture has systematically evaluated slender oat (*A. barbata*) for crown rust resistance. This wild tetraploid species is considered to be of poor agronomic quality, but has been a source of resistance to powdery mildew and stem rust. Some resistance was observed in accessions of the slender oat species, but has remained untapped as of yet (Carson, 2008).

While *A. barbata* as a source of broad-spectrum resistance seems possible, achieving more durable resistance than from other species remains unlikely. It is possible that a variety of new resistance genes exists in the slender oat species that could prove useful if pyramided in various combinations into deployed cultivars. Though introgression will be challenging due to varying ploidy levels between tetraploid and hexaploid oat, a backcrossing method has been successfully used with stem rust genes when irradiated and treated with colchicines while using slender oat as the female parent (Carson, 2010; Rines et al., 2006).

One proposed method for coping with crown rust is the use of multiline cultivars. The use of such cultivars would increase intra-crop diversity for disease resistance and possibly achieve more durable resistance to the highly variable *P. coronata* (Browning et al., 1979; Marshall and Weir, 1985; Wolfe, 1985). The advantages to using multilines further include a reduction in the amount of initial inoculums requirements and a lower rate of epidemic development since only part of the fungal population is virulent upon any component of a multiline (Browning et al., 1979; Garrett and Mundt, 1999; Mundt, 2002). Resistant plants serve as a barrier to spore dispersal, thereby decreasing the spread of crown rust (Carson, 2009). Another potential barrier to disease spread in

multiline is the mixture of compatible races with incompatible races infecting the plants (Garrett and Mundt, 1999; Mundt, 2002). Multilines or cultivar mixtures may potentially inhibit or slow the rise of "super races" of crown rust, but ultimately fail to provide a durable solution (Barrett, 1980; Groth, 1976).

While the advantages of using multilines are numerous, many disadvantages were uncovered during a 2009 study. Virulence increased late in the season negatively impacting the durability of the resistance in the multilines evaluated. It was presumed that a continued cultivation of a multiline for a number of years could likely result in the production of rust super races which would effectively eradicate the multiline's ability to reduce disease (Carson, 2009). Furthermore, the study concluded that isolates of the crown rust pathogen are able to yield a variety of unnecessary virulences without an apparent cost in fitness (Carson, 2008; Leonard, 2003). A core concept of multilines is their ability to copy occurrences in a natural ecosystem, yet the expected equilibrium between a diverse host population and the pathogen population does not demonstrate a reduction in disease levels or a lack of predomination in complex races. Iowa State University discovered that multiline cultivars are unable to compete agronomically with pure-line cultivars (Browning et al., 1979). Presumably, backcross breeding used to develop the isoline components of multilines is too conservative. By the time successful resistance has been achieved via backcrossing and a multiline has been released the agronomic performance of the recurrent parent is rendered obsolete. Additionally, the measure of crown rust control cannot compete with the high resistance of pure-lines, despite the inevitable short lifespan of the latter (Carson, 2009).

A more promising approach than multilines for oat breeding programs could be the use of race-nonspecific or partial crown rust resistance. Selection for such genes is difficult due to the low heritability, association with late maturity, and poor agronomic performance of sources of resistance. Also, it is tasking to distinguish partial resistance from race-specific seedling genes that are effective against crown rust. Even though selection for this type of resistance has been challenging, the development and use of a variety of molecular markers suitable for marker-assisted selection may remove some of the barriers to this approach (Carson, 2009).

Durable resistance is the goal, and a challenging one. The use of a wide array of resistance mechanisms in current germplasms indicates an increase in durability (Rubiales and Niks, 2000). Combining minor effects genes with race-nonspecific and race-specific seedling genes could also lead to longer lasting resistance. Molecular markers will be necessary to identify these genes (Kulcheski et al., 2010).

**Association mapping**

Association mapping (AM), also known as linkage-disequilibrium mapping, is a useful genetic methodology for detecting quantitative trait loci (QTL) in a diverse population in contrast to QTL linkage mapping which is generally performed on a bi-parental $F_2$ or backcross population. This is an especially useful approach in species for which mapping populations cannot be easily created. Association mapping is of particular use when attempting to exploit a wide range of genetic variation to identify QTL segregating across diverse germplasm. The ability to identify markers as closely

linked as possible to underlying QTL is reliant on how linkage disequilibrium (LD) decreases as the distance between QTL and marker increase.  Linkage disequilibrium can be defined as the observed frequency of a gamete in a population minus the product of the frequencies of corresponding alleles (Bernardo, 2010).  Association mapping is a method used to detect the relationships between phenotypic expression and genotypes within a population of individuals based on LD.   The LD principle is based on the non-random association of alleles at adjacent loci within a population (Yu et al., 2011)(Yu et al., 2011).

The goal of genome wide association studies (GWAS) is to identify useful QTL, and hopefully genes, causal to a segregating trait of interest in the population.  Association mapping can be used to identify useful allelic diversity and to generate a high resolution map detailing the diversity.  Association mapping has never been conducted in oat and using this tool for detecting QTL could prove valuable to the oat breeding community (Jannink et al., 2001; Newell et al., 2011).  Currently there are few bi-parental maps for oat, all of which are incomplete and fragmented (Jackson et al., 2009; Jackson et al., 2007).  Expanding on these maps will significantly contribute to knowledge about the oat germplasm and could lead to important discoveries which will likely improve the performance of the oat crop.

This type of mapping is a most useful tool for screening a large population of unrelated individuals, such as a germplasm sample of an entire population.  Association mapping may also be used to simultaneously analyze segregating biparental populations (Liu et al., 2011).  Advantageously, association mapping is an efficient use of resources

since multiple traits can be studied simultaneously in a given population while using the same genotypic information. Additionally, more of the molecular markers are likely to be polymorphic allotting increased coverage of the studied genome than biparental maps. Multi-year and multi-location phenotypic data can also be obtained without incurring extra costs (Breseghello and Sorrells, 2006; Rafalski, 2002).

There are several negative aspects to AM that should be considered. For example, a higher probability of making a Type I or Type II error is possible due to the presence of unaccounted subdivisions within a population structure (Pritchard et al., 2000). Covariances among individuals could arise unaccounted for in the model, generating bias in estimated allelic effects (Kennedy et al., 1992). An increase in Type II error can be attributed to lower correlation between markers and genes, an unbalanced design based on the presence of alleles at varying frequencies, or a multiple-testing problem associated with very strict genome-wise significance thresholds (Carlson et al., 2004). Ultimately, these limitations imply that association mapping will be inadequate for detecting rare variants or genes that are variable between populations while remaining fixed within subpopulations (Breseghello and Sorrells, 2006). Nevertheless, using association mapping to evaluate quantitative traits is a promising strategy (Lu et al., 2010; Yu et al., 2011) with the potential to decode complex traits within a genome (Flint-Garcia et al., 2003).

**Single nucleotide polymorphism markers**

Using markers to identify genes associated with crown rust resistance will potentially remove barriers associated with achieving durable resistance (Carson, 2008). Single nucleotide polymorphism (SNP) markers are becoming increasingly popular at present because they overcome some limitations associated with other types of markers. SNPs are abundantly frequent and suitable for high throughput genotyping using automated platforms (Chen et al., 2007). These markers are highly stable and are commonly located in the gene coding region, promoting the discovery of genes associated with phenotypic traits (Yanagisawa et al., 2003). SNPs can also be found in the non-coding region. Thus, in addition to contributing directly to the phenotype, they can be associated with a phenotype via linkage disequilibrium or genetic linkage (Chen et al., 2006). Additionally, SNPs are able to be used efficiently and at a relatively low cost since a number of semi-automated scoring platforms already exist for their usage (Chen et al., 2007). SNPs have been widely employed in a variety of genetic studies for wheat (Mochida et al., 2003), barley (Close et al., 2009), sugar beet (*Beta vulgaris* L.) (Mohring et al., 2004), soybean (*Glycine max* L.) (Zhu et al., 2003), and rice (Nasu et al., 2002).

While SNPs are relatively inexpensive compared to other markers, there is a significant up-front cost associated with SNP equipment. The initial costs are offset by the abundance of benefits which can be achieved for plant breeders as SNP marker information is generated. For plant breeding purposes, SNPs feature multiplexing capabilities, such as single-base extension assay, including the facilitation of gene

pyramiding. SNPs have already been used to distinguish between plants homozygous for the rust resistance gene *Pc68* and those that are susceptible heterozygous individuals. This is useful for screening and eliminating heterozygotes early in a breeding program (Chen et al., 2006) as well as to select against plant types lacking the trait or traits of interest, especially if the trait is genetically controlled or highly complex (Bailey and Edwards, 2007).

**Diversity arrays technology markers**

Diversity arrays technology (DArT) markers are a relatively new technology. These markers are based on microarray hybridization which detects and compares the presence or absence of individual DNA fragments (Jaccoud et al., 2001; Wenzl et al., 2004). DArT markers, like SNPs are suitable for high throughput application and can be rapidly developed for nearly any genome. These molecular markers are capable of detecting a large number of parallel markers without requiring the development of an assay once these markers have been identified (Kilian et al., 2003). DArT markers were developed for a range of species including Arabidopsis (*Arabidopsis thaliana*) (Wittenberg et al., 2005) and cassava (*Manihot esculenta*) (Xia et al., 2005), but have been used in grass crops, such as wheat (Akbari et al., 2006) and rye (Bolibok-Bragoszewska et al., 2009). While these markers are being used more frequently in commonly studied plant species, crops with high polyploidy levels, such as wheat, indicate a possible decrease in map resolution (Akbari et al., 2006). The use of these markers in triticale (Badea et al., 2011) demonstrates that DArTs are an efficient tool for

evaluating genetic diversity. DArTs are expected to complement existing marker technologies and can be used for fine mapping, identifying QTL, screening genomes, and whole-genome marker-assisted selection or introgression of selected genomes (Badea et al., 2011).

DArT markers are not sufficiently usable with the aid of other markers due to a heavy reliance on the presence or absence of hybridization signals (Akbari et al., 2006). Another negative component to DArTs is that they are a dominant marker system. Therefore, it is impossible to score heterozygous individuals without resulting in a high segregation distortion (Francki et al., 2009). Additionally, DArT markers remain unsuitable for marker assisted selection with cost being the primary limiting factor preventing widespread use (Kilian et al., 2003). Another limitation of DArTs is the ownership rights of these markers, which is restricted to the company "A Diversity Arrays Technology Pty Ltd (DArT P/L) (Diversity Arrays Technology, 2009).

One advantage to this technology is that the DArT platform can provide comprehensive genome coverage without prior sequencing information (Jaccoud et al., 2001; Wenzl et al., 2004), making this an excellent tool for little-characterized genomes, such as oat. DArT markers have already been used to develop the first complete oat linkage map, shedding light on the oat genome ancestry and the crop's domestication (Oliver et al., 2011).

**Conclusions**

Oats are a complex, but beneficial crop with a number of human health advantages. In order to provide oat growers and breeders with the tools to help oat succeed, more information about the oat genome is needed. Employing molecular markers, such as DArTs and SNPs, will contribute to more comprehensive QTL mapping of the oat genome. This map combined with associated phenotypic observations represents an association map study which will lead to the generation of better oat varieties. These varieties could feature many advantages, including resistance to crown rust, thereby eliminating one of the greatest challenges to global oat breeders.

# CHAPTER III

# METHODOLOGY

**Association mapping panels**

The association mapping panel consisted of three sub-panels, referred to as the 'Winter', 'Spring', and 'Core' panels, respectively. These panels were planted at four locations: Castroville, TX, Baton Rouge, LA, Fargo, ND and St. Paul, MN (Figure 3.1). Castroville, TX and Baton Rouge, LA serve as locations where winter oats are commonly grown, while Fargo, ND and St. Paul, MN serve as sites where spring oats are commonly grown. The panels were grown for two years at each location for a total of two repetitions, except at the Fargo, ND location, where a single rep was grown. Each of these panels was grown for a total of two years at four locations in a randomized complete block design. Spring, winter and core panels were separated in the field by a row of wheat. Seeds were planted using a Heague 1000® small grains experimental drill to plant 48 inch long head rows with 15 inch row spacing, except in Fargo, ND. At this location, seeds were planted as a hill plot nursery in 4-row plots, 2 meters (78.74 inches) long with 30 centimeter (11.81 inches) row spacing. In Castroville, TX seeds were planted on November 18, 2009 and November 17, 2010, respectively. In Baton Rouge, LA seeds were planted on December 12, 2009 and November 29, 2010, respectively. In Fargo, ND seeds were planted May 27, 2010 and May 26, 2011, respectively. In 2011, planting was delayed due to wet soil conditions; however, this delay also provided for very heavy natural crown rust infection. In St. Paul, MN seeds were planted on April

26

28, 2010 and May 11, 2011, respectively.  Pure seed was obtained via seed increase

trials for the breeder lines analyzed in this study.



**Figure 3.1.  The four locations where oat panels were grown.**

The spring panel is composed of 360 breeder lines and six checks.  Five of these

checks are designated spring checks and include the following oat lines: 'Ogle', 'CDC

Dancer', 'HiFi', 'Leggett', and 'Gem'.  The remaining check is a designated winter oat

named 'Horizon 270'.  These checks were repeated five times each.  There were a total

of 414 plots in the spring evaluation panel (Table 3.1).  Breeder lines were contributed

by the Agricultural Research Station (ARS)-Aberdeen, ID, Cornell University,

University of Illinois, Purdue University, University of Wisconsin, ARS-Minnesota,

North Dakota State University, Ottawa, University of Saskatchewan, and Winnipeg,

Canada.

The winter panel consisted of 120 breeder lines, five winter checks and one

spring check. The winter checks included 'TAMO397', 'TAMO406', 'LA99016',

'Horizon 270', and 'Rodgers'. The spring check is referred to as 'Ogle'. Each check

was repeated five times. There were a total of 160 plots in the winter panel (Table 3.1).

Breeder lines were contributed by Louisiana State University, Texas A&M University,

and North Carolina State University.

The core panel consisted of 108 lines designated as elite material by North

American oat breeders (Table 3.1). The genotypes used in this panel were included in

the winter and spring panels, depending on growth habit. The core panel was not

analyzed separately for the purposes of this thesis.

**Table 3.1.  List of genotypes, source of origin, growth habit and pedigree for all oat lines tested in this study.**

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| 001A1-24-2-4-1-3 | Indiana | Spring | 001A1-24-2-4-1-3 |
| 00Ab6112 | Idaho | Spring | 94Ab 6921/Ajay |
| 00Ab6711 | Idaho | Spring | 83Ab 3250/Ab Sp9-2 |
| 00Ab6963 | Idaho | Spring | 82Ab 248/Ab Sp9-2 |
| 00Ab7006 | Idaho | Spring | 90Ab 1322/Ab Sp9-2 |
| 00Ab7085 | Idaho | Spring | 90Ab 1322/Ab Sp9-2 |
| 00Ab8118 | Idaho | Spring | 90Ab 1322/Derby |
| 0216A1-1-55 | Indiana | Spring | 0216A1-1-55 |
| 0219A1-84-4-4-4-4 | Indiana | Spring | 0219A1-84-4-4-4-4 |
| 021A1-78-1-5 | Indiana | Spring | 021A1-78-1-5 |
| 0222A1-21-7-5-1-1 | Indiana | Spring | 0222A1-21-7-5-1-1 |
| 026A1-88-2-2 | Indiana | Spring | 026A1-88-2-2 |
| 027A1-87-8-1 | Indiana | Spring | 027A1-87-8-1 |
| 02Ab5836 | Idaho | Spring | 95AB1284/Powell |
| 02Ab6078 | Idaho | Spring | 95Ab1284/Powell |
| 02Ab6655 | Idaho | Spring | 95Ab1284/Powell |
| 02HO-139 | Idaho | Spring | Maverick/IA91324-2 |
| 02HO-209 | Idaho | Spring | IA91001-2/Powell//Powell |
| 04P07B-GT3D | Ottawa | Spring | OT2022/Leggett |
| 0513A1-18-5 | Indiana | Spring | 0513A1-18-5 |
| 0514A1-16-3 | Indiana | Spring | 0514A1-16-3 |
| 0528A1-1 | Indiana | Spring | 0528A1-1 |
| 053B1-95 | Indiana | Spring | 053B1-95 |
| 0541A1-1 | Indiana | Spring | 0541A1-1 |
| 055A1-3-5-3 | Indiana | Spring | 055A1-3-5-3 |
| 059A1-2-2-4 | Indiana | Spring | 059A1-2-2-4 |
| 833-99AB118 | Louisiana | Winter | PURIFICATION SLECTION OF '833 |
| 8669C2-4-6-16-33 | Indiana | Spring | 8669C2-4-6-16-33 |
| 95Ab12770 | Idaho | Spring | 86Ab1867/87Ab5597 |
| 95Ab13050 | Idaho | Spring | 84Ab825/86Ab5259 |
| 971A9-7-4-11 | Indiana | Spring | 971A9-7-4-11 |
| 97Ab7761 | Idaho | Spring | IL81-2570/83Ab3250 |
| 97Ab7767 | Idaho | Spring | IL81-2570/83Ab3250 |
| 9876C1-2-1-5-2-4-1 | Indiana | Spring | 9876C1-2-1-5-2-4-1 |
| 98Ab7265 | Idaho | Spring | Corbit/88Ab3073 |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|------|--------|--------------|----------|
| 99Ab10937 | Idaho | Spring | MN83207/74Ab2608 |
| 99Ab10971 | Idaho | Spring | 90Ab1322/Monida |
| 99Ab10987 | Idaho | Spring | 90Ab1322/Monida |
| 99Ab11098 | Idaho | Spring | 90Ab1322/91Ab2 |
| 99Ab11136 | Idaho | Spring | 90Ab1322/91Ab2 |
| 99Ab11227 | Idaho | Spring | 90Ab1322/SP3-2 |
| 99Ab11391 | Idaho | Spring | 87Ab6153/SP3-9 |
| 99Ab11787 | Idaho | Spring | 91Ab2/SP9-7 |
| Aarre | Finland | Unknown | Puhti(Hannes/Ryhti) X Veli (Titus/Sisu) |
| Adrew | Indiana | Spring | Adrew |
| Ajax | Winnipeg | Spring | Victory(Milton(Sweden)/Milton(Sweden)) X Hajira(Sel from Algeria/Sel from Algeria) |
| Ajay | Idaho | Spring | 74AB1952(unknown/unknown) X 74Ab2608(Cayuse/Otana) |
| Akiyutaka | Japan | Unknown | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Allen | Indiana | Spring | unnamed_4878 (Purdue 5124 A6-4/Milford)/unnamed_6500 (unnamed_6496/unnamed_6499) |
| Anthony | Indiana | Spring | White Tartar/Victory (Milton Sweden/Milton Sweden) |
| ARDENTE | Norway | Spring | KANTON_X_BELINDA |
| Asencao | Brazil | Winter | Nora X Iowa Multiline(AsencaoE) |
| Assiniboia/S42 | Saskatchewan | Spring | AC Assiniboia(90GC144/Robert) X S42(SunII/unnamed_18354) |
| Aurora | North Carolina | Winter | Red Rustproof (sel. From Red Algerian (Stanton, 1954 or introduced from Mexico Stanton, 1954/sel. From Red Algerian (Stanton, 1954 or introduced from Mexico Stanton, 1954)/Red Rustproof (sel. From Red Algerian (Stanton, 1954 or introduced from Mexico Stanton, 1954/sel. From Red Algerian (Stanton, 1954 or introduced from Mexico Stanton, 1954) |
| Ave117.2 | Saskatchewan | Spring | INIA, Carillanca Station, Temuco, Chile |
| AVENY | Norway | Spring | BELINDA_X_SW 951865 |
| Balado | United Kingdom | Spring | 97-48Cn (Birnam/92-88ACn3/1)/Kingfisher (Gerald/Chamois) |
| Baler_CDC | Saskatchewan | Spring | Av2401/2(Av1893/11/11/19/1 X Saladin) X SO 86044 (W79478/Calibre) |
| BARRA | Norway | Spring | SELMA_X_ |
| Belinda | Sweden | Spring | Frode(SvVg75842/Dula) X Silvano(unknown/unknown) |
| Bia | Sweden | Spring | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Biri | Norway | Spring | Grakall (Voll/Nidar II)/Lena (Sang/Unisignum) |
| Blaze | Illinois | Spring | IL83-7646(P72261-2-3-2/IL75-5665) X Newdak (unnamed_6609/Ogle) |
| Bond | North Carolina | Winter | Avena sterilis (strain from Algeria, 1918) (wild material/wild material)/Golden Rain (Probsteier/Probsteier) |

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**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| Boudrias | Alberta | Spring | LAO-597-NZ(AC Belmont/AC Assiniboia) X LAO-597-NZ(AC Belmont/AC Assiniboia) |
| Bountiful | United Kingdom | Spring | Unnamed_5517(unnamed_8874/Black Winter) X Unnamed_5520(Goldfinder/Black Tartar) |
| Boyer_CDC | Saskatchewan | Spring | SO 82030 (Cascade/Hudson(Canada)) X OT235 (CI964P2-R4/C4963P2HHAM4) |
| Brooks | North Carolina | Winter | unnamed_6911 (Carolee/Fulgrain)/unnamed_14653 (Fulgrain/unnamed_14652) |
| Brown 1409-164 | Ottawa | Spring | Brown 1409-164 |
| Buckskin | Illinois | Spring | AC Assiniboia(90GC144/Robert) X IL92-6728(IL86-5262/unnamed_181093) |
| Buffalo | United Kingdom | Spring | 85-47CnIII/2(84-24/Solva) X 90-153Acn2(Gerald/89-164) |
| Bullion | United Kingdom | Spring | 08974CnI/1 (HOJ36-4/4n/07609CnV/3/5n)/ 08944Cn1 (08252CnIII/3n/08671CnI/2n) |
| Bw103 | Saskatchewan | Spring | INTA, Barrow Station, Tres Arroyos, Argentina |
| Bw1103 | Saskatchewan | Spring | INTA, Barrow Station, Tres Arroyos, Argentina |
| Bw4903 | Saskatchewan | Spring | INTA, Barrow Station, Tres Arroyos, Argentina |
| Calibre | Saskatchewan | Spring | Gemini(bulk progeny of cross/Unknown) X Clintford(Purdue 5124A6-4/Milford) |
| Cantal | Ottawa | Spring | QO190.2 / QO189.5 (QO190.2 = W.B.16384 / Dorval // Fraser) |
| Carolee | North Carolina | Winter | Letoria (Lee/Victoria - Argentina)/unnamed_6503(Clinton/unnamed_6502) |
| CDC Minstrel | Saskatchewan | Spring | OT293 / CDC Dancer |
| CDC Orrin | Saskatchewan | Spring | OT349 / J775-1 |
| CDC Weaver | Saskatchewan | Spring | OT369 / OT2007 |
| Ceirch Du Boch | North Carolina | Winter | Ceirch Du Boch |
| Centennial | Wisconsin | Spring | N569-42-51(Holden/irradiated monosomicated monosomic alien sub. line) X Unnamed_6468(Froker/Stormont) |
| Chaps | Illinois | Spring | Ogle(Brave/unnamed_336) X Unnamed_5458(IL75-5667/Ogle) |
| Chernigovskij 27B | Ukraine | Unknown | Jaycee(WIX643-33/Putman) X Chernigovskii83(unknown/Unnamed_16170) |
| Cherokee | Iowa | Spring | Iowa No.D69(Richland/Green Russian) X Bond (Avena sterilis(strain from Algeria,1918)/Golden Rain) |
| Chinese 4 | Ottawa | Spring | Chinese 4 |
| CI 4706-2 | Unknown | Unknown | Unknown X Unknown |
| CI1712-5 | Minnesota | Spring | Siberian selection (Ottawa) |
| CI7035-1 | Minnesota | Spring | Buck selection 1952 (Argentina) |
| CI8000-4 | Minnesota | Spring | AR 2-31-20 (Arkansas) |
| CIav 6209 | Unknown | Unknown | SantaFe(sel. from Argentina oat(Coffman F.A. 1977)/sel. from Argentina oat (Coffman F.A. 1977) X Benton(Sac/Sac) |
| CILLA | Norway | Spring | A 83180_X_STIL |
| CIRCLE | Norway | Spring | Sv 92158_X_Sv 923793 |
| Classic | Indiana | Spring | Ogle (Brave/unnamed_336)/unnamned_9285 (IN09201/P8221RB1-44-6 |
| Clintford | Indiana | Spring | Purdue 5124 A6-4 (Clinton 59/unnmaed_5254)/Milford (Victory/S172) |
| Clintland | Indiana | Spring | Clinton 59 (unnamed_6925/Bond)/unnamed_5257 (Clinton 59/unnamed_5258) |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| Clintland 60 | Indiana | Spring | Clintland (Clinton 59/unnamed_5257)/unnamed_9214 (Clintland/unnamed_9210) |
| Clintland 64 | Indiana | Spring | unnamed_6497 (Clintland/unnamed_6425)/unnamed_9222 (Clintland/unnamed_9221) |
| Clinton | Iowa | Spring | Iowa No.D69(Richland/Green Russian) X Bond (Avena sterilis(strain from Algeria,1918)/Golden Rain) |
| Clinton 59 | Indiana | Spring | unnamed_6925 (Richland/Green Russian)/Bond (Avena sterilis - strain from Algeria, 1918/Golden Rain) |
| Coker 227 | South Carolina | Winter | Unnamed_6857(Unnamed_6772/unnamed_6786) X Unnamed_6855(Suregrain/unnamed_6854) |
| Coker 234 | South Carolina | Winter | Unnamed_6857(Unnamed_6772/unnamed_6786) X Unnamed_6855(Suregrain/unnamed_6854) |
| Coker 242 | North Carolina | Winter | Victorgrain (Victoria - Argentian/Fulgrain)/unnamed_12823 (Fulwood/unnamed_6315) |
| Coker 716 | North Carolina | Winter | Coker 62-30 (unknown/unknown)/Beltsville Selection 279 (unnamed_9419/Clintland) |
| Colberson | North Carolina | Winter | Colberson |
| Columbia | Indiana | Spring | offtype plant selection from Fulghum (Fulghum/Fulghum)/offtype plant selection from Fulghum (Fulghum/Fulghum) Red Rust Proof |
| Corondo | North Carolina | Winter | Corondo |
| Dal | Wisconsin | Spring | X660(Belar/Trispernia) X Beedee(Beacon/unnamed_4877) |
| Dancer_CDC | Saskatchewan | Spring | OT344(OT235/OT743) X W90279(Konrad/OT244) |
| Dane | Wisconsin | Spring | WI X3530-47(N569-42-51/Froker) X Ogle(Brave/Unnamed_336) |
| Delair | North Carolina | Winter | Fulghum (Red Rustproof/Red Rustproof)/Bond (Avena sterilis - strain from Algeria, 1918/Golden Rain) |
| Derby | Saskatchewan | Spring | Calibre / Cascade |
| DeSoto | North Carolina | Winter | Lee (Winter Turf/Aurora)/Victoria - Argentina (sel. From artificial (mass) population of lines 64q, 64r, 64t, grown in Uruguay (increased in Argentina) |
| Dominik (Bauer) | Germany | Spring | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Drummond | New Zealand | Unknown | Unknown (unknown/Unknown) X Unknown(unknown/unknown) |
| Excel | Indiana | Spring | sle. From Wintok (Wintok/Wintok)/sle. From Wintok (Wintok/Wintok) (Hairy Culberson/Winter Fulghum) |
| Exeter | Winnipeg | Spring | Victory(Milton(Sweden)/Milton(Sweden)0 X Rusota(Green Russian/Green Russian) |
| Firth | United Kingdom | Spring | CR 3/418 (unknown/unknown)/ Flamingsvita (Marga/Selma) |
| FL0047-J9 | Florida | Winter | Horizon 474/TX97C1168 |
| FL0115-J2 | Florida | Winter | FL97AB15-A5-B6/TX97C1130 |
| FL0238BSB-22 | Florida | Winter | TX96M1560/ND 961161 |
| FL03001BSB-S7 | Florida | Winter | LA9339E45/Bw3996 |
| FL03053-S06-15-B-S1B | Florida | Winter | LA989IBI-51-B-I1-I2/UFRGS 01B6189-6-3 |
| FL03129-Ab7 | Florida | Winter | FL92OHR28,204 /NCO348-U3//Bw 4899/3/UPF96146-5-7-2 |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| FL03146BSB-S1-B-S1 | Florida | Winter | TAMO 405/HZN 474 |
| FL03167BSB-145 | Florida | Winter | LA9818IBIB-I2-B-I1(LA90151C11-2-1/TX96M1554)/FL0205 F1 (P973A38-3-6/202-97 (Uruguay)) |
| FL03167BSB-147 | Florida | Winter | LA9818IBIB-I2-B-I1(LA90151C11-2-1/TX96M1554)/FL0205 F1 (P973A38-3-6/202-97 (Uruguay)) |
| FL03167BSBS-3 | Florida | Winter | LA9818IBIB-I2-B-I1(LA90151C11-2-1/TX96M1554)/FL0205 F1 (P973A38-3-6/202-97 (Uruguay)) |
| FL03184-FLID-B-S1 | Florida | Winter | LA9824IBI-19-I2-C-I4-I1/UFRGS 017130-3(Naked, Porto Alegro) |
| FL04155-S06-31-B-S1 | Florida | Winter | FL03139 F1 (TROPHY/MN00226)/FL03224 F1 (UPF94174-1/FL9605-A6-B4) |
| FL04178-FLID-B-S-2 | Florida | Winter | FL03144 F1 (Bw 1000/SD000813) /LA9914IBI-23-12-G7 |
| FL99084-J2 | Florida | Winter | TX96D210FL/98008 F1(LA90151-BB-11-2-1/UFRGS 940556) |
| FL99153FBS-45-1-B-S-B-S1-B-S1 | Florida | Winter | TX95C3147/FL98007 F1(SC 942283/UFRGS 940556) |
| FL99212-D6 | Florida | Winter | UFRGS 921260/FL98091 F1 (P8674B1-2-4-2-5/TX97C1130) |
| Flaemingsnova | Germany | Spring | Pendek(Flamingold/Binder) X Flamingsstahl(unnamed_6736/Dippes WeiB) |
| Florida 167 | North Carolina | Winter | Bond (Avena sterilis - strain from Algeria, 1918/Golden Rain)/Fulghum (Red Rustproof/Red Rustproof) |
| Florida 500 | North Carolina | Winter | Florad (Floriland Irradiated/unknown)/unnamed_6485 (unnamed_6484/unnamed_6483) |
| Florida 501 | Florida | Winter | Florad(Floriland Irradiated/Unknown) X Unnamed_6485(unnamed_6484/Unnamed_6483) |
| Floriland | North Carolina | Winter | Florida 167 (Bond/Fulghum)/Landhafer (Red Algerian/Red Algerian) |
| Ford Early Giant | Unknown | Unknown | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Forkedeer | North Carolina | Winter | sel. From Fulghum (699-2011, CI 2499) (Flughum/Fulghum)/sel. From Fulghum (699-2011, CI 2499) (Flughum/Fulghum) |
| Freddy | Germany | Spring | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| FREJA | Norway | Spring | Vg 75842_X_DULA |
| Fulghum | Georgia | Winter | Red Rustproof(Sel from Red Algerian(Stanton 1954)or introduced from Mexico (Stranton,1954)/sel from Red Algerian (Stranton1954)or introduced from Mexico(Stranton,1954) X Red Rustproof(Sel from Red Algerian(Stranton1954)or introduced from Mexico(Stranton,1954)/Sel. from Red Algerian(Stranton1954)or introduced from Mexico (Stranton,1954) |
| Fulgrain | North Carolina | Winter | Big Boy (unknown/unknown)/Navarro (sel. From North American landrace/sel. From North American landrace) |
| Furlong | Winnipeg | Spring | W93069(Pg16)(W86226(Pg16)/Robert) X Ac Assiniboia(90GC144/Robert) |
| Gehl | Ottawa | Spring | 06751-64-1(NO70-1/05305-63) X 06540(AC Baton/06523) |
| Gem | Wisconsin | Spring | WI X6051(MO 07468/unnamed_4882) X Ogle (Brave/unnamed_336) |
| Gere | Norway | Spring | Gere |
| GN04399 | Norway | Spring | GN04399 |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| Goslin | Ottawa | Spring | OA952-3(OA797-7/02540-3-7-2) X 06196(Pc48/OA952-3) |
| Grane | Norway | Spring | unknown/unknown |
| Grenader | Norway | Spring | Hedmarkshavre/Hedmarkshavre |
| GUNHILD | Norway | Spring | Sv 97707_X_SANNA |
| H927-1-6-1-x-x-24 | Unknown | Unknown | Hairy Culberson(Culberson/Culberson) X unnamed_18804(Fulghum/RedRustproof) |
| HA05AB10-47 | Idaho | Spring | 95Ab1284 / Powell |
| HA05AB10-51 | Idaho | Spring | 95Ab1284 / Powell |
| HA05AB16-31 | Idaho | Spring | Powell / 96Ab9074 |
| HA05AB20-1 | Idaho | Spring | 82Ab248/ND930122 |
| HA05AB21-7 | Idaho | Spring | 90Ab1322/ND930122 |
| HA05AB22-9 | Idaho | Spring | 94Ab5543/ND 930122 |
| HA05AB29-17 | Idaho | Spring | AbSP 9-2/MN 94112 |
| HA05AB29-39 | Idaho | Spring | AbSP 9-2/MN 94112 |
| HA05AB31-15 | Idaho | Spring | 90Ab1322/MN 94112 |
| HA05AB34-48 | Idaho | Spring | 90Ab1620/95Ab12743 |
| HA05AB35-16 | Idaho | Spring | 95Ab12743/90Ab1322 |
| HA05AB36-33 | Idaho | Spring | 96Ab8796/95Ab12743 |
| HA05AB38-22 | Idaho | Spring | 97Ab8510/90Ab1322 |
| HA05AB38-39 | Idaho | Spring | 97Ab8510/90Ab1322 |
| HA05AB41-38 | Idaho | Spring | 84Ab358 / 95Ab12729 |
| HA05AB42-20 | Idaho | Spring | P909A23-1 / AbSP9-2 |
| HA05AB53-40 | Idaho | Spring | 94Ab5326 / 95Ab10854 |
| HA05AB9-32 | Idaho | Spring | 91Ab502 / ND930122 |
| HA05AB9-52 | Idaho | Spring | 91Ab502 / ND930122 |
| HA08-03X09-1 | Idaho | Spring | 98Ab6346/TAMO6-4 |
| HA08-03X31-1 | Idaho | Spring | 99Ab11899/TAMO7-3 |
| HA08-03X45-1 | Idaho | Spring | Ajay/TAMO5-4 |
| HA08-03X49-1 | Idaho | Spring | CDC Dancer/Monida |
| Harrison | South Carolina | Winter | unknown/unknown |
| Hazel | Illinois | Spring | Coker 227(unnamed_6857/unnamed_6855) X unnamed_5457(Clintford/Portal) |
| HiFi | North Dakota | Spring | ND90141(ND894904/ND852107) X ND900118(MN78142/ND852158) |
| HLA05AB1-34 | Idaho | Spring | 95Ab12970 / 95Ab11091 |
| Horizon 201 | Florida | Winter | FL92OHR35183-Y1/TX96M1384 (=FL99201-D29-E1) |
| Horizon 270 | Unknown | Unknown | FL95MEO29/TX93M2107 |
| HORIZON LA976 | Louisiana | Winter | FL92OHR26763/TX93M2107 |
| Hurdal | Norway | Unknown | A90017(Unkown/Unknown) X Martin(Grakall/Tador) |

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**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|------|--------|--------------|----------|
| IL00-654 | Illinois | Spring | Brawn/IL95-8346 |
| IL02-10836 | Illinois | Spring | IL97-19238/SD 97852 |
| IL02-5630 | Illinois | Spring | IL95-1555/IL97-18116 |
| IL02-8011 | Illinois | Spring | Tack  / IL94-3961 (IL88-14751/IL86-4189) |
| IL02-8658 | Illinois | Spring | Tack /Spurs |
| IL03-2658 | Illinois | Spring | IL94-784/IL94-3961 |
| IL03-7936 | Illinois | Spring | IL96-16806 /IL98-18614 |
| IL04-2727 | Illinois | Spring | Sesqui/ IL3538 |
| IL04-3664 | Illinois | Spring | Spurs/ IL96-11037 |
| IL04-4410 | Illinois | Spring | IL96-3151/ IL98-14767 |
| IL04-7077 | Illinois | Spring | Buckskin /  Tack |
| IL05-10015 | Illinois | Spring | IL00-8279/ IL00-8622 |
| IL05-10069 | Illinois | Spring | IL00-8439/ IL98-10145 |
| IL05-11942 | Illinois | Spring | P971A9-7-4/ IL00-8279 |
| IL05-1705 | Illinois | Spring | OA1021-1/ IL00-4858 |
| IL05-1778 | Illinois | Spring | OA1021-1/ IL00-8279 |
| IL05-3337 | Illinois | Spring | IL96-10351/ OA1021-1 |
| IL05-3806 | Illinois | Spring | IL98-2344/ Buckskin |
| IL05-3928 | Illinois | Spring | IL98-2344/ IL00-8279 |
| IL05-6223 | Illinois | Spring | IL99-1515/ OA1021-1 |
| IL05-8515 | Illinois | Spring | IL00-4858/ IL2838-1 |
| IL05-9330 | Illinois | Spring | IL00-8007/ Spurs |
| IL05-9931 | Illinois | Spring | IL00-8279/ IL00-8622 |
| IL05-9948 | Illinois | Spring | IL00-8279/ IL00-8622 |
| IL06-1161 | Illinois | Spring | P971A10-4-6/ IL00-7931 |
| IL06-3258 | Illinois | Spring | Buckskin/ Winona |
| IL06-3751 | Illinois | Spring | IL00-205/ Buckskin |
| IL06-5456 | Illinois | Spring | IL00-4827/ Buckskin |
| IL2250-15 (PI641978) | Illinois | Spring | Clintland 64*5/IL86-5698 |
| IL2250-18 (PI641979) | Illinois | Spring | Clintland 64*5/IL86-5698 |
| IL2294-1 (PI641996) | Illinois | Spring | Clintland 64*5/IL86-6404 |
| IL2294-2 (PI641997) | Illinois | Spring | Clintland 64*5/IL86-6404 |
| IL2294-3 (PI641998) | Illinois | Spring | Clintland 64*5/IL86-6404 |
| IL2294-8 (PI641999) | Illinois | Spring | Clintland 64*5/IL86-6404 |
| IL250-14 (PI641977) | Illinois | Spring | Clintland 64*5/IL86-5698 |
| IL250-3 (PI641976) | Illinois | Spring | Clintland 64*5/IL86-5698 |

Table 3.1 *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| IL2815 (PI641965) | Illinois | Spring | IL86-5698/IL86-1156//Ogle/IL86-6404 |
| IL2838 (PI641966) | Illinois | Spring | IL86-5698/IL86-1156//Ogle/IL86-6404 |
| IL2858 (PI641967) | Illinois | Spring | IL86-5698/IL86-1156//Ogle/IL86-6404 |
| IL2901 (PI641968) | Illinois | Spring | IL86-5698/IL86-1156//Ogle/IL86-6404 |
| IL3555 (PI641970) | Illinois | Spring | IL86-5698/IL86-1156//Ogle/IL86-6404 |
| IL75-5665 | Illinois | Spring | Coker 227// Clintford / Portal |
| IL75-5743 | Illinois | Spring | Coker 227 // CI5068 /CI 8074 |
| IL86-1156 | Illinois | Spring | Ogle*2/IL75-5743 |
| IL86-4189 | Illinois | Spring | Lang/IL75-5662//IL79-1776 |
| IL86-5698 (PI539875) | Illinois | Spring | IL74-5234/IL75-5662//IL81-1454 |
| IL86-5698-3 | Illinois | Spring | IL86-5698(unnamed_7075/IL81-1454) X IL86-5698(unnamed_7075/IL81-1454) |
| IL86-6404 (PI539874) | Illinois | Spring | IL74-5234/IL75-5662//IL81-1454 |
| IL98-10145 | Illinois | Spring | IL88-854 (Newdak/IL82-1657 (Froker/Hazel)) / IL90-7147 (IL86-4467 /Pennuda) |
| IN09201 | Indiana | Spring | IN09201 |
| Jay | Indiana | Spring | P8640A1-31(P79103B1-7-2/Unnamed_9242) X P8640A1-31(P79103B1-7-2/Iowa H728) |
| Jerry | North Dakota | Spring | Valley(unnamed_2588/Porter) X ND810458 (unnamed_6644/unnamed_6645) |
| Kangaroo | Australia | Winter | Unnamed_15143(SV88123-104/WA84Q406) X SV86153_101(unnamed_11891/Unknown) |
| Kanota | Kansas | Winter | Fulghum(Red Rustproof/Red Rustproof) X Fulghum (Red Rustproof/Red Rustproof) |
| Kapp | Norway | Spring | Grakall (Voll/Nidar II)/Tador (Sang/Unisignum) |
| Kaufman | Alberta | Spring | AC Assiniboia(90GC144/Robert) X AC Medallion(90GC142.143/Dumont) |
| Kolbu | Norway | Spring | unknown/unknown |
| LA02012-S-B-139-S2-B-S2-B-S2 | Louisiana | Winter | LA9513IBTB-80-I1-B/MF9424-24 |
| LA02035-I-J1 | Florida | Winter | LA978GIB-172/HZN LA976 |
| LA0210SBSBSBSB-S1 | Louisiana | Winter | 9513BTB-80-I2/TX00D176 |
| LA03012SBSBSB-12 | Louisiana | Winter | LA966BIB32-1-1-B/TX01AB7097 |
| LA03012SBSBSB-61 | Louisiana | Winter | LA966BIB32-1-1-B/TX01AB7097 |
| LA03018SBSBSB-65-S1 | Louisiana | Winter | LA9819IBI-75-2-B/FL9418-A3-B4-B-I |
| LA03040SBSBSB-83 | Louisiana | Winter | LA9339/HORIZON321 |
| LA03046SBS7-B-S1 | Louisiana | Winter | LA9339/TAMO405 |
| LA03060SBSBSB-S1 | Louisiana | Winter | TX96M1398/LA9339 |
| LA03063SBSBSB-6 | Louisiana | Winter | UFRGS 952521/LA966BIB32-1-1-B |
| LA03063SBSBSB-S4 | Louisiana | Winter | FL92OHR26763/TX93M2107 |
| LA03066SBS-L1 | Louisiana | Winter | UFRGS 952521/LA966BIB32-1-1-B |
| LA04004SBSB-121 | Louisiana | Winter | UFRGS995080-1/9818IBI-24-B-I1 |
| LA04004SBSB-61-B-S1 | Louisiana | Winter | LA97006GBS-30-1-C/LA90113-1-B3-AFL2-1-19-3-1 |
| LA04014SBSB-39 | Louisiana | Winter | LA97006GBS-30-1-C/LA90113-1-B3-AFL2-1-19-3-1 |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| LA04018SBSB-181 | Louisiana | Winter | TX96M1385/LA604//833 |
| LA04018SBSB-86 | Louisiana | Winter | HARRISON/TAMO405 |
| LA05006GSBS-7-S1 | Louisiana | Winter | HARRISON/TAMO405 |
| LA06058SBS-32-S1 | Louisiana | Winter | LA9339/TAMO 405 |
| LA06059SBS-84-S1 | Louisiana | Winter | TAMO 405/HZN LA976 |
| LA604 | Louisiana | Winter | Coker76-30/5/Coker75-27/4/Coker76-29/3/Coker76-23//Coker75-28/CI8335/6/Coker84-15/4/'Blizzard'/3/Coker 79-21//'Coker 234'/CI9139 |
| LA9339 | Louisiana | Winter | Coker85-13/X470 |
| LA97006GSB-59-2-4-SBS1 | Louisiana | Winter | TAMO 405/LA99016 |
| LA99016 | Louisiana | Winter | TX96M1385/SECTLA495 |
| LA99017 | Louisiana | Winter | TX96M1385/LA604 |
| Landhafer | North Carolina | Winter | Red Algerian (native cultivated red oat of Algeria/unknown)/Red Algerian (native cultivated red oat of Algeria/unknown) |
| Lang | Illinois | Spring | Tyler(Clintland60/unnamed_4021) X Orbit (Alamo/unnamed_5461) |
| LAO-900-042 | Ottawa | Spring | OT903 / Kaufmann // Ronald |
| Lee | North Carolina | Winter | Winter Turf(unknown/unknown)/Aurora (Appler/Appler) |
| Lena | Norway | Spring | Sang (Sv 01771/Condor)/Unisignum (Regent - Bickelmann, 1989/Phonix) |
| Lennon | United Kingdom | Spring | Lennon |
| LIPOPLUS | Norway | Spring | BELINDA_X_MATILDA |
| Lutz | Germany | Spring | Unnamed_11632(Flamingsstern/AJ20-61) X Fagot(unknown/unknown) |
| Madison | North Carolina | Winter | unnamed_8035 (Delair/Carolee)/Coker 69-20 (Coker 62-30/Beltsville Selection 279) |
| Maida | North Dakota | Spring | ND873126/ASSINIBOIA |
| Maldwyn | United Kingdom | Spring | Victory(Milton(Sweden)/Milton(Sweden)) X Radnorshire Spring(landrace/ landrace) |
| MAM 17-5 | Wisconsin | Spring | JR2-3-3-B(N770-165-2-1/DCS 1789) X Heritage(Unnamed_11009/Marino) |
| Marie_AC | Winnipeg | Spring | Unnamed_4579(REG3239/OT224) X OT233(Harmon HAMXDx7) |
| Marion (Canada) | St. Foy, Can. | Spring | Q.O.130.4(Unnamed_7393/Unnamed_4006) X Q.O.51.27(Q.O.22.21/Q.O.21.5) |
| Matilda | Sweden | Spring | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Maverick | Unknown | Unknown | 80Ab988(74Ab1952/74Ab2603) X Monida(Cayuse/Otana) |
| Melys | United Kingdom | Spring | 07524CnVI/6n(Maris Oberson/07022CnI/5n) X Caron(Maris Oberson/Milo) |
| MF9522-523 | Pennsylvania | Unknown | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| MN 811045 | Minnesota | Spring | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| MN06108 | Minnesota | Spring | SD986600/ND981502 |
| MN06109 | Minnesota | Spring | SD986600/ND981502 |
| MN06125 | Minnesota | Spring | IL99-8803/MN01135 |
| MN06239 | Minnesota | Spring | Sask01T-602-05-06/MN01117 |
| MN07203 | Minnesota | Spring | Morton/IL95-1241 |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|------|--------|--------------|----------|
| MN07210 | Minnesota | Spring | Sesqui*2/Bettong//MN02108 |
| MN08106 | Minnesota | Spring | Sesqui/WIX7571-1//Kame |
| MN08123 | Minnesota | Spring | Sesqui/WIX7571-1//Kame |
| MN08124 | Minnesota | Spring | Sesqui/WIX7571-1//ND010426 |
| MN08129 | Minnesota | Spring | Kame//IL99-912/MN00206 |
| MN08130 | Minnesota | Spring | IL99-912/MN00206//Loyal |
| MN08131 | Minnesota | Spring | Morton//IL99-912/MN00206 |
| MN08132 | Minnesota | Spring | Sask01T-602-05-06/MN00206//MN03115 |
| MN08134 | Minnesota | Spring | SA03668/MN02231 |
| MN08137 | Minnesota | Spring | SA03668/Morton |
| MN08139 | Minnesota | Spring | Morton/SA02880 |
| MN08141 | Minnesota | Spring | SA04994/Kame |
| MN08146 | Minnesota | Spring | MN02218/3wSQC3-10 |
| MN08150 | Minnesota | Spring | MN02231/MN03205 |
| MN08155 | Minnesota | Spring | UFRGS952521/X7464-4 |
| MN08160 | Minnesota | Spring | IL99-8803/Sesqui |
| MN08211 | Minnesota | Spring | ACAss/S42/SA01717=SA060726 |
| MN08212 | Minnesota | Spring | OT2022/OT3006=SA061027 |
| MN08217 | Minnesota | Spring | OT2008/OT394=SA060201 |
| MN08222 | Minnesota | Spring | ACAssiniboia/S42/OT394=SO04600 |
| MN08225 | Minnesota | Spring | 3wSCC2-15/MN03205 |
| MN08230 | Minnesota | Spring | W98241/CDCORRIN//ND010426 |
| MN08234 | Minnesota | Spring | Morton//IL99-912/MN00206 |
| MN08238 | Minnesota | Spring | ND010786//SA01511/Leonard |
| MN08242 | Minnesota | Spring | SO03244//MN862055/MN00206 |
| MN08243 | Minnesota | Spring | Sesqui/WIX7571-1//SA03668 |
| MN08251 | Minnesota | Spring | SA04305/Loyal |
| MN08252 | Minnesota | Spring | SA04913/MN02225 |
| MN08253 | Minnesota | Spring | MN02218/3wSQC3-10 |
| MN08254 | Minnesota | Spring | MN02155/3wSQC3-15 |
| MN08260 | Minnesota | Spring | MN01117/WIX7571-1 |
| MN08262 | Minnesota | Spring | ACAss/S42/OT394 |
| MN08266 | Minnesota | Spring | MN02231/MN03205 |
| MN08268 | Minnesota | Spring | MN03119/MN03205 |
| MN08270 | Minnesota | Spring | MN02231/SO04390 |
| MN841801-1 | Minnesota | Spring | MN841801(MN65B663/65B1362) X MN841801(MN65B663/65B1362) |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| Moholt | Norway | Spring | Voll (Nidar/Grenader)/Palu (Orn/Minor) |
| Morgan_AC | Alberta | Spring | OT526 X O'T764 |
| Mortlock | Australia | Winter | Elan(unnamed_9330/Florida 500) X 66QO1-44(unnamed_7579/Swan) |
| Morton | North Dakota | Spring | ND880922(ND830775/Riel) X IAB605-X(sel.from an irradiated compsite cross pop/sel from an irradiated composite cross pop.) |
| Navaro | Ottawa | Spring | Navaro |
| ND000861 | North Dakota | Spring | ND950524/HiFi |
| ND001397 | North Dakota | Spring | BG27/BG25  NPB880304/95-40-4-4 (13/21)155 |
| ND020290 (PO 808) | North Dakota | Spring | MN97112/ND971454  99043SSD  25/221  OBEE JUD |
| ND030078 | North Dakota | Spring | YOUNGS/ND980479 |
| ND040196 | North Dakota | Spring | ND931314/Souris |
| ND040492 | North Dakota | Spring | ND970216/Souris |
| ND050017 | North Dakota | Spring | HiFi-11/ND001407  02007  14/225  BG |
| ND050490 | North Dakota | Spring | ND981903/ND990232  02085  87/101  NRPB  Pc91 lo |
| ND050506 | North Dakota | Spring | ND981906/RONALD  02087  88/256  a Pc68 Dw |
| ND050578 | North Dakota | Spring | ND990232/ND970216  02103  101/56  IAB a |
| ND051037 | North Dakota | Spring | ND000306/ND980370  02160  171/64  a HiF |
| ND051069 | North Dakota | Spring | ND000490/ND000916  02164  178/207  Ao lo Pc91HiFi |
| ND051236 | North Dakota | Spring | ND000798/ND980370  02181  193/64  HiFi Pc91 NRPB a |
| ND051306 | North Dakota | Spring | ND000811/ND980671  02185  199/69  Pc91 lo HiF |
| ND051312 | North Dakota | Spring | ND000811/ND980671  02185  199/69  Pc91 lo HiF |
| ND051467 | North Dakota | Spring | ND001336/HiFi-19  02207  220/15  BG HiFi |
| ND051513 | North Dakota | Spring | ND001444/HiFi-51  02214  227/16  BG HiF |
| ND060111 | North Dakota | Spring | 96-503 Cn32/ND990232  03001  1/58  Pc91 lo |
| ND060182 | North Dakota | Spring | CDC Dancer/ND011608  03016  5/228  Pc91 a |
| ND060223 | North Dakota | Spring | HiFi-9/ND980370  03020  7/36  NRPB a |
| ND060235 | North Dakota | Spring | HiFi-93/ND981442  03022  9/42  Pc91 lo BG Comp |
| ND060249 | North Dakota | Spring | HiFi-117/HiFi SR1  03023  10/11  Pc91 BG |
| ND060342 | North Dakota | Spring | Killdeer/ND000931  03033  13/135  Pc91 a |
| ND060418 | North Dakota | Spring | ND931318/ND931314  03052  23/22  Pc91 lo |
| ND060432 | North Dakota | Spring | ND970216/ND000750  03062  32/114  Pc91 lo? a |
| ND060449 | North Dakota | Spring | ND980671/Souris  03065  38/30  a Pc91 lo? |
| ND060464 | North Dakota | Spring | ND981065/ND011600  03069  40/225  Pc91 lo Hyt |
| ND060487 | North Dakota | Spring | ND981845/HiFi-9  03077  46/7  Pc91 a |
| ND060507 | North Dakota | Spring | ND981887/ND011288  03078  48/211  Pc45 a |
| ND060570 | North Dakota | Spring | ND990148/ND991293  03092  55/82  Pc91  a lo? |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| ND060652 | North Dakota | Spring | ND990355/ND000802 03107 64/118 Pc91 lo HiFi |
| ND060897 | North Dakota | Spring | ND000824/ND010278 03163 122/175 HiFi Pc91 68 a |
| ND060925 | North Dakota | Spring | ND000865/ND991056 03168 126/73 Pc91 a |
| ND061097 | North Dakota | Spring | ND001018/Souris 03187 Tall 139/30 IAB Pc91 a Dw |
| ND061590 | North Dakota | Spring | ND011598/ND000223 03259 224/98 Pc91 lo Hyt |
| ND061614 | North Dakota | Spring | ND011604/ND981065 03262 227/40 Pc91 lo Hyt |
| ND061813 | North Dakota | Spring | Tri.Crown/ND010074 03319 282/165 Pc68 a |
| ND061868 | North Dakota | Spring | HiFi/IAN979-5-1-22 ND030288 Am Pc91 |
| ND061975 | North Dakota | Spring | Otana//M2609/Otana 03336 271/02297 |
| ND070388 | North Dakota | Spring | ND011054/ND030612 St Gr 04070 |
| ND070813 | North Dakota | Spring | ND000824/ND010848 04167 63/101 106/252 |
| ND071063 | North Dakota | Spring | ND011616/ND9508252-7-2 Drov/Jud BG 04211 |
| ND071521 | North Dakota | Spring | ND031348/ND951394 B 04271 261/37 123/33 |
| ND071694 | North Dakota | Spring | ND873126/Morton (Diego #3) |
| ND072258 | North Dakota | Spring | ND990118/ND030288 05030 15/7 |
| ND080724 | North Dakota | Spring | Drover/MN00207 05085 32/21 |
| ND081924 | North Dakota | Spring | Triple Crown/ ND030220 Mtn 232 05383 293/123 |
| Nes | Norway | Spring | Nes |
| Nice | Ottawa | Spring | Sylva // PGR8648 / Woodstock /3/ Donegal) |
| Noble-2 | Minnesota | Spring | Noble(Tippecanoe/unnamed_10546) X Noble(Tippecanoe/unnamed_10546) |
| Novojatkovo | Unknown | Unknown | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Nudist | Norway | Spring | Nudist |
| OA1058-4 | Ottawa | Spring | AC Aylmer / 06897 (=AC Aylmer*2 / Pc96) |
| OA1063-8 | Ottawa | Spring | 05627-49(Pc68/Donegal) X Capital(Q.O.151.55/OT521) |
| OA1130-1 | Ottawa | Spring | 06914-1-1 / 06919-5-1 (= Pc48 / OAC Arrow // AC Aylmer / OAC Arrow) |
| OA1174-3 | Ottawa | Spring | Ida / 06909-3-94 |
| OA1176-1 | Ottawa | Spring | Ida / 06909-1-19 |
| OA1180-4 | Ottawa | Spring | Ida / OA1019-6 |
| OA1180-5 | Ottawa | Spring | Ida /06909-2-26 |
| OA1189-1 | Ottawa | Spring | OA1025-1/ 07800-2-8-1-1a |
| OA1189-4 | Ottawa | Spring | OA1025-1/ 07800-2-8-1-1a |
| OA1196-3 | Ottawa | Spring | 07800-2-8-8-1a / OA1025-1 |
| OA1197-1 | Ottawa | Spring | 07800-2-8-5-1a / Sherwood |
| OA1202-1 | Ottawa | Spring | 07783-3-2-1-1a / SA99297 |
| OA1204-2 | Ottawa | Spring | MN-00222/07836-2-9-2-1a |
| OA1207-1 | Ottawa | Spring | 95Ab10854 / 07776-3-9-1-1a |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| OA1226-1 | Ottawa | Spring | 07836-2-9-3-1a-2 / ND960620 |
| OA1226-4 | Ottawa | Spring | 07836-2-9-3-1a-2 / ND960620 |
| OA1228-1 | Ottawa | Spring | W99A747 / 07836-2-5-2-1a-4 |
| OA1232-2 | Ottawa | Spring | 06973-5-10-15-2 / ND960620 |
| OA1232-5 | Ottawa | Spring | 06973-5-10-15-2 / ND960620 |
| OA1234-1 | Ottawa | Spring | OT288/Triple Crown |
| OA1242-5 | Ottawa | Spring | 06909-3-94/Irish |
| OA1248-1 | Ottawa | Spring | 07836-2-9-2-1a-1/07823-2-4-3-1a-1 |
| OA1250-1 | Ottawa | Spring | Souris/07836-2-5-2-1a-2 |
| OA1250-2 | Ottawa | Spring | Souris/07836-2-5-2-1a-2 |
| OA1251-1 | Ottawa | Spring | Souris/07774-3-9-1-1a-1 |
| OA1253-1 | Ottawa | Spring | 97Ab7979/07189-10-1-5 |
| OA1256-1 | Ottawa | Spring | Souris/07189-10-8-6 |
| OA1260-1 | Ottawa | Spring | OA1070-2/07834-3-1-1-1a-1 |
| OA1262-1 | Ottawa | Spring | 07593-1-1-2/07989-10-1-8 |
| OA1263-2 | Ottawa | Spring | 07878-3-6-5/07870-3-5-4 |
| OA1266-1 | Ottawa | Spring | 07869-2-9-4/07868-2-1-1 |
| OA1268-3 | Ottawa | Spring | 07868-1-71-1/07867-1-14-1 |
| OA1272-1 | Ottawa | Spring | 07877-3-13-4/07878-3-7-1 |
| Odal | Norway | Spring | Guldregn (Milton/Milton)/Foredlad Dalahavre |
| Ogle | Illinois | Spring | Brave(Putnam/unknown_2618) X unnamed_336(Tyler/Egdolon23) |
| Olram | Norway | Spring | Sv692013/POL (Bambu/Norum 206) |
| Osage | North Carolina | Winter | Fulton (Fulghum/Markton)/Sel.5562 (Vicotria - Argentian/Richland) |
| OT3028 | Saskatchewan | Spring | AC Goslin / SA96400 |
| OT3036 | Saskatchewan | Spring | OT396 / HiFi |
| OT3037 | Saskatchewan | Spring | AC AssS42 / OT385 |
| OT3039 | Saskatchewan | Spring | OT3004 / CDC-01-499-04-227 |
| OT3040 | Saskatchewan | Spring | OT3002 / OT394 |
| OT3045 | Saskatchewan | Spring | OT3002 / OT394 |
| OT3046 | Saskatchewan | Spring | OT392 / OT557 |
| OT3047 | Saskatchewan | Spring | OT393 / OA019-1 |
| OT3048 | Saskatchewan | Spring | CDC Sol-Fi / HiFi |
| OT3050 | Saskatchewan | Spring | OT399 / Freddy |
| OT380 | Saskatchewan | Spring | OT366(SO 88118/J775-1) X OT356(SO 85190/SO85022) |
| OT399 | Saskatchewan | Spring | OT368 / Gem |
| OT586 | Saskatchewan | Spring | Unnamed_14836(Marion(Canada)/AC Assiniboia) X Unnamed_14837(Riel/Goslin) |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| OT7053 | Saskatchewan | Spring | CR245-Dw // Paul / Kauf |
| Otana | Idaho | Spring | CIav 5345(unnamed_9199/Overland) X Zanster(unknown/unknown) |
| Ozark | Arkansas | Winter | Florida 167 (Bond/Fulghum)/6-81-3 (unknown/unknown) |
| Pacer_CDC | Saskatchewan | Spring | W84425(unnamed_6382/OT224) X OT751(unnamed_6383/unnamed_6384) |
| Pg11 | Unknown | Unknown | SES Sel.52(Burt/Burt) X OT313(Corbit/Random) |
| Pg16 | Unknown | Unknown | Rodney O (Rodney/unnamed_5273) X Unnamed_5321(Rodney O/unnamed_5320) |
| PI260616-1 | Minnesota | Spring | Amarela 5282 FB 32 (Brazil) |
| PI266887-1 | Minnesota | Spring | San Jose (Portugal) |
| Pinnacle_AC | Winnipeg | Spring | 91RAT20(OT248/OT237) X AC Medallion(90GC142.143/Dumont) |
| Pioneer | North Carolina | Winter | Flughum (Red Rustproof/Red Rustproof)/Winter Turf (unknown/unknown) |
| Pl263412-1 | Minnesota | Spring | Pl263412-1 |
| POL | Norway | Spring | Bambu (unnamed_6329/unnamed_6330)/Norum 206 (unk/unk) |
| Porter | Indiana | Spring | P623A1-1-9-1 (CI 7684 selection/unnmaed_7208)/Stout (unnamed_7447/unnamed_7471) |
| Prescott | Ottawa | Spring | OA1021(OA973-1/AC Aylmer) X OA1021(OA973-1/AC Aylmer) |
| ProFi_CDC | Saskatchewan | Spring | Gem(WI X6051/Ogle) X CDC Boyer (SO 82030/OT235) |
| Provena | Idaho | Spring | Pennlo(Egdolon 23/Otee) X Yung 492 (Unknown/Unknown) |
| Pusa Hybrid G | India | Unknown | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Putnam 61 | Indiana | Spring | Putnam (Purdue 3714A4-7-5/Clinton)/unnamed_8806 (Putnam/unnamed_8805) |
| Quincy Gray | North Carolina | Winter | unnamed_10592 (Victoria - Argentian/Norton)/Red Rustproof (sel. From Red Algerian (Stanton, 1954 or introduced from Mexico Stanton, 1954) |
| Racoon | United Kingdom | Spring | Krypton (unknown/Solva)/91-221Cn4 (Pendragon/90-273Cn) |
| Ranch | France | Unknown | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Red Algerian | North Carolina | Winter | native vultivated red oat of Algeria |
| Red Rustproof | California | Unknown | Sel. From Red Algerian(Stanton,1954)or introduced from Mexico(Stanton1954)(Unknown/Unknown) X Sel. From Red Algerian(Stanton,1954)or introduced from Mexico(Stranton1954)(Unknown/Unknown) |
| Rigodon_AC | St. Foy, Can. | Spring | Unnamed_9110(Ogle/unnamed_9109) X Q.O.174.19(A.O.9.4/Tarpan) |
| Ringsaker | Norway | Spring | Ringsaker |
| Robust | Indiana | Spring | P973A38-9-3 (P973A38/P973A38)/P973A38-9-3 (P973A38/P973A38) |
| Robust | Indiana | Spring | P973A38-9-3(P973A38/P973A38) X P973A38-9-3(P973A38/P973A38) |
| Rogers | North Carolina | Winter | Coker 80-33 (unnamed_12819/Coker 716)/NC 81-376 (Brooks/Coker 72-24) |
| Ronald_AC | Winnipeg | Spring | W89329(Dwarf)(W84188(tall)/Robert) X Ac Medallion(90GC142.143/Dumont) |
| Russell | Ottawa | Spring | Unnamed_4024(Garry/Ukraine) X Abegweit(Vanguard/Erban) |
| SA01223-02 | Saskatchewan | Spring | Gem / CDC Boyer |
| SA051172 | Saskatchewan | Spring | CDC Sol-Fi / HiFi |
| SA060605 | Saskatchewan | Spring | X7535-14 / OT3002 |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|------|--------|--------------|----------|
| SA060830 | Saskatchewan | Spring | OT399 / OT2030 |
| SA061148 | Saskatchewan | Spring | SA98741-11 / CDC ProFi |
| SA070089 | Saskatchewan | Spring | CDC Dancer / CDC ProFi |
| SA070270 | Saskatchewan | Spring | Ajay / OT399 |
| SA070367 | Saskatchewan | Spring | TAM2002 / CDC ProFi |
| SA070444 | Saskatchewan | Spring | OT3007 / SA99940 |
| SA070452 | Saskatchewan | Spring | OT399 / Quoll |
| SA070469 | Saskatchewan | Spring | OT399 / ABSP14-6 |
| SA070513 | Saskatchewan | Spring | SA01714 / 99-511Cn161 |
| SA070576 | Saskatchewan | Spring | OT559 / CDC ProFi |
| SA070592 | Saskatchewan | Spring | Jordan / CDC Orrin |
| SA070631 | Saskatchewan | Spring | Jordan / SA01594 |
| SA070655 | Saskatchewan | Spring | OT399 / CDC Dancer |
| SA070712 | Saskatchewan | Spring | Leggett / CDC Orrin |
| SA070781 | Saskatchewan | Spring | CDC Weaver / OT572 |
| SA070845 | Saskatchewan | Spring | 96Ab8597 / CDC Weaver |
| SA070860 | Saskatchewan | Spring | CDC Weaver / 98Ab6491 |
| SA070906 | Saskatchewan | Spring | CDC Sol-Fi / OT399 |
| SA070972 | Saskatchewan | Spring | 94-116Cn4/1 / CDC Weaver |
| SA071369 | Saskatchewan | Spring | SO02249 / OT3013 |
| SA071405 | Saskatchewan | Spring | CDC Weaver / Betania |
| SA071616 | Saskatchewan | Spring | SO03224 / Betania |
| SA071760 | Saskatchewan | Spring | CDC Weaver / Vista |
| Salomon | Germany | Spring | Alfred ( Mg63305/Mustang(Germany)) X Unnamed_11669(Astor/Salzmunde 95560/66) |
| Sang | Sweden | Spring | Sv01771(unnamed_6881-Sv56687) X Condor(Minor/Express) |
| Santa Fe | Argentina | Winter | Sel. From Argentina oat (Coffman, F.A. 1977)/Sel. From Argentina oat (Coffman, F.A. 1977) |
| SECTARIAT LA495 | Louisiana | Winter | Coker 84-15*2/4/'Blizzard'/3/Coker 79-21//'Coker 234'/CI9139 |
| Sesqui | Minnesota | Spring | P8640A1-31-1(P8640A1-31/P8640A1-31) X MI 84-0-6(P72288RB1-3-4-3/unnamed_6172) |
| Shadow | Quebec, Can. | Spring | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Sherwood | Ottawa | Spring | AC Aylmer / Goslin (or OA966-1 // OA952-3*2 / Pc48) |
| Simpson | North Carolina | Winter | Ballard (Pentagon (Stanton, 1955/Pentagon (Stanton, 1955)/S172 4Cn3/1/3/58/602Cn) |
| SO-1 | Saskatchewan | Spring | AC Assiniboia(90GC144/Robert) X SA96121(ND870425/CDC Boyer) |
| Sol-Fi_CDC | Saskatchewan | Spring | N979-5-1(MO 07929/IL85-6183-1) X OT 366(SO 88118/J775-1) |

Table 3.1 *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| Stout | Indiana | Spring | Unnamed_7447(Shield sib/unnamed_7216) X unnamed_7471(unnamed_7451/unnamed_7470) |
| Sun II-1 | Sweden | Spring | Stjarn(Victory/Crown) X Orn(Seger/VenLochow's Gelbhafer) |
| Sure Grain | North Carolina | Winter | Sure Grain |
| SW Betania | Sweden | Spring | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| SW INGEBORG | Norway | Spring | Sv 88359_X_SILVANO |
| SW KERSTIN | Norway | Spring | PETRA_X_BALETT |
| SW VAASA | Norway | Spring | Sv 841034_X_Sv 83626 |
| Sylva | Ottawa | Spring | Shaw / Ogle |
| TAM O-301 | Texas | Winter | AB555(Coronado/Cortez) X Unnamed_7141(unnamed_7182/unnamed_5530) |
| TAM O-397 | Texas | Winter | re-selection from TAMO- 386(TAMO-386/TAMO -386) X reselection from TAMO-386(TAMO-386/TAMO-386) |
| TAMO 405 | Texas | Winter | unknown (single vol. plant sel.) |
| TAMO 406 | Texas | Winter | Mitchell/TX83Ab2923/TAMO386R |
| TAMO 606 | Texas | Winter | Citation/84IORN#30 (=CX466-1-B4-D3-5) |
| Tardis | United Kingdom | Spring | 87-42Cn1/2/2/1/1(87-42CnI/2/2 X 87-42CnI/2/2) X 95-69RCn(87-42CnI/2/2 X 94-13) |
| Tift | North Carolina | Winter | Tift |
| Tippecanoe | Indiana | Spring | Clntland 60 (Clintland/unnamed_9214)/unnamed_4021 (clintland 60/MO 0-205) |
| Triactor | Saskatchewan | Spring | SW9619019 / Stork |
| Triple Crown | Saskatchewan | Spring | Unnamed_6891(unnamed_6893/unnamed-6892) X WW17734(unknown/unknown) |
| Trisparinia | North Carolina | Winter | Trisparinia |
| Trophy | Louisiana | Winter | LA90120C2-3-AB1/TX96M1558 |
| Troy | South Dakota | Spring | Unnamed_8040(WI X 2221-2/unnamed_8039) X MN 78142 (Otter/unnamed_6697) |
| TX02U 7029 | Texas | Winter | 92 SAT4-4//79C1515/79C5287/80Ab2726 |
| TX02U 7047 | Texas | Winter | TAMO386ERB/TAMO386R/92SAT24-4 |
| TX02U 7065 | Texas | Winter | UFRGS Q120101-4/TAMO386ERB/92SAT24-4 |
| TX02U 7097 | Texas | Winter | TX92M1505(C5-2 1563 CR Cpx/SR Cpx/unknown)/TX83Ab2923 |
| TX02U 7103 | Texas | Winter | Mitchell/T386'S'/TAMO386ERB/TAMO386R |
| TX02U 7104 | Texas | Winter | Mitchell/T386'S'/TAMO386ERB/TAMO386R |
| TX02U 7176 | Texas | Winter | C5-2,1563 CRcpx/SR cpx/Unknown |
| TX02U 7181 | Texas | Winter | C5-2,1563 CRcpx/SR cpx/Unknown |
| TX02U 7219 | Texas | Winter | TX92M1505/TX83Ab2923 |
| TX02U 7227 | Texas | Winter | TX92M1596/TX83Ab2923 |
| TX02U 7237 | Texas | Winter | TAMO386ERB/TAMO386R/92SAT24-4 |
| TX02U 7325 | Texas | Winter | UFRGS Q120101-4/TAMO386ERB/92SAT24-4 |
| TX02U 7443 | Texas | Winter | UFRGS Q120101-4/TAMO386ERB/92SAT24-4 |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| TX02U 7473 | Texas | Winter | TX94Ab343/TAMO386ERB |
| TX02U 7479 | Texas | Winter | 92M1009(T386"S"/94Ab347 |
| TX02U 7490 | Texas | Winter | 92M1065(TAMO386'S')/TAMO386ERB |
| TX02U 7518 | Texas | Winter | TAMO386ERB/TX93Ab693(833'S') |
| TX02U 7605 | Texas | Winter | TX92M1596(79Bord/Kenya SR/TAMO 386)/TX83Ab2923 |
| TX02U 7651 | Texas | Winter | Mitchell/TX83Ab2923/TAMO386R |
| TX02U 7682 | Texas | Winter | TAMO386ERB/TX83Ab2923 |
| TX05CS 347-1 | Texas | Winter | TAMO 405/Plot Spike LA9339 |
| TX05CS 347-2 | Texas | Winter | TAMO 405/Plot Spike LA9339 |
| TX05CS 542 | Texas | Winter | Rodgers/TAMO 405 |
| TX05CS 556 | Texas | Winter | Trophy/TAMO 405 |
| TX07CS1039 | Texas | Winter | Nora//TAMO 405 |
| TX07CS1228 | Texas | Winter | Horizon 314//TAMO 405 |
| TX07CS1268 | Texas | Winter | Horizon 321//TAMO 405 |
| TX07CS1402 | Texas | Winter | TX00D276=(C81-32//76-30*4/76-29) (=CX407-1-B3-1-FL-93-103-33-37)//TAMO 405 |
| TX07CS1564 | Texas | Winter | TX00M617=(98C893) UPF85380-A-1/92M1090(TAMO 386 RESEL.)//TAMO 405 |
| TX07CS1584 | Texas | Winter | TX00M628=(98C917)TX93AB693 RESEL=H833 OFF-TYPE SEL.(97CS693DS)//TAMO 405 |
| TX07CS1805 | Texas | Winter | TAMO 406=(Mitchell/TX83Ab2923/TAMO386R)//TAMO 405 |
| TX07CS1832 | Texas | Winter | Rodgers//TAMO 405 |
| TX07CS1948 | Texas | Winter | FL9701-P30=(Horizon 314/Chapman)//TAMO 405 |
| TX07CS1965 | Texas | Winter | FL9708-P71=(Coker 92Ab719/Horizon 314)//TAMO 405 |
| TX07CS1997 | Texas | Winter | LA9535D118-4=(T91AB2965/5/C88D1547Seln:85-13/4/84-15/3/81-21//79-22*2/Omega)//TAMO 405 |
| TX07CS2001 | Texas | Winter | LA966IBI-151-1=(FL9595MEO29/TX93M2107)//TAMO 405 |
| TX07CS2140 | Texas | Winter | NC97-8972N=(Bulk Sel)//TAMO 405 |
| TX07CS2201 | Texas | Winter | SC961246=(C75-28/TAM-O-312//Coker234/CMB10/3/C76-30*4/C76-29/4/Omega)//TAMO 405 |
| TX07CS2235 | Texas | Winter | SC96R036=(C86Five(C86-13/5/C84-15*2/4/C81-21/3/C79-21//C234/6/Omega)//TAMO 405 |
| TX07CS2350 | Texas | Winter | TX00D166=(Dallas/TAMO 386 (=OX90D009-7-76-20))//TAMO 405 |
| TX07CS2609 | Texas | Winter | Dallas//TAMO 406 |
| TX07CS2652 | Texas | Winter | Harrison//TAMO 406 |
| TX07CS2765 | Texas | Winter | Horizon 321//TAMO 406 |
| TX07CS2795 | Texas | Winter | TX01B3156=(TAMO 386ERB/TX83Ab2923)//TAMO 406 |
| Tyler | Indiana | Spring | Clintland 60 (Clintland/unnamed_9214)/unnamed_4021 (Clintland 60/MO 0-205) |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| UFRGS 8 | Brazil | Winter | OA338(00072-3-5/OA123-124) X WI X2682-1(unknown/unknown) |
| UFRGS 881971 | Brazil | Winter | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| UFRGS 930605 | Brazil | Winter | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| UFRGS077011-4 | Louisiana | Winter | UFRGS 987016-1 / UFRGS 19 |
| UFRGS077026-2 | Louisiana | Winter | UFRGS 007020-2 / UFRGS 984060-1 |
| UFRGS087023-5 | Louisiana | Winter | UFRGS 995088-3 / UFRGS 960257-5 |
| UFRGS087129-1 | Louisiana | Winter | UFRGS 995078-2 / URS 21 |
| UFRGS087157-3 | Louisiana | Winter | UFRGS 995088-3 / UFRGS 006049 |
| Ukraine reselection | Iowa | Spring | Reselection from Ukraine(CI3259)(Ukraine/Ukraine) X Reselection from Ukraine (CI3259)(Ukraine/Ukraine) |
| UPF95H900-10 | Louisiana | Winter | UPF14/UFRGS16 |
| UPF97H300-2-11 | Louisiana | Winter | UPF90H400/UFRGS16 |
| UPF98H2000-4 | Louisiana | Winter | UPF16/UPF91AL100-1-4-3 |
| UPFA20 | Louisiana | Winter | TEIXEIRINHA |
| UPFA22 | Louisiana | Winter | TEMPRANA |
| Urano | Chile | Unknown | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| URS 21 | Louisiana | Winter | QION 92/162 = UFRGS 10 / CTC 84B993 |
| URS 22 | Louisiana | Winter | URS 22 |
| VAO -58 | Ottawa | Spring | AC Gwen/Gehl |
| VAO-44 | Ottawa | Spring | 2002VB-33/Gehl |
| Vao-48 | Ottawa | Spring | VAO-1 (06751-64-1/06540)/OA516-2 (sel. of daylight insensitive dormats 119/sel. of daylight insensitive dormats 119) |
| VAO-51 | Ottawa | Spring | 2002VB-33/Gehl |
| Victoria | Uruguay | Unknown | Sel. From artificial(mass)pop. Of lines 64q.64r.64t grown in Uruguay(increasedin Argentina)(Unknown/Unknown) X Sel. From articicial ( mass) pop. Of lines 64q. 64r.64t grown in Uruguay(increased in Argentina)(Unknown/Unknown) |
| Vista | Wisconsin | Spring | Unnamed_6396(Ogle/MO 07468) X Centennial(N569-42-51/Unnamed_6468) |
| WAOAT2132 | Australia | Winter | Unknown(Uknown/Unknown) X Unknown(Unknown/Unknown) |
| Winter Fulghum | North Carolina | Winter | sel. From Fulghum (C.I. 699) (Richland/Richland)/sel. From Fulghum (C.I. 699) (Richland/Richland) |
| Winter Turf | North Carolina | Winter | unknown/unknown |
| WNPG 01 | Winnipeg | Spring | AC Ronald/00USDA05 |
| WNPG 02 | Winnipeg | Spring | AC Ronald//ND931475/AC Assiniboia |
| WNPG 03 | Winnipeg | Spring | CR245-Dw//Paul/AC Kaufmann |
| WNPG 04 | Winnipeg | Spring | CR245-Dw//Paul/AC Kaufmann |
| WNPG 05 | Winnipeg | Spring | CDC Dancer//Paul/AC Kaufmann |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| WNPG 06 | Winnipeg | Spring | AC Ronald/OT299 |
| WNPG 07 | Winnipeg | Spring | Assiniboia/Omskij |
| WNPG 08 | Winnipeg | Spring | Assiniboia/Omskij |
| WNPG 09 | Winnipeg | Spring | Omskij/Ronald |
| WNPG 10 | Winnipeg | Spring | Omskij/Ronald |
| WNPG 11 | Winnipeg | Spring | Baragan/Pinnacle//Ronald |
| WNPG 12 | Winnipeg | Spring | Baragan/Pinnacle//Ronald |
| WNPG 13 | Winnipeg | Spring | AC Mustang/Baragan//01HN3021(ND931475/ASB) |
| WNPG 14 | Winnipeg | Spring | AC Mustang/Baragan//01HN3021(ND931475/ASB) |
| WNPG 15 | Winnipeg | Spring | W97254/Pinnacle//Assiniboia/Omskij |
| WNPG 16 | Winnipeg | Spring | W97254/Pinnacle//Assiniboia/Omskij |
| WNPG 17 | Winnipeg | Spring | W97254/Pinnacle//Assiniboia/Omskij |
| WNPG 18 | Winnipeg | Spring | 01RAT26/CDC Sol-Fi |
| WNPG 19 | Winnipeg | Spring | Leggett/01RAT23 |
| WNPG 20 | Winnipeg | Spring | Leggett/OT2022 |
| WNPG 21 | Winnipeg | Spring | Leggett/OT2022 |
| WNPG 22 | Winnipeg | Spring | OT2022/Leggett |
| WNPG 23 | Winnipeg | Spring | OT2022/Leggett |
| WNPG 24 | Winnipeg | Spring | OT2022/Leggett |
| WNPG 25 | Winnipeg | Spring | OT2022/Leggett |
| WNPG 26 | Winnipeg | Spring | OT2022/01RAT23 |
| WNPG 27 | Winnipeg | Spring | OT2022/01RAT23 |
| WNPG 28 | Winnipeg | Spring | OT2022/01RAT23 |
| WNPG 29 | Winnipeg | Spring | OT2022/01RAT23 |
| WNPG 30 | Winnipeg | Spring | AC Morgan/AC Mustang |
| WNPG 31 | Winnipeg | Spring | AC Morgan/AC Mustang |
| WNPG 32 | Winnipeg | Spring | AC Morgan/OT394 |
| WNPG 33 | Winnipeg | Spring | AC Morgan/OT394 |
| WNPG 34 | Winnipeg | Spring | AC Morgan//Elvy/CDC Boyer |
| WNPG 35 | Winnipeg | Spring | AC Morgan//Elvy/CDC Boyer |
| WNPG 36 | Winnipeg | Spring | AC Morgan//Elvy/CDC Boyer |
| WNPG 37 | Winnipeg | Spring | OT7000(AC Belmont/AC Assiniboia)//Paul/AC Kaufmann |
| WNPG 38 | Winnipeg | Spring | JC1624#3/HiFi#3 |
| WNPG 39 | Winnipeg | Spring | ND9508252-75/CR245-Dw |
| WNPG 40 | Winnipeg | Spring | ND9508252-75-5//03P22A-BM1/Pc97 |
| Woodburn | Indiana | Spring | Woodburn |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
| --- | --- | --- | --- |
| X8787-1 | Wisconsin | Spring | X7535-9 / X7395-4 |
| X8791-1 | Wisconsin | Spring | X7571-1 / X6984-3 |
| X8826-1 | Wisconsin | Spring | IL92-7186 / X6356-2 |
| X8903-2 | Wisconsin | Spring | X7728-3 / X7509-1 |
| X8995-4 | Wisconsin | Spring | OA966-1 / Vista |
| X9082-1 | Wisconsin | Spring | X7822-3 / X7066-5 |
| X9150-1 | Wisconsin | Spring | X7994-2 / Gem |
| X9192-5 | Wisconsin | Spring | X8191-2 / ND961161 |
| X9195-2 | Wisconsin | Spring | X8208-5 / ND961161 |
| X9195-6 | Wisconsin | Spring | X8208-5 / ND961161 |
| X9200-4 | Wisconsin | Spring | OA981-9 / X8208-6 |
| X9221-6 | Wisconsin | Spring | X8163-1 / ND961161 |
| X9221-8 | Wisconsin | Spring | X8163-1 / ND961161 |
| X9253-1 | Wisconsin | Spring | X8163-1 / X8179-1 |
| X9258-5 | Wisconsin | Spring | X8175-2 / DRUMLIN |
| X9270-4 | Wisconsin | Spring | X8191-2 / X7571-1 |
| X9285-1 | Wisconsin | Spring | X8313-2 / X7766-1 |
| X9287-2 | Wisconsin | Spring | X8208-6 / X7464-4 |
| X9290-2 | Wisconsin | Spring | X8208-6 / DRUMLIN |
| X9368-1 | Wisconsin | Spring | X8163-2 / X8342-6 |
| X9375-1 | Wisconsin | Spring | X8170-3 / X8179-1 |
| X9384-2 | Wisconsin | Spring | X8184-2 / X8463-3 |
| X9386-1 | Wisconsin | Spring | X8188-5 / X8163-2 |
| X9392-1 | Wisconsin | Spring | X8191-5 / X8463-3 |
| X9395-2 | Wisconsin | Spring | X8191-8 / X7994-2 |
| X9396-1 | Wisconsin | Spring | X8191-8 / X8179-1 |
| X9396-4 | Wisconsin | Spring | X8191-8 / X8179-1 |
| X9410-1 | Wisconsin | Spring | X8342-1 / X8179-1 |
| X9410-2 | Wisconsin | Spring | X8342-1 / X8179-1 |
| X9414-1 | Wisconsin | Spring | X8342-6 / X8254-5 |
| X9421-3 | Wisconsin | Spring | X8177-1 / X7535-14 |
| X9422-1 | Wisconsin | Spring | X8177-1 / X8254-5 |
| X9435-1 | Wisconsin | Spring | X8463-3 / X8179-1 |
| X9439-1 | Wisconsin | Spring | ND9508252 / X8341-3 |
| X9449-1 | Wisconsin | Spring | OA021-2 / X8341-3 |
| X9474-2 | Wisconsin | Spring | X8177-1 / X8341-3 |

**Table 3.1** *Continued*

| NAME | SOURCE | GROWTH HABIT | PEDIGREE |
|---|---|---|---|
| X9487-1 | Wisconsin | Spring | X8402-2 / X9191-5 |
| X9487-4 | Wisconsin | Spring | X8402-2 / X9191-5 |
| X9492-1 | Wisconsin | Spring | X8416-2 / X8175-3 |
| X9498-1 | Wisconsin | Spring | X8470-6 / X8163-2 |
| X9500-2 | Wisconsin | Spring | X8470-6 / X8177-1 |
| X9500-6 | Wisconsin | Spring | X8470-6 / X8177-1 |
| X9503-1 | Wisconsin | Spring | X7994-2 / X8470-6 |
| X9507-1 | Wisconsin | Spring | X8210-2 / X8377-1 |
| X9507-3 | Wisconsin | Spring | X8210-2 / X8377-1 |
| X9509-3 | Wisconsin | Spring | X8377-1 / X8179-1 |
| X9509-4 | Wisconsin | Spring | X8377-1 / X8179-1 |
| X9513-1 | Wisconsin | Spring | X8583-1 / X8177-4 |
| Z615-4 | Unknown | Unknown | CAV2941(unknown/Unknown) X Ogle(Brave/Unnamed_336) |
| Zuton | United Kingdom | Spring | 12799Cn4/6n (Bullion/Neon)/ Bullion (08974CnI/1/08944Cn1) |

**Phenotypic analysis**

Traditional note-taking methods were employed to acquire disease severity and infection type ratings. This included visual screening of phenotypic disease traits of individual plants in each plot. Phenotypic data consisted of two types of ratings, disease severity and infection type (Figure 3.2). Disease severity (*DS*) refers to the percentage of the plant population exhibiting symptoms. This numerical value ranges from 0-100%. Infection type (*IT*) is a qualitative analysis of the type of symptoms being exhibited by the plant population. Infection types are limited to resistant (*R*), moderately resistant (*MR*), moderately susceptible (*MS*), or susceptible (*S*). Resistant plant types exhibit no visible signs or symptoms of crown rust. Flecks of chlorosis may be seen without pustules. Moderately resistant types are characterized by very small, non- to low sporulating pustules with surrounding chlorosis or small, low sporulating pustules with chlorosis. Moderately susceptible ratings refer to the mid-large sporulating pustules with chlorosis. Susceptible types include large, heavy sporulating pustules with very little surrounding chlorosis. Figure 3.2 depicts each infection type. Plant tissue may become brown and necrotic due to a severe disease infection. A combination of infection types were often seen within a given plot. For example, it was possible for a plot to be rated as 40 MRMS. Data was standardized across locations by converting qualitative data into quantitative measurements. Infection types were assigned a value on a scale of 0-1 (Table 3.2). To account for both types of crown rust ratings, the coefficient of infection (*CI*) was obtained. This value is calculated by multiplying *DS* ratings by *IT* numerical values as is shown: *CI = (DS x IT)*

**Table 3.2. The numerical scale assigned for each infection type (IT) rating used to generate the CI.**

| IT | R | RMR | MR | MRMS | MS | MSS | S |
|----|---|-----|-----|------|-----|-----|---|
| **Scale** | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 0.9 | 1 |
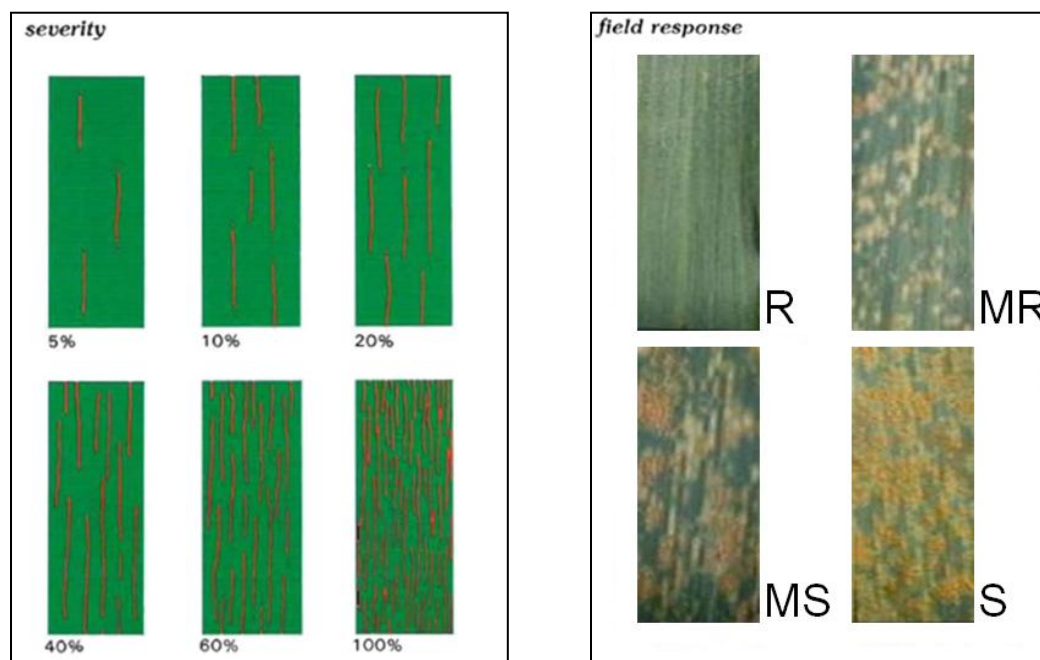


**Figure 3.2.   Examples of the scale used to determine disease severity (left) and infection type (percentage of oat plant tissue exhibiting disease symptoms (right).**

In addition to traditional phenotypic note-taking, representative pictures were taken of each plot and analyzed using Assess 2.0® software (Figure 3.3).   Four flag leaves per plot were excised and photographed side-by-side on a basic black ring stand using a standard twelve-inch ruler to provide scale.   The leaves were held in place using four cow magnets.   A Canon Digital Rebel XT camera (Model Ef-F-S18-55MM) was used to take pictures from a consistent height.   A neutral-colored umbrella was used to provide consistent lighting throughout the day as photographs were taken.   Pre-labeled

Ziploc® bags were used to transport leaves to maintain organization and freshness while samples were queued for pictures.



**Figure 3.3.  Four representative flag leaves, e.g. 'TAM O-397'.** (Leaves were arranged side-by-side and held in place with four cow magnets on a basic ring stand.  Photographs were taken from a consistent height.  All non-leaf components are of neutral colors to avoid interference with the software's analysis. Neutral colors refer to those which are not able to be mistaken for either leaf tissue or disease**.)**

The photographs were uploaded to a computer and analyzed using Assess 2.0 software, which is an application of existing image analysis algorithms to disease measurement to be used for routine disease measurement screening (Figure 3.4).  The software first separates the leaf from the background images and then separates the diseased tissue from the healthy tissue within the boundary of the leaf.  It is necessary for the background and the lesions to differ in some property, e.g. color or brightness. Assess relies on the Hue-Saturation-Intensity color model to distinguish between leaf material, diseased tissue, and background.  The software's effectiveness is attributed to the flexibility in using and combining various color models and color planes to extract the necessary components (Lamari, 2008).  A severity rating is generated based on the

percentage of infected tissue in comparison to healthy tissue. The ratings calculated by

the software were compared to the visually-acquired traditional phenotypic ratings.
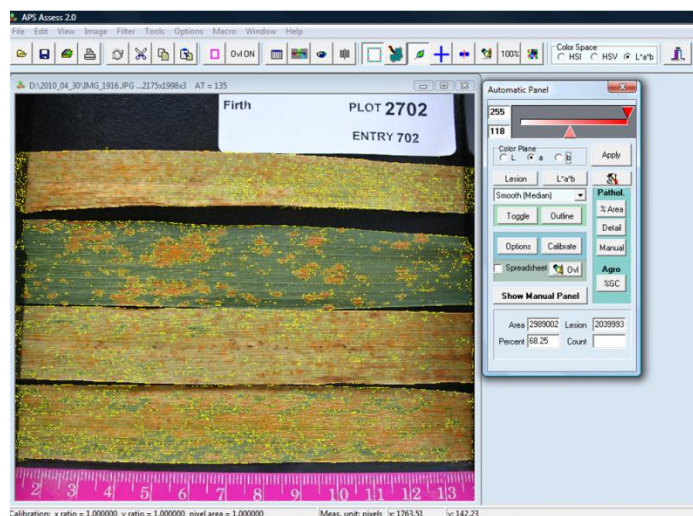


**Figure 3.4.    The Assess software interface used to analyze the percent of infected plant in comparison to green tissue and calculates severity.**

In Castroville, TX notes were taken April 26-28, 2010 and May 13, 2011,

respectively. Photographs were taken only in 2010. In 2011, due to the late presence of

crown rust in the field, plants were already beginning to ripen for harvest and leaf tissue

was turning brown. As the Assess software is unable to distinguish brown leaf tissue

from disease, it would be ineffective to analyze photographs of each plot in this manner.

In Baton Rouge, LA notes were taken in April 2010 and 2011, r. In Fargo, ND notes

were taken on August 3, 2010 and July 20, 2011, respectively. In St. Paul, MN notes

were taken on June 29-July 7, 2010 and July 7-July 19, 2011, respectively.

**Statistical analysis**

Data was analyzed using Microsoft Excel and Statistical Analysis System Version 9.3 (SAS Institute, 2007). Individual and combined locations, genotype by environment interactions, and individual genotype means were analyzed as a randomized complete block design with PROC GLM (Table 3.3). The variable *n* refers to the number of environments at which the lines were evaluated. The variable *r* refers to the number of repetitions. The variable *t* refers to the number of testers, or in this circumstance, the number of genotypes which were evaluated.

Table 3.3. Summary of analysis of variance and expected mean squares.

| Source of variation | DF | Expected mean square |
|---|---|---|
| Environment | n-1 | $\sigma^2 + r\sigma^2_{GE} + t\sigma^2_{R(E)} + rt\sigma^2_E$ |
| Rep (Environment) | n(r-1) | $\sigma^2 + t\sigma^2_{R(E)}$ |
| Genotypes | t-1 | $\sigma^2 + r\sigma^2_{GE} + rn\sigma^2_G$ |
| Environment * Genotypes | (n-1)(t-1) | $\sigma^2 + r\sigma^2_{GE}$ |
| Error | n(r-1)(t-1) | $\sigma^2$ |

**Heritability**

In a breeding program, a breeder relies on the idea that phenotypic variation exists within a population. Some of this variation is due to environmental effects, while a proportion of variation can be traced back to genetics. Heritability is the proportion of phenotypic variance which is genetic in origin (Brown and Caligari, 2008).

There are two types of heritability which can be calculated using this type of data. The first, broad-sense heritability ($H$), refers to the amount of genetic variance ($\sigma_G$) expressed in proportion to the total phenotypic variance ($\sigma_P$), as follows:

$$H = \sigma_G / \sigma_P$$

Broad-sense heritability measures the significance of environment versus genotype in the expression of a quantitative trait (Bernardo, 2010; Brown and Caligari, 2008).

The second, narrow-sense heritability ($h^2$), refers to the amount of additive variance ($\sigma_A$) expressed in proportion to the total phenotypic variance ($\sigma_P$) as follows:

$$h^2 = \sigma_A / \sigma_P$$

Additive genetic variance is the variation between homozygotes in a segregating population (Brown and Caligari, 2008). Narrow-sense heritability is often considered more meaningful than broad-sense heritability because it determines the amount of progress which can be gained from selecting and recombining specific individuals in a given population. However, broad-sense heritability remains more meaningful when all types of genetic variance may be exploited. In both cases, a higher heritability value is indicative of greater breeding value (Bernardo, 2010; Brown and Caligari, 2008).

Heritability was calculated manually using the ANOVA output obtained from SAS (Table 3.4).

**Table 3.4. Summary of the concept of broad-sense heritability ($h^2$).**

| Source of variation | DF | MS | Expected mean square |
|---|---|---|---|
| Environment | n-1 | M1 | $\sigma^2 + r\sigma^2_{GE} + t\sigma^2_{R(E)} + rt\sigma^2_E$ |
| Rep (Environment) | n(r-1) | M2 | $\sigma^2 + t\sigma^2_{R(E)}$ |
| Genotypes | t-1 | M3 | $\sigma^2 + r\sigma^2_{GE} + rn\sigma^2_G$ |
| Environment * Genotypes | (n-1)(t-1) | M4 | $\sigma^2 + r\sigma^2_{GE}$ |
| Pooled error | n(r-1)(t-1) | M5 | $\sigma^2$ |
| **Genotypic variance** | | | $(\sigma^2 + r\sigma^2_{GE} + rn\sigma^2_G) - (\sigma^2 + r\sigma^2_{GE})$ |
| **Phenotypic variance** | | | $\sigma^2_G + \sigma^2_E + \sigma^2_{GE}$ |
| *$h^2$* | | | $\sigma^2_G / \sigma^2_P$ |

## Repeatability

Repeatability is the ratio of 'between individual components' to 'total phenotypic variance'. A concept developed by Kempthorne and Lush in the 1900's for use in breeding and quantitative genetics, repeatability has three primary uses. The first is to establish the upper limits of heritability for a given character. Secondly, repeatability is used to establish predictions regarding expected future performance based on previously-acquired data. Finally, this parameter may be used to determine increase in accuracy resulting from repeated measurements of the same characteristic (Kempthorne, 1957). Thus, a higher repeatability value indicates that fewer measurements would be statistically sufficient and measurements may be repeatable over space or time (Falconer, 1988; Falconer and Mackay, 1996).

Repeatability utilizes environmental variation ($\sigma_E$) rather than genetic variation ($\sigma_G$). The $\sigma_E$ value is separated into temporary and permanent components during analysis, also known as temporary effects or permanent effects. These components include special environmental variance ($\sigma_{Es}$) and general environmental variance ($\sigma_{Eg}$).

The $\sigma_{Es}$ value is the component of within individual variance which arises from temporary or localized circumstances.  The $\sigma_{Eg}$ value is the component of between individual variance which arises from permanent or non-localized circumstances (Falconer, 1988; Falconer and Mackay, 1996).

Repeatability was calculated manually using the ANOVA output obtained from SAS (Table 3.5).  The variable $n$ refers to the number of individuals, which in this circumstance refers to repetitions at each location.  The variable $m$ refers to the number of observations per individual, which in this circumstance is the number of genotypes evaluated at each location.

Table 3.5.  **Summary of the concept of repeatability.**

| Source of variation | DF | MS | Expected mean square |
|---|---|---|---|
| Between genotypes | n-1 | $MS_B$ | $\sigma^2_W + m\sigma^2_B$ |
| Within genotypes | n(m-1) | $MS_W$ | $\sigma^2_W$ |
| $\sigma^2_P$ | | | $\sigma^2_B + \sigma^2_W$ |
| **Repeatability** | | | $\sigma^2_B / \sigma_P$ |

Components of variation used for calculating repeatability include the component due to variation between individuals ($\sigma^2_B$) and the component due to variation within individuals ($\sigma^2_W$).  The $\sigma^2_B$ value represents the permanent environmental variation and the total genetic variation as shown:

$$\sigma^2_B = \frac{MS_B - MS_W}{m} \quad = \quad \sigma_G + \sigma_{Eg}$$

Where $\sigma^2_W$ is the variation among measurements and represents the temporary environmental variance. Repeatability is derived as an intra-class correlation which expresses the proportion of variance of single measurements due to permanent, or non-localized, differences between individuals, both genetic and environmental. Thus $1 - R$ $= \sigma_{Es} / \sigma_P$. Repeatability may be summarized as follows:

$$R = \frac{\sigma^2_B}{\sigma^2_B + \sigma^2_W} = \frac{\sigma_G + \sigma_{E\,g}}{\sigma_G + \sigma_{E\,g} + \sigma_{E\,s}} = \frac{\sigma_G + \sigma_{E\,g}}{\sigma_P}$$

Repeatability allows the estimation of $\sigma_{Es}$ to be separated due to special environment as a proportion of the total variance. The advantage to calculating repeatability is that it can make up for the challenge associated with genotype-by-environment interactions, particularly the failure of a given genotype to perform the same across multiple locations. As it sets the upper limit to heritability, repeatability will always be greater than broad-sense heritability, which in turn is always greater than narrow-sense heritability ($R > h^2_B > h^2_N$).

There are several assumptions associated with repeatability calculations. Measurements used to obtain the 'between individual component' are assumed to have equal variance. Also, measurements represent the same character and are not inherently rendered dissimilar by virtue of separation by time or space (Falconer, 1988; Falconer and Mackay, 1996).

**Biplot analysis**

A biplot analysis is conducted for further evaluation of multi-environmental trial data, with emphasis on genotype-by-environment (G x E) interaction. A biplot is a graphically displayed scatter plot which analyzes row and column factors to estimate the relationships among and across factors, including any possible underlying interactions between factors. The graphical display is used to visually represent all of these relationships simultaneously. While biplot analysis is similar to principle component analysis (PCA), biplot allows for a more comprehensive use visualizing factor interactions (Yan and Tinker, 2006). The GGEbiplot software was used for this analysis.

Mathematically, a biplot is a graphical display of matrix multiplication which is used to address several questions. First, how is the data being centered and scaled, i.e. which model is being used to generate the biplot? Second, how are the individual values being separated? This will determine whether or not the relationships may be appropriately represented. Third, what is the goodness of fit of the two-way table data? Additionally, biplots are based on the assumption that all axes are drawn to scale (Yan and Tinker, 2006).

For G x E interactions, it is necessary to establish whether or not there are relevant rank changes of a specific genotype within a given environment. For example, a winter oat line is expected to perform better in a southern environment, such as Castroville, TX, than a spring oat line. If there are not relevant rank changes, a superior genotype may be identified as a high performer in all environments. A biplot allows a

breeder to determine whether or not a single environment should be divided into multiple mega-environments to exploit or avoid any potential G x E interactions. A biplot can also assist a breeder in identifying the sources of G x E interactions. The most ideal test environments and superior genotypes can be identified through the use of biplot analysis (Yan and Tinker, 2006).

Four types of biplot views were generated for analysis of spring and winter oats. These views include representativeness of test environments, relationships among test environments, mean performance and stability of genotypes, and which-won-where.

During the two years during which the association mapping panel was grown, there was a significant amount of missing data. Missing values range from individual plots within the population to entire data sets for either year at a given location. Missing values for individual plots may be attributed to environmental conditions or human error. For the year 2010 in Baton Rouge, LA, no data was retrieved due to drought conditions which left the field too dry for plants to thrive. Additionally, crown rust relies on moisture in the air in order to spread. In Castroville, TX in 2011, crown rust spread too late in the season to collect data on the entire winter oat panel. The winter oats were already ripe by the time the spring and core panels were exhibiting symptoms of crown rust. It may be beneficial to repeat the field trials at each of the four locations for another year in order to fill in gaps within the data. This would further enhance the strength of the genotypic data when generating the association map.

# CHAPTER IV

# RESULTS AND DISCUSSION

Three panels of North American oats (winter, spring, and a core containing selected lines from the two growth habits) were statistically evaluated for resistance to crown rust in four field environments at Castroville, TX, Baton Rouge, LA, St. Paul, MN, and Fargo, ND for a total of two years in 2010 and 2011. Within the four environments, the winter lines consistently outperformed the spring lines in terms of crown rust resistance. The study demonstrated a high degree of repeatability and heritability for estimating coefficient of infection, while revealing the population to be highly variable. This variability, in combination with the high degree of heritability and repeatability will prove beneficial when mapping QTL for crown rust resistance.

**Statistical analysis**

Analysis of variance (ANOVA) was performed for crown rust coefficient of infection across locations for both years using SAS Version 9.3. Results for spring oat lines indicate significant differences across environments and within genotypes. Additionally, significant genotype-by-environment interactions were shown as well (Table 4.1).

**Table 4.1. Analysis of variance of CI for spring oat lines in Castroville, TX, Baton Rouge, LA, Fargo, ND, and St. Paul, MN for 2010 and 2011.**

| Source of variation | DF | SS | MS | F value | P value |
|---|---|---|---|---|---|
| Environment | 4 | 111738.05 | 27934.51* | 269.11 | <.0001 |
| Rep (Environment) | 5 | 4452.59 | 890.52* | 8.58 | <.0001 |
| Genotype | 360 | 865539.07 | 2404.28* | 23.16 | <.0001 |
| Environment * Genotype | 1431 | 422605.06 | 295.32* | 2.85 | <.0001 |
| Error | 1645 | 170756.86 | 103.80 | | |
| $R^2$ | 0.89 | | | | |
| CV% | 60.65 | | | | |
| Root MSE | 10.19 | | | | |
| Grand Mean | 16.80 | | | | |

*Significant at the 0.05 probability level

Results for winter oat lines indicate significant differences across environments and within genotypes. Additionally, significant genotype-by-environment interactions were observed as well (see Table 4.2).

**Table 4.2.  Analysis of variance of CI for winter oat lines in Castroville, TX, Baton Rouge, LA, Fargo, ND, and St. Paul, MN for 2010 and 2011.**

| Source of variation | DF | SS | MS | F value | P value |
|---|---|---|---|---|---|
| Environment | 3 | 28007.44 | 9335.81$^*$ | 208.34 | <.0001 |
| Rep (Environment) | 4 | 1420.63 | 355.16$^*$ | 7.93 | <.0001 |
| Genotype | 118 | 336852.00 | 2854.68$^*$ | 63.71 | <.0001 |
| Environment * Genotype | 352 | 110577.38 | 314.14$^*$ | 7.01 | <.0001 |
| Error | 446 | 19985.22 | 44.81 | | |
| **R$^2$** | 0.96 | | | | |
| **CV%** | 38.96 | | | | |
| **Root MSE** | 6.69 | | | | |
| **Grand Mean** | 17.18 | | | | |

$^*$Significant at the 0.05 probability level

Significant variability exists for crown rust resistance among the North American oat germplasm as demonstrated by Tables 4.1 and 4.2.  This variability is expected to contribute to the effectiveness of any oat map that will be generated as a result of this study as it is useful for identifying QTL associated with disease resistance.  Raw data for analysis can be found in Tables 4.3 and 4.4.

**Table 4.3. CI means of spring oat lines for individual genotypes in Castroville, TX, Baton Rouge, LA, Fargo, ND, and St. Paul, MN for 2010 and 2011.**

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 001A1-24-2-4-1-3 | 24.00 | 8.00 | 11.25 | 1.10 | 0.60 | 8.00 | 13.50 | 9.49 |
| 2 | 00Ab6112 | 60.00 | 100.00 | 26.25 | 11.00 | 55.00 | 100.00 | 28.00 | 54.32 |
| 3 | 00Ab6711 | 65.00 | 100.00 | 19.50 | 42.30 | 16.00 | 100.00 | 33.50 | 53.76 |
| 4 | 00Ab6963 | 70.00 | 20.00 | 18.00 | 6.60 | 27.50 | 100.00 | 33.50 | 39.37 |
| 5 | 00Ab7006 | 80.00 | 100.00 | 33.50 | 6.43 | 0.00 | 100.00 | 27.00 | 49.56 |
| 6 | 00Ab7085 | 67.50 | 100.00 | 38.50 | 61.40 | 1.00 | 100.00 | 38.50 | 58.13 |
| 7 | 00Ab8118 | 55.00 | 100.00 | 45.00 | 26.40 | 6.00 | 100.00 | 55.00 | 55.34 |
| 8 | 0216A1-1-55 | 50.00 | 10.00 | 12.00 | 35.37 | 0.00 | 60.00 | 9.00 | 25.20 |
| 9 | 0219A1-84-4-4-4-4 | 0.00 | 8.00 | 7.50 | 0.00 | 0.00 | 60.00 | 13.50 | 12.71 |
| 10 | 021A1-78-1-5 | 12.00 | 40.00 | 13.50 | 3.30 | 0.00 | 80.00 | 36.00 | 26.40 |
| 11 | 0222A1-21-7-5-1-1 | 0.00 | 40.00 | 33.50 | 0.00 | 0.00 | 80.00 | 20.25 | 24.82 |
| 12 | 026A1-88-2-2 | 12.00 | 16.00 | 12.15 | 2.03 | 2.00 | 32.00 | 22.50 | 14.10 |
| 13 | 027A1-87-8-1 | 10.00 | 40.00 | 13.50 | 3.30 | 0.00 | 80.00 | 11.25 | 22.58 |
| 14 | 02Ab5836 | 82.50 | 100.00 | 30.00 | 48.80 | 70.00 | 100.00 | 48.00 | 68.47 |
| 15 | 02Ab6078 | 72.50 | 80.00 | 19.00 | 24.60 | 17.00 | 100.00 | 30.00 | 49.01 |
| 16 | 02Ab6655 | 70.00 | 60.00 | 25.00 | 17.60 | 2.00 | 100.00 | 40.00 | 44.94 |
| 17 | 02HO-139 | 65.00 | 100.00 | 45.00 | 78.17 | 4.00 | 100.00 | 38.50 | 61.52 |
| 18 | 02HO-209 | 67.50 | 100.00 | 28.50 | 6.60 | 5.00 | 100.00 | 33.50 | 48.73 |
| 19 | 04P07B-GT3D | 0.00 | 0.00 | 0.50 | 0.17 | 0.00 | 0.00 | 0.40 | 0.15 |
| 20 | 0513A1-18-5 | 8.00 | 60.00 | 12.00 | 0.00 | 0.00 | 80.00 | 28.50 | 26.90 |
| 21 | 0514A1-16-3 | 10.00 | 20.00 | 11.25 | 0.00 | 0.00 | 60.00 | 9.00 | 15.75 |
| 22 | 0528A1-1 | 18.00 | 32.00 | 24.00 | 0.00 | 0.00 | 24.00 | 21.00 | 16.95 |
| 23 | 053B1-95 | 4.50 | 20.00 | 11.25 | 0.00 | 0.00 | 8.00 | 4.00 | 6.80 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 0541A1-1 | 2.00 | 20.00 | 6.75 | 0.00 | 0.00 | 8.00 | 13.50 | 7.18 |
| 25 | 055A1-3-5-3 | 15.50 | 4.00 | 3.75 | 0.00 | 0.00 | 32.00 | 1.65 | 8.10 |
| 26 | 059A1-2-2-4 | 25.00 | 10.00 | 7.50 | 0.00 | 0.00 | 32.00 | 13.50 | 12.55 |
| 27 | 8669C2-4-6-16-33 | 70.00 | 100.00 | 27.00 | 40.00 | 35.00 | 100.00 | 43.50 | 59.36 |
| 28 | 95Ab12770 | 70.00 | 100.00 | 35.00 | 61.40 | 19.64 | 100.00 | 33.00 | 59.86 |
| 29 | 95Ab13050 | 75.00 | 100.00 | 45.00 | 83.50 | 65.00 | 100.00 | 45.00 | 73.36 |
| 30 | 971A9-7-4-11 | 4.00 | 0.00 | 6.00 | 0.00 | 0.00 | 32.00 | 41.25 | 11.89 |
| 31 | 97Ab7761 | 60.00 | 80.00 | 25.00 | 35.60 | 0.00 | 100.00 | 15.00 | 45.09 |
| 32 | 97Ab7767 | 75.00 | 80.00 | 45.00 | 55.90 | 41.00 | 100.00 | 24.50 | 60.20 |
| 33 | 9876C1-2-1-5-2-4-1 | 8.00 | 10.00 | 13.50 | 0.00 | 0.00 | 4.00 | 22.50 | 8.29 |
| 34 | 98Ab7265 | 77.50 | 80.00 | 50.00 | 72.50 | 34.00 | 100.00 | 38.50 | 64.64 |
| 35 | 99Ab10937 | 67.50 | 100.00 | 19.50 | 67.00 | 4.00 | 100.00 | 38.00 | 56.57 |
| 36 | 99Ab10971 | 50.00 | 80.00 | 22.50 | 33.40 | 6.00 | 100.00 | 24.00 | 45.13 |
| 37 | 99Ab10987 | 60.00 | 100.00 | 40.00 | 71.30 | 27.00 | 100.00 | 38.50 | 62.40 |
| 38 | 99Ab11098 | 65.00 | 100.00 | 35.00 | 17.60 | 23.50 | 100.00 | 45.00 | 55.16 |
| 39 | 99Ab11136 | 70.00 | 60.00 | 23.50 | 41.20 | 10.00 | 100.00 | 17.25 | 45.99 |
| 40 | 99Ab11227 | 60.00 | 100.00 | 30.00 | 26.40 | 0.00 | 100.00 | 34.00 | 50.06 |
| 41 | 99Ab11391 | 60.00 | 100.00 | 45.00 | 2.20 | 3.00 | 100.00 | 31.75 | 48.85 |
| 42 | 99Ab11787 | 67.50 | 100.00 | 40.00 | 35.70 | 2.00 | 100.00 | 22.50 | 52.53 |
| 43 | Adrew | 42.50 | 100.00 | 30.00 | 43.30 | 10.00 | 100.00 | 50.00 | 53.69 |
| 44 | Allen | 45.00 | 100.00 | 28.50 | 4.40 | 30.00 | 100.00 | 55.00 | 51.84 |
| 45 | Anthony | 50.00 | 100.00 | 18.00 | 45.60 | 46.00 | 100.00 | 9.40 | 52.71 |
| 46 | ARDENTE | 45.00 | 100.00 | 50.00 | 32.83 | 5.00 | 100.00 | 43.50 | 53.76 |
| 47 | AVENY | 3.00 | 0.00 | 13.50 | 1.10 | 0.00 | 100.00 | 29.25 | 20.98 |
| 48 | BARRA | 60.00 | 100.00 | 30.00 | 62.10 | 7.20 | 100.00 | 40.00 | 57.04 |
| 49 | Bw103 | 50.00 | 8.00 | 8.09 | 6.60 | 0.00 | 80.00 | 9.47 | 23.17 |
| 50 | Bw1103 | 36.00 | 8.00 | 19.09 | 1.10 | 0.45 | 100.00 | 0.77 | 23.63 |
| 51 | Bw4903 | 12.00 | 1.00 | 4.35 | 6.60 | 0.00 | 4.00 | 9.00 | 5.28 |
| 52 | CDC Minstrel | 0.50 | 40.00 | 11.25 | 0.00 | 0.00 | 8.00 | 18.00 | 11.06 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
| 53 | CDC Orrin | 45.00 | 60.00 | 21.75 | 26.40 | 0.00 | 100.00 | 18.00 | 38.68 |
| 54 | CDC Weaver | 2.00 | 10.00 | 13.50 | 1.10 | 0.36 | 8.00 | 24.00 | 8.42 |
| 55 | Chinese 4 | 75.00 | 80.00 | 25.00 | 66.83 | 48.00 | 100.00 | 13.00 | 58.26 |
| 56 | CI1712-5 | 7.00 | 20.00 | 0.00 | 5.50 | 0.00 | 4.00 | 0.10 | 5.10 |
| 57 | CIRCLE | 70.00 | 100.00 | 50.00 | 55.90 | 16.00 | 100.00 | 60.00 | 64.56 |
| 58 | Classic | 4.00 | 8.00 | 11.25 | 1.10 | 0.00 | 32.00 | 24.00 | 11.48 |
| 59 | Clintford | 65.00 | 80.00 | 22.50 | 22.40 | 25.00 | 48.00 | 28.50 | 41.63 |
| 60 | Clintland 60 | 45.00 | 80.00 | 18.00 | 1.10 | 20.00 | 100.00 | 33.00 | 42.44 |
| 61 | Clintland 64 | 47.50 | 80.00 | 22.50 | 1.10 | 6.00 | 48.00 | 29.00 | 33.44 |
| 62 | Clinton 59 | 65.00 | 100.00 | 40.00 | 44.97 | 12.50 | 100.00 | 55.00 | 59.64 |
| 63 | Columbia | 65.00 | 100.00 | 24.00 | 49.20 | 12.50 | 100.00 | 31.00 | 54.53 |
| 64 | Derby | 35.00 | 100.00 | 19.50 | 13.03 | 0.00 | 100.00 | 20.25 | 41.11 |
| 65 | Firth | 65.00 | 100.00 | 40.00 | 61.50 | 4.00 | 80.00 | . | Non-est |
| 66 | FREJA | 67.50 | 100.00 | 40.00 | 48.90 | 2.00 | 100.00 | 35.00 | 56.20 |
| 67 | Gere | 75.00 | 100.00 | 55.00 | 66.83 | 0.36 | 100.00 | 50.00 | 63.88 |
| 68 | GN04399 | 55.00 | 100.00 | 40.00 | 35.60 | 7.00 | 100.00 | 38.50 | 53.73 |
| 69 | Grane | 45.00 | 80.00 | 50.00 | 50.00 | 1.64 | 100.00 | 45.00 | 53.09 |
| 70 | Grenader | 45.00 | 100.00 | 29.09 | 7.70 | 3.00 | 80.00 | 7.00 | 38.83 |
| 71 | GUNHILD | 70.00 | 100.00 | 40.00 | 56.00 | 0.10 | 100.00 | 20.00 | 55.16 |
| 72 | HA05AB10-47 | 85.00 | 80.00 | 28.50 | 40.00 | 11.00 | 100.00 | 35.00 | 54.21 |
| 73 | HA05AB10-51 | 87.50 | 100.00 | 34.00 | 35.60 | 6.00 | 100.00 | 35.00 | 56.87 |
| 74 | HA05AB16-31 | 62.50 | 60.00 | 28.50 | 57.70 | 20.00 | 100.00 | 22.50 | 50.17 |
| 75 | HA05AB20-1 | 70.00 | 100.00 | 43.00 | 45.60 | 7.00 | 100.00 | 31.50 | 56.73 |
| 76 | HA05AB21-7 | 60.00 | 100.00 | 40.00 | 35.03 | 8.00 | 100.00 | 31.50 | 53.50 |
| 77 | HA05AB22-9 | 67.50 | 80.00 | 24.00 | 40.00 | 40.00 | 100.00 | 25.00 | 53.79 |
| 78 | HA05AB29-17 | 67.50 | 80.00 | 40.00 | 26.80 | 17.00 | 100.00 | 38.50 | 52.83 |
| 79 | HA05AB29-39 | 57.50 | 100.00 | 15.00 | 8.80 | 2.30 | 100.00 | 43.00 | 46.66 |
| 80 | HA05AB34-48 | 57.50 | 100.00 | 13.50 | 8.80 | 20.00 | 100.00 | 18.00 | 45.40 |
| 81 | HA05AB35-16 | 65.00 | 80.00 | 24.75 | 55.83 | 8.00 | 0.00 | 39.00 | 38.94 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
|-------|----------|------------------|-------------|---------------|--------------------|------------------|-------------|---------------|---------|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
| 82 | HA05AB36-33 | 65.00 | 80.00 | 29.00 | 42.30 | 9.00 | 100.00 | 28.50 | 50.54 |
| 83 | HA05AB38-22 | 50.00 | 40.00 | 20.25 | 45.60 | 4.00 | 100.00 | 21.50 | 40.19 |
| 84 | HA05AB38-39 | 50.00 | 60.00 | 24.00 | 13.03 | 6.00 | 80.00 | 24.00 | 36.72 |
| 85 | HA05AB41-38 | 40.00 | 100.00 | 30.00 | 26.40 | 25.00 | 100.00 | 42.50 | 51.99 |
| 86 | HA05AB42-20 | 55.00 | 100.00 | 33.50 | 40.00 | 6.00 | 100.00 | 31.50 | 52.29 |
| 87 | HA05AB53-40 | 65.00 | 100.00 | 35.00 | 72.50 | 11.50 | 100.00 | 40.00 | 60.57 |
| 88 | HA05AB9-32 | 70.00 | 60.00 | 23.50 | 35.60 | 10.00 | 100.00 | 24.00 | 46.16 |
| 89 | HA05AB9-52 | 47.50 | 100.00 | 28.50 | 13.20 | 16.00 | 100.00 | 30.47 | 47.95 |
| 90 | HA08-03X09-1 | 36.00 | 8.00 | 28.50 | 11.00 | 34.00 | 100.00 | 26.25 | 34.82 |
| 91 | HA08-03X31-1 | 60.00 | 100.00 | 40.00 | 26.40 | 0.00 | 100.00 | 38.50 | 52.13 |
| 92 | HA08-03X49-1 | 50.00 | 80.00 | 31.50 | 44.63 | 8.00 | 100.00 | 22.50 | 48.09 |
| 93 | IL00-654 | 40.00 | 60.00 | 28.50 | 17.60 | 9.50 | 32.00 | 33.00 | 31.51 |
| 94 | IL02-10836 | 47.50 | 80.00 | 50.00 | 83.50 | 5.00 | 80.00 | 43.00 | 55.57 |
| 95 | IL02-5630 | 27.50 | 100.00 | 35.00 | 89.17 | 2.30 | 80.00 | 38.50 | 53.21 |
| 96 | IL02-8011 | 30.00 | 40.00 | 24.00 | 17.43 | 2.45 | 60.00 | 29.00 | 28.98 |
| 97 | IL02-8658 | 6.00 | 8.00 | 29.00 | 2.03 | 6.00 | 8.00 | 22.50 | 11.65 |
| 98 | IL03-2658 | 55.00 | 48.00 | 28.50 | 45.60 | 45.00 | 48.00 | 18.00 | 41.16 |
| 99 | IL03-7936 | 50.00 | 100.00 | 47.00 | 13.20 | 8.00 | 100.00 | 45.00 | 51.89 |
| 100 | IL04-2727 | 2.15 | 20.00 | 40.00 | 23.50 | 1.00 | 80.00 | 39.00 | 29.38 |
| 101 | IL04-3664 | 38.00 | 60.00 | 23.00 | 77.83 | 55.00 | 100.00 | 27.00 | 54.40 |
| 102 | IL04-4410 | 37.50 | 16.00 | 22.50 | 19.80 | 14.00 | 80.00 | 14.50 | 29.19 |
| 103 | IL04-7077 | 6.45 | 20.00 | 15.75 | 26.80 | 10.00 | 32.00 | 40.00 | 21.57 |
| 104 | IL05-10015 | 36.00 | 80.00 | 13.50 | 55.83 | 0.36 | 80.00 | 24.75 | 41.49 |
| 105 | IL05-10069 | 35.00 | 80.00 | 22.50 | 19.80 | 0.00 | 100.00 | 29.00 | 40.90 |
| 106 | IL05-11942 | 19.00 | 20.00 | 40.00 | 0.00 | 0.00 | 80.00 | 35.00 | 27.69 |
| 107 | IL05-1778 | 4.50 | 0.00 | 24.75 | 0.00 | . | 8.00 | 27.00 | Non-est |
| 108 | IL05-3337 | 14.00 | 40.00 | 26.00 | 0.00 | -0.36 | 4.00 | 38.00 | 17.35 |
| 109 | IL05-3806 | 40.00 | 32.00 | 38.50 | 4.40 | 2.50 | 80.00 | 38.50 | 33.70 |
| 110 | IL05-3928 | 35.00 | 80.00 | 24.00 | 13.20 | 0.36 | 100.00 | 33.50 | 40.87 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
| 111 | IL05-6223 | 31.00 | 8.00 | 4.50 | 33.50 | 0.00 | 4.00 | 22.50 | 14.79 |
| 112 | IL05-8515 | 16.00 | 20.00 | 22.50 | 8.80 | 0.00 | 48.00 | 33.00 | 21.19 |
| 113 | IL05-9330 | 54.00 | 40.00 | 18.00 | 20.00 | 12.00 | 32.00 | 15.75 | 27.39 |
| 114 | IL05-9931 | 58.00 | 80.00 | 10.50 | 24.20 | 3.00 | 100.00 | 27.00 | 43.24 |
| 115 | IL05-9948 | 32.50 | 20.00 | 28.50 | 35.60 | 4.15 | 100.00 | 24.00 | 34.96 |
| 116 | IL06-1161 | 50.00 | 80.00 | 18.00 | 22.00 | 10.36 | 80.00 | 24.00 | 40.62 |
| 117 | IL06-3258 | 26.00 | 0.00 | 27.00 | 2.03 | 0.00 | 4.00 | 34.00 | 13.29 |
| 118 | IL06-3751 | 27.50 | 0.00 | 45.00 | 26.23 | 0.00 | 8.00 | 43.00 | 21.39 |
| 119 | IL06-5456 | 56.00 | 100.00 | 13.50 | 61.50 | 10.36 | 100.00 | 43.50 | 54.98 |
| 120 | IL2250-15-PI641978 | 30.00 | 40.00 | 24.00 | 3.30 | 5.30 | 60.00 | 31.50 | 27.73 |
| 121 | IL2250-18-PI641979 | 30.00 | 40.00 | 28.50 | 37.90 | 1.10 | 32.00 | 33.50 | 29.00 |
| 122 | IL2294-1-PI641996 | 20.45 | 16.00 | 24.00 | 4.40 | 0.30 | 80.00 | 31.50 | 25.24 |
| 123 | IL2294-3-PI641998 | 22.50 | 8.00 | 30.00 | 4.57 | 7.00 | 100.00 | 37.50 | 29.94 |
| 124 | IL250-14-PI641977 | 37.50 | 100.00 | 40.00 | 26.23 | 15.00 | 100.00 | 50.00 | 52.68 |
| 125 | IL250-3-PI641976 | 60.00 | 100.00 | 33.50 | 67.00 | 5.00 | 100.00 | 40.00 | 57.93 |
| 126 | IL2815-PI641965 | 50.00 | 100.00 | 40.00 | 55.90 | 16.00 | 100.00 | 70.00 | 61.70 |
| 127 | IL2838-PI641966 | 45.00 | 100.00 | 20.25 | 11.00 | -0.36 | 100.00 | 38.00 | 44.84 |
| 128 | IL2858-PI641967 | 50.00 | 100.00 | 18.00 | 24.20 | 6.00 | 80.00 | 29.25 | 43.92 |
| 129 | IL2901-PI641968 | 50.00 | 40.00 | 22.50 | 28.00 | 6.00 | 100.00 | 20.25 | 38.11 |
| 130 | IL3555-PI641970 | 60.00 | 100.00 | 45.00 | 35.03 | 38.00 | 100.00 | 40.00 | 59.72 |
| 131 | IL75-5665 | 55.00 | 60.00 | 45.00 | 28.00 | 19.64 | 80.00 | 43.50 | 47.31 |
| 132 | IL75-5743 | 50.00 | 60.00 | 23.50 | 13.20 | 17.50 | 60.00 | 24.75 | 35.56 |
| 133 | IL86-1156 | 45.00 | 80.00 | 30.00 | 38.90 | 7.00 | 100.00 | 35.00 | 47.99 |
| 134 | IL86-5698-PI539875 | 56.00 | 60.00 | 35.00 | 17.43 | 12.15 | 80.00 | 29.00 | 41.37 |
| 135 | IL86-6404-PI539874 | 65.00 | 100.00 | 19.50 | 45.60 | 40.00 | 80.00 | 27.00 | 53.87 |
| 136 | IL98-10145 | 42.50 | 48.00 | 45.00 | 77.83 | 6.00 | 48.00 | 45.00 | 44.62 |
| 137 | IN09201 | 28.00 | 100.00 | 24.00 | 0.17 | 2.00 | 100.00 | 22.50 | 39.52 |
| 138 | Kapp | 60.00 | 100.00 | 35.00 | 88.83 | 45.00 | 100.00 | 35.00 | 66.26 |
| 139 | Lena | 55.00 | 100.00 | 30.00 | 89.17 | 22.00 | 100.00 | 33.50 | 61.38 |

Table 4.3 *Continued*

| | | 2010 | | | 2011 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ENTRY | GENOTYPE | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | AVERAGE |
| 140 | Lennon | 60.00 | 60.00 | 28.50 | 35.03 | 65.00 | 100.00 | . | Non-est |
| 141 | LIPOPLUS | 80.00 | 100.00 | 50.00 | 32.83 | 75.00 | 100.00 | 31.50 | 67.05 |
| 142 | Maida | 0.00 | 1.00 | 13.50 | 2.20 | 0.00 | 16.00 | 27.00 | 8.53 |
| 143 | MN06108 | 0.00 | 0.00 | 9.00 | 0.00 | 0.36 | 1.50 | 20.25 | 4.42 |
| 144 | MN06125 | 1.00 | 0.00 | 10.50 | 0.00 | 0.00 | 2.00 | 7.50 | 3.00 |
| 145 | MN06239 | 0.60 | 0.00 | 5.10 | 0.00 | 0.00 | 4.00 | 13.50 | 3.31 |
| 146 | MN07203 | 0.50 | 4.00 | 9.75 | 0.00 | 0.00 | 32.00 | 1.65 | 6.84 |
| 147 | MN07210 | 0.50 | 10.00 | 9.00 | 1.10 | 0.00 | 2.00 | 12.00 | 4.94 |
| 148 | MN08106 | 10.00 | 1.00 | 10.50 | 0.00 | 0.00 | 4.00 | 18.00 | 6.21 |
| 149 | MN08123 | 2.00 | 0.00 | 4.05 | 0.00 | 0.00 | 0.40 | 9.15 | 2.23 |
| 150 | MN08124 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 6.00 | 0.91 |
| 151 | MN08129 | 0.10 | 0.00 | 4.50 | 0.00 | 0.00 | 0.00 | 6.75 | 1.62 |
| 152 | MN08130 | 13.50 | 0.00 | 12.00 | 17.43 | 22.50 | 4.00 | 18.00 | 12.49 |
| 153 | MN08131 | 1.50 | 0.00 | 11.25 | 0.00 | 0.00 | 6.00 | 9.00 | 3.96 |
| 154 | MN08132 | 0.30 | 0.40 | 7.50 | 4.40 | 0.00 | 16.00 | 18.00 | 6.66 |
| 155 | MN08134 | 0.00 | 0.00 | 11.50 | 0.00 | 0.00 | 0.40 | 9.00 | 2.96 |
| 156 | MN08137 | 0.00 | 16.00 | 3.75 | 0.00 | 0.00 | 8.00 | 13.50 | 5.89 |
| 157 | MN08139 | 0.10 | 48.00 | 4.50 | 0.00 | 0.00 | 60.00 | 9.75 | 17.45 |
| 158 | MN08146 | 7.00 | 4.00 | 7.50 | 0.00 | 0.00 | 4.00 | 20.25 | 6.11 |
| 159 | MN08150 | 9.00 | 0.00 | 9.00 | 1.10 | 0.00 | 16.00 | 18.00 | 7.59 |
| 160 | MN08155 | 3.50 | 0.00 | 6.45 | 26.23 | 0.00 | 3.00 | 0.60 | 5.68 |
| 161 | MN08160 | 0.15 | 1.00 | 9.00 | 0.00 | 0.00 | 2.00 | 27.00 | 5.57 |
| 162 | MN08211 | 2.00 | 0.00 | 0.90 | 0.00 | 0.00 | 0.00 | 0.30 | 0.46 |
| 163 | MN08212 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 164 | MN08217 | 15.00 | 8.00 | 13.50 | 3.30 | 0.00 | 4.00 | 11.25 | 7.86 |
| 165 | MN08222 | 0.10 | 0.00 | 4.50 | 2.03 | 0.00 | 2.00 | 4.50 | 1.88 |
| 166 | MN08225 | 4.00 | 2.00 | 3.60 | 4.40 | 0.00 | 4.00 | 12.00 | 4.29 |
| 167 | MN08230 | 0.10 | 5.00 | 11.25 | 6.60 | 0.00 | 4.00 | 18.00 | 6.42 |
| 168 | MN08234 | 25.00 | 10.00 | 11.25 | 5.50 | 0.00 | 80.00 | 18.00 | 21.39 |

Table 4.3 *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
| 169 | MN08238 | 0.00 | 0.00 | 0.60 | 2.03 | 0.00 | 0.00 | 0.20 | 0.40 |
| 170 | MN08242 | 0.00 | 0.00 | 0.60 | 0.17 | 0.00 | 0.40 | 15.00 | 2.31 |
| 171 | MN08243 | 0.00 | 0.00 | 2.85 | 0.00 | 0.00 | 4.00 | 4.50 | 1.60 |
| 172 | MN08251 | 1.50 | 4.00 | 1.20 | 4.23 | 0.00 | 8.00 | 4.50 | 3.35 |
| 173 | MN08252 | 1.00 | 0.00 | 0.20 | 0.17 | 0.00 | 0.00 | 0.40 | 0.25 |
| 174 | MN08253 | 2.15 | 0.00 | 4.50 | 4.40 | 0.00 | 4.00 | 15.75 | 4.40 |
| 175 | MN08254 | 0.10 | 0.00 | 3.00 | 0.00 | 0.00 | 2.00 | 12.00 | 2.44 |
| 176 | MN08260 | 0.00 | 0.00 | 2.40 | 0.00 | 0.00 | 0.40 | 0.50 | 0.45 |
| 177 | MN08262 | 2.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.36 |
| 178 | MN08266 | 0.20 | 0.00 | 18.00 | 0.17 | 0.00 | 4.00 | 10.50 | 4.70 |
| 179 | MN08268 | 0.20 | 10.00 | 9.00 | 0.00 | 0.00 | 4.00 | 19.00 | 6.03 |
| 180 | MN08270 | 0.10 | 0.00 | 6.75 | 0.00 | 0.36 | 0.40 | 13.50 | 3.02 |
| 181 | Moholt | 50.00 | 100.00 | 35.00 | 61.50 | 0.00 | 100.00 | 35.00 | 54.50 |
| 182 | Navaro | 40.00 | 40.00 | 29.00 | 30.80 | 15.00 | 64.00 | 13.50 | 33.19 |
| 183 | ND000861 | 6.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.40 | 1.65 | 1.26 |
| 184 | ND001397 | 40.00 | 60.00 | 35.00 | 53.43 | 59.64 | 100.00 | 36.25 | 54.90 |
| 185 | ND020290-PO-808 | 8.00 | 20.00 | 19.50 | 1.10 | 0.00 | 32.00 | 15.75 | 13.76 |
| 186 | ND030078 | 0.00 | 10.00 | 6.00 | -0.17 | 0.00 | 8.00 | 18.47 | 6.04 |
| 187 | ND040196 | 0.00 | 0.00 | 3.75 | 0.00 | 0.00 | 0.00 | 5.40 | 1.31 |
| 188 | ND040492 | 0.00 | 0.00 | 2.25 | 0.00 | 0.00 | 0.00 | 2.85 | 0.73 |
| 189 | ND050017 | 0.00 | 0.00 | 9.00 | 0.00 | 0.00 | 0.00 | 7.50 | 2.36 |
| 190 | ND050490 | 0.00 | 5.00 | 4.50 | 3.30 | 0.00 | 4.00 | 7.50 | 3.47 |
| 191 | ND050506 | 0.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.40 | 3.00 | 0.89 |
| 192 | ND050578 | 0.00 | 0.00 | 3.00 | 0.00 | . | 0.40 | 8.25 | Non-est |
| 193 | ND051037 | 0.10 | 0.00 | 2.10 | 0.00 | 0.00 | 0.40 | 6.75 | 1.31 |
| 194 | ND051069 | 0.00 | 0.00 | 7.50 | 0.00 | 0.00 | 0.40 | 9.75 | 2.52 |
| 195 | ND051236 | 1.00 | 0.00 | 0.60 | 0.00 | 0.00 | 0.00 | 0.55 | 0.31 |
| 196 | ND051306 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 |
| 197 | ND051312 | 0.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.40 | 0.00 | 0.17 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
|---|---|---|---|---|---|---|---|---|---|
| 198 | ND051467 | 0.00 | 0.00 | 2.85 | 0.00 | 0.00 | 0.40 | 0.95 | 0.60 |
| 199 | ND051513 | 0.10 | 0.00 | 0.75 | 0.00 | 0.00 | 0.00 | 1.10 | 0.28 |
| 200 | ND060111 | 0.00 | 0.00 | 7.50 | . | 0.00 | 0.40 | 9.75 | Non-est |
| 201 | ND060182 | 1.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.35 | 0.23 |
| 202 | ND060223 | 0.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 6.00 | 1.29 |
| 203 | ND060235 | 0.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 6.00 | 1.29 |
| 204 | ND060249 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 14.85 | 2.16 |
| 205 | ND060342 | 0.00 | 4.00 | 13.50 | 2.03 | 0.00 | 4.00 | 8.25 | 4.54 |
| 206 | ND060418 | 0.00 | 0.00 | 4.50 | 0.00 | 0.00 | 0.40 | 15.75 | 2.90 |
| 207 | ND060432 | 0.00 | 0.00 | 2.10 | 0.00 | 0.00 | 0.00 | 7.50 | 1.35 |
| 208 | ND060449 | 0.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.40 | 4.50 | 1.13 |
| 209 | ND060464 | 0.00 | 0.00 | 6.15 | 0.17 | 0.00 | 0.40 | 9.00 | 2.25 |
| 210 | ND060487 | 0.00 | 0.00 | 0.90 | 0.00 | 0.36 | 0.00 | 0.15 | 0.20 |
| 211 | ND060507 | 0.50 | 0.00 | 1.80 | 0.00 | 0.00 | 0.00 | 1.70 | 0.57 |
| 212 | ND060570 | 1.00 | 0.00 | 3.75 | 0.00 | 0.00 | 3.00 | 7.50 | 2.18 |
| 213 | ND060652 | 0.50 | 0.00 | 3.75 | 0.00 | 0.00 | 0.00 | 6.00 | 1.46 |
| 214 | ND060897 | 0.00 | 0.00 | 1.10 | 0.00 | 0.00 | 0.40 | 4.65 | 0.88 |
| 215 | ND060925 | 1.00 | 0.00 | 3.75 | . | 0.36 | 0.00 | 3.30 | Non-est |
| 216 | ND061097 | 0.00 | 0.00 | 4.50 | 0.00 | 0.00 | 0.40 | 4.50 | 1.34 |
| 217 | ND061590 | 0.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 6.00 | 1.26 |
| 218 | ND061614 | 0.10 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 1.70 | 0.69 |
| 219 | ND061813 | 10.00 | 10.00 | 13.50 | 0.00 | 0.00 | 32.00 | 22.50 | 12.55 |
| 220 | ND061868 | 0.00 | 0.00 | 6.00 | 0.17 | 0.00 | 0.00 | 1.20 | 1.05 |
| 221 | ND061975 | 0.00 | 0.00 | 3.75 | 0.00 | 0.00 | 0.40 | 8.25 | 1.77 |
| 222 | ND070388 | 0.00 | 0.00 | 4.00 | 0.00 | 3.00 | 0.40 | 4.50 | 1.70 |
| 223 | ND070813 | 0.00 | 0.00 | 6.00 | 0.00 | 0.00 | 0.40 | 5.25 | 1.66 |
| 224 | ND071063 | 1.00 | 0.00 | 2.40 | 0.00 | 0.00 | 0.00 | 2.40 | 0.83 |
| 225 | ND071521 | 4.00 | 1.00 | 11.25 | 0.00 | 0.00 | 8.00 | 11.25 | 5.07 |
| 226 | ND071694 | 0.00 | 0.00 | 23.15 | 0.00 | 0.00 | 12.00 | 13.50 | 6.95 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
| 227 | ND072258 | 0.00 | 40.00 | 26.75 | 4.40 | 0.00 | 100.00 | 28.50 | 28.52 |
| 228 | ND080724 | 0.00 | 0.00 | 3.75 | 0.00 | 0.00 | 0.40 | 4.50 | 1.24 |
| 229 | ND081924 | 2.00 | 0.00 | 0.60 | 0.00 | 0.00 | 0.40 | 3.75 | 0.96 |
| 230 | Nes | 70.00 | 100.00 | 50.00 | 78.17 | 1.50 | 100.00 | 55.00 | 64.95 |
| 231 | Nice | 28.00 | 60.00 | 23.50 | 26.23 | 0.00 | 100.00 | 9.75 | 35.35 |
| 232 | Nudist | 90.00 | 100.00 | 45.00 | 72.50 | 55.00 | 100.00 | 60.00 | 74.64 |
| 233 | OA1058-4 | 0.00 | 0.00 | 0.00 | 1.10 | 0.00 | 0.00 | 0.10 | 0.17 |
| 234 | OA1130-1 | 1.15 | 4.00 | 13.50 | 23.50 | 0.00 | 60.00 | 24.00 | 18.02 |
| 235 | OA1174-3 | 0.00 | 8.00 | 6.00 | 0.00 | 0.00 | 12.00 | 15.75 | 5.96 |
| 236 | OA1176-1 | 0.00 | 0.00 | 9.00 | 0.00 | . | 4.00 | 15.00 | Non-est |
| 237 | OA1180-5 | 70.00 | 80.00 | 9.00 | 67.00 | -0.06 | 60.00 | 18.00 | 43.42 |
| 238 | OA1189-1 | 0.00 | 0.00 | 13.50 | 6.60 | 0.00 | 32.00 | 22.50 | 10.66 |
| 239 | OA1189-4 | 3.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 4.80 | 1.54 |
| 240 | OA1196-3 | 0.10 | 0.00 | 3.00 | 0.00 | 0.00 | 2.00 | 6.00 | 1.59 |
| 241 | OA1197-1 | 0.00 | 0.00 | 1.80 | 0.00 | 0.00 | 0.40 | 0.30 | 0.36 |
| 242 | OA1202-1 | 20.00 | 1.00 | 9.75 | 3.30 | 4.00 | 4.00 | 6.00 | 6.86 |
| 243 | OA1204-2 | 16.50 | 4.00 | 7.50 | 0.00 | 5.00 | 8.00 | 1.97 | 6.14 |
| 244 | OA1207-1 | 95.00 | 100.00 | 35.00 | 72.50 | 65.00 | 100.00 | 27.00 | 70.64 |
| 245 | OA1226-1 | 12.00 | 4.00 | 13.50 | 4.57 | 0.00 | 100.00 | 10.50 | 20.65 |
| 246 | OA1226-4 | 50.00 | 8.00 | 18.00 | 2.20 | 0.00 | 48.00 | 18.00 | 20.60 |
| 247 | OA1228-1 | 0.00 | 0.00 | 2.85 | 0.00 | 0.00 | 100.00 | 2.40 | 15.04 |
| 248 | OA1232-2 | 0.00 | 8.00 | 1.05 | 0.00 | 0.00 | 8.00 | 3.75 | 2.97 |
| 249 | OA1232-5 | 0.00 | 0.00 | 0.90 | 0.00 | 0.00 | 2.00 | 0.45 | 0.48 |
| 250 | OA1234-1 | 0.00 | 1.00 | 9.00 | 0.00 | 0.00 | 2.00 | 12.00 | 3.43 |
| 251 | OA1242-5 | 0.10 | 0.00 | 14.00 | 0.00 | 0.36 | 32.00 | 15.00 | 8.78 |
| 252 | OA1248-1 | 6.15 | 4.00 | 5.25 | 0.00 | 0.00 | 4.00 | 2.25 | 3.09 |
| 253 | OA1250-1 | 50.00 | 20.00 | 9.00 | -0.17 | 1.00 | 48.00 | 6.00 | 19.12 |
| 254 | OA1250-2 | 45.00 | 8.00 | 8.25 | 0.00 | 2.50 | 100.00 | 6.00 | 24.25 |
| 255 | OA1251-1 | 35.00 | 60.00 | 21.38 | 35.60 | 17.50 | 32.00 | 22.50 | 32.00 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
|-------|----------|------|---|---|------|---|---|---|---------|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
| 256 | OA1253-1 | 27.00 | 40.00 | 21.75 | 0.00 | 0.00 | 4.00 | 24.00 | 16.68 |
| 257 | OA1256-1 | 0.00 | 0.00 | 1.80 | 0.00 | 0.00 | 0.00 | 0.30 | 0.30 |
| 258 | OA1260-1 | 0.00 | 10.00 | 24.00 | 0.00 | 0.00 | 48.00 | 14.50 | 13.79 |
| 259 | OA1262-1 | 0.00 | 0.00 | 6.00 | 0.00 | 0.00 | 0.40 | 3.00 | 1.34 |
| 260 | OA1263-2 | 27.00 | 0.00 | 1.90 | 0.00 | . | 0.40 | 3.00 | Non-est |
| 261 | OA1266-1 | 0.00 | 0.00 | 7.50 | 0.00 | 0.00 | 2.00 | 0.30 | 1.40 |
| 262 | OA1268-3 | 8.15 | 16.00 | 3.00 | 4.40 | 8.00 | 8.00 | 2.00 | 7.08 |
| 263 | OA1272-1 | 36.00 | 8.00 | 6.00 | 6.60 | 0.00 | 8.00 | 10.50 | 10.73 |
| 264 | Odal | 70.00 | 100.00 | 40.00 | 40.10 | 12.00 | 80.00 | 35.00 | 53.87 |
| 265 | Olram | 45.00 | 100.00 | 40.00 | 88.83 | . | 100.00 | 20.00 | Non-est |
| 266 | OT3028 | 2.15 | 4.00 | 18.00 | 1.10 | 0.00 | 60.00 | 18.00 | 14.75 |
| 267 | OT3036 | 30.00 | 80.00 | 17.09 | 34.60 | 4.30 | 48.00 | 24.00 | 34.00 |
| 268 | OT3037 | 1.00 | 1.00 | 0.70 | 0.00 | 0.00 | 4.00 | 13.50 | 2.89 |
| 269 | OT3039 | 30.00 | 40.00 | 17.09 | 17.43 | 2.00 | 16.00 | 9.50 | 18.86 |
| 270 | OT3045 | 0.00 | 1.00 | 11.25 | 13.20 | 0.00 | 4.00 | 29.00 | 8.35 |
| 271 | OT3046 | 0.00 | 20.00 | 33.50 | 0.00 | 0.00 | 80.00 | 33.00 | 23.76 |
| 272 | OT3047 | 0.00 | 40.00 | 28.50 | 0.00 | 0.00 | 80.00 | 26.25 | 24.96 |
| 273 | OT3048 | 0.00 | 0.00 | 6.75 | 78.00 | 26.00 | 0.40 | 8.25 | 17.06 |
| 274 | OT3050 | 0.00 | 60.00 | 19.00 | 0.00 | 0.00 | 60.00 | 7.50 | 20.88 |
| 275 | OT399 | 0.00 | 4.00 | 16.50 | 4.40 | 0.00 | 20.00 | 18.00 | 8.99 |
| 276 | OT7053 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.40 | 0.45 | 0.15 |
| 277 | Porter | 60.00 | 60.00 | 35.00 | 40.10 | 8.45 | 80.00 | 24.00 | 43.94 |
| 278 | Putnam 61 | 80.00 | 60.00 | 40.00 | 44.40 | 2.50 | 100.00 | 36.00 | 51.84 |
| 279 | Ringsaker | 77.50 | 100.00 | 50.00 | 77.83 | 29.00 | 100.00 | 50.00 | 69.19 |
| 280 | Robust | 3.00 | 16.00 | 13.50 | 0.00 | 0.00 | 32.00 | 16.50 | 11.57 |
| 281 | SA01223-02 | 6.10 | 40.00 | 13.50 | 0.00 | 0.00 | 100.00 | 19.50 | 25.56 |
| 282 | SA051172 | 0.00 | 8.00 | 7.00 | 0.00 | 0.00 | 0.40 | 4.95 | 2.91 |
| 283 | SA061148 | 27.50 | 100.00 | 30.00 | 32.40 | 7.00 | 100.00 | 28.50 | 46.49 |
| 284 | SA070089 | 8.10 | 8.00 | 6.00 | 0.00 | 0.00 | 60.00 | 3.00 | 12.13 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
|---|---|---|---|---|---|---|---|---|---|
| 285 | SA070270 | 8.00 | 16.00 | 9.00 | 17.77 | 20.00 | 8.00 | 12.00 | 12.97 |
| 286 | SA070367 | 2.00 | 0.00 | 24.75 | 8.63 | 0.00 | 60.00 | 22.50 | 16.84 |
| 287 | SA070444 | 0.00 | 40.00 | 18.00 | 0.00 | 0.00 | 80.00 | 22.50 | 22.93 |
| 288 | SA070452 | 2.00 | 40.00 | 50.00 | 2.03 | 0.00 | 100.00 | 33.50 | 32.50 |
| 289 | SA070513 | 8.00 | 32.00 | 10.50 | 0.00 | 0.00 | 48.00 | 13.50 | 16.00 |
| 290 | SA070576 | 35.00 | 80.00 | 20.00 | 8.63 | 6.00 | 80.00 | 11.25 | 34.41 |
| 291 | SA070592 | 26.00 | 80.00 | 26.75 | 55.50 | 16.00 | 100.00 | 30.00 | 47.75 |
| 292 | SA070631 | 0.50 | 20.00 | 18.00 | 0.00 | 0.36 | 4.00 | 13.50 | 8.05 |
| 293 | SA070655 | 0.10 | 20.00 | 29.00 | 3.30 | 0.00 | 32.00 | 25.00 | 15.63 |
| 294 | SA070712 | 0.00 | 0.00 | 0.60 | 1.10 | 0.00 | 0.00 | 0.00 | 0.19 |
| 295 | SA070781 | 0.00 | 10.00 | 30.00 | 0.00 | 0.00 | 40.00 | 34.00 | 16.29 |
| 296 | SA070845 | 0.15 | 10.00 | 23.50 | -0.17 | 0.00 | 80.00 | 29.25 | 20.39 |
| 297 | SA070860 | 8.00 | 10.00 | 35.00 | 0.00 | 0.00 | 8.00 | 24.00 | 12.14 |
| 298 | SA070906 | 1.00 | 20.00 | 15.00 | 0.00 | 0.00 | 48.00 | 15.00 | 14.14 |
| 299 | SA070972 | 0.10 | 1.00 | 29.00 | 35.37 | 0.00 | 80.00 | 33.50 | 25.52 |
| 300 | SA071369 | 4.50 | 8.00 | 5.09 | 0.00 | 0.00 | 4.00 | 4.50 | 3.73 |
| 301 | SA071405 | 1.00 | 20.00 | 15.75 | 4.40 | 0.00 | 48.00 | 21.00 | 15.74 |
| 302 | SA071616 | 2.50 | 1.00 | 27.00 | 1.10 | 0.00 | 32.00 | 20.25 | 11.98 |
| 303 | Sherwood | 20.00 | 20.00 | 28.50 | 0.00 | 0.00 | 2.00 | 9.00 | 11.28 |
| 304 | SW INGEBORG | 75.00 | 60.00 | 45.00 | 83.50 | 4.00 | 100.00 | 45.00 | 58.93 |
| 305 | SW KERSTIN | 37.50 | 100.00 | 45.00 | 26.40 | 20.00 | 100.00 | 40.00 | 52.70 |
| 306 | SW VAASA | 75.00 | 100.00 | 29.00 | 61.50 | 7.64 | 100.00 | 45.00 | 59.73 |
| 307 | Sylva | 42.50 | 60.00 | 16.75 | 51.10 | 11.00 | 80.00 | 25.00 | 40.91 |
| 308 | Tippecanoe | 72.50 | 100.00 | 45.00 | 55.90 | 40.00 | 100.00 | 55.00 | 66.91 |
| 309 | Triactor | 2.15 | 8.00 | 6.00 | 4.23 | 0.36 | 60.00 | 9.00 | 12.82 |
| 310 | Tyler | 75.00 | 100.00 | 45.00 | 26.23 | 6.00 | 100.00 | 42.50 | 56.39 |
| 311 | VAO-58 | 65.00 | 80.00 | 27.00 | 55.83 | 0.00 | 100.00 | 27.00 | 50.69 |
| 312 | VAO-44 | 50.00 | 100.00 | 35.00 | 35.03 | 28.00 | 100.00 | 38.50 | 55.22 |
| 313 | Vao-48 | 70.00 | 60.00 | 38.00 | 77.83 | 50.00 | 100.00 | 42.50 | 62.62 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 Castroville, TX | Fargo, ND | St. Paul, MN | 2011 Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|
| 314 | Woodburn | 7.00 | 60.00 | 22.50 | 4.40 | 0.00 | 100.00 | 35.00 | 32.70 |
| 315 | X8787-1 | 0.20 | 2.00 | 3.60 | 0.00 | 0.00 | 8.00 | 11.25 | 3.53 |
| 316 | X8791-1 | 0.20 | 4.00 | 6.00 | 0.00 | 0.00 | 0.90 | 3.00 | 2.01 |
| 317 | X8826-1 | 7.00 | 16.00 | 6.75 | 22.00 | 5.00 | 32.00 | 12.00 | 14.39 |
| 318 | X8903-2 | 33.00 | 80.00 | 21.00 | 44.50 | 12.50 | 100.00 | 33.50 | 46.36 |
| 319 | X8995-4 | 0.20 | 5.00 | 4.50 | 6.60 | 0.00 | 4.00 | 10.50 | 4.35 |
| 320 | X9082-1 | 1.00 | 60.00 | 10.50 | 2.20 | 0.00 | 8.00 | 16.50 | 14.03 |
| 321 | X9150-1 | 2.00 | 0.00 | 1.80 | 2.03 | 0.00 | 4.00 | 4.50 | 2.00 |
| 322 | X9192-5 | 0.00 | 20.00 | 4.50 | 4.40 | 0.00 | 80.00 | 13.50 | 17.49 |
| 323 | X9195-2 | 0.00 | 0.00 | 6.00 | 0.00 | 0.00 | 0.00 | 2.70 | 1.24 |
| 324 | X9195-6 | 0.10 | 0.00 | 3.60 | 0.00 | 0.00 | 0.00 | 4.50 | 1.17 |
| 325 | X9200-4 | 2.24 | 40.00 | 18.00 | 15.40 | 0.00 | 32.00 | 29.00 | 19.52 |
| 326 | X9221-6 | 0.50 | 60.00 | 0.20 | 24.20 | 5.00 | 3.00 | 1.50 | 13.49 |
| 327 | X9221-8 | 0.00 | 0.00 | 0.60 | 0.00 | 0.00 | 0.00 | 0.65 | 0.18 |
| 328 | X9253-1 | 0.50 | 4.00 | 4.50 | 2.20 | 1.00 | 8.00 | 7.50 | 3.96 |
| 329 | X9258-5 | 0.00 | 8.00 | 0.80 | 0.00 | 0.00 | 8.00 | 3.20 | 2.81 |
| 330 | X9270-4 | 0.10 | 10.00 | 3.00 | 0.00 | 0.00 | 4.00 | 4.50 | 3.03 |
| 331 | X9285-1 | 0.00 | 4.00 | 6.00 | 0.00 | 0.00 | 8.00 | 22.50 | 5.79 |
| 332 | X9287-2 | 0.10 | 0.00 | 0.40 | 0.17 | 0.00 | 0.00 | 3.00 | 0.52 |
| 333 | X9290-2 | 0.00 | 8.00 | 6.00 | 0.00 | 0.00 | 8.00 | 15.75 | 5.39 |
| 334 | X9368-1 | 0.00 | 8.00 | 1.05 | 0.00 | 0.00 | 4.00 | 6.00 | 2.72 |
| 335 | X9375-1 | 0.00 | 0.00 | 1.70 | 0.00 | 0.00 | 0.60 | 0.40 | 0.39 |
| 336 | X9384-2 | 0.00 | 10.00 | 1.65 | 4.23 | 0.00 | 8.00 | 5.25 | 4.16 |
| 337 | X9386-1 | 0.00 | 2.00 | 1.65 | 17.60 | 0.00 | 8.00 | 2.10 | 4.48 |
| 338 | X9392-1 | 0.65 | 0.00 | 0.80 | 0.00 | 0.36 | 3.00 | 9.00 | 1.97 |
| 339 | X9395-2 | 0.10 | 8.00 | 0.50 | 4.57 | 0.00 | 0.40 | 3.75 | 2.47 |
| 340 | X9396-1 | 1.10 | 0.00 | 3.75 | 6.60 | 0.00 | 4.00 | 7.50 | 3.28 |
| 341 | X9396-4 | 1.15 | 0.00 | 6.00 | 17.60 | 0.15 | 2.00 | 26.00 | 7.56 |
| 342 | X9410-1 | 0.15 | 8.00 | 7.65 | 0.00 | 0.00 | 4.00 | 1.00 | 2.97 |

**Table 4.3** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Castroville, TX | Fargo, ND | St. Paul, MN | |
| 343 | X9410-2 | 0.00 | 0.00 | 1.70 | 0.00 | 0.00 | 0.00 | 6.00 | 1.10 |
| 344 | X9414-1 | 0.10 | 2.00 | 0.20 | 0.00 | 0.00 | 2.00 | 8.25 | 1.79 |
| 345 | X9421-3 | 2.00 | 4.00 | 3.00 | 14.30 | 2.00 | 8.00 | 7.50 | 5.83 |
| 346 | X9422-1 | 2.00 | 10.00 | 1.70 | 4.40 | 0.00 | 8.00 | 3.00 | 4.16 |
| 347 | X9435-1 | 0.20 | 0.00 | 0.00 | 0.00 | 10.00 | 4.00 | 7.50 | 3.10 |
| 348 | X9439-1 | 2.50 | 16.00 | 15.00 | 1.10 | 0.36 | 60.00 | 15.00 | 15.71 |
| 349 | X9449-1 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 5.25 | 0.76 |
| 350 | X9474-2 | 0.00 | 0.00 | 2.10 | 17.43 | 0.36 | 4.00 | 2.25 | 3.73 |
| 351 | X9487-1 | 0.20 | 0.00 | 3.00 | 0.00 | 0.00 | 4.00 | 6.00 | 1.89 |
| 352 | X9487-4 | 0.20 | 1.00 | 2.85 | 0.00 | 0.00 | 32.00 | 1.65 | 5.39 |
| 353 | X9492-1 | 6.00 | 20.00 | 12.00 | 8.80 | 1.00 | 4.00 | 21.00 | 10.40 |
| 354 | X9498-1 | 1.00 | 8.00 | 4.20 | 3.30 | 0.36 | 8.00 | 4.50 | 4.19 |
| 355 | X9500-2 | 0.00 | 0.00 | 0.35 | 2.37 | 0.00 | 8.00 | 1.50 | 1.75 |
| 356 | X9500-6 | 0.00 | 0.00 | 0.90 | 0.00 | 2.00 | 4.00 | 2.25 | 1.31 |
| 357 | X9503-1 | 0.10 | 0.00 | 0.58 | 0.00 | 0.36 | 4.00 | 1.50 | 0.91 |
| 358 | X9507-1 | 0.50 | 4.00 | 6.50 | 7.70 | 0.00 | 8.00 | 3.75 | 4.35 |
| 359 | X9507-3 | 0.50 | 1.00 | 2.50 | 0.00 | 0.00 | 4.00 | 15.00 | 3.26 |
| 360 | X9509-3 | 0.65 | 1.00 | 4.50 | 6.60 | 0.00 | 8.00 | 13.50 | 4.89 |
| 361 | X9509-4 | 0.00 | 20.00 | 3.75 | 0.00 | 0.00 | 32.00 | 9.00 | 9.25 |
| | **CV%** | 42.49 | . | 36.62 | 86.56 | 152.51 | . | 52.47 | 48.74 |
| | **Grand Mean** | 23.65 | 35.42 | 17.26 | 16.36 | 6.39 | 45.57 | 19.59 | 20.90 |
| | **Range** | 0 - 95.00 | 0 – 100.00 | 0 - 55.00 | 0 - 89.17 | 0 - 75.00 | 0 – 100.00 | 0 – 70.00 | 0 - 74.64 |
| | **LSD** | 19.79 | . | 12.55 | 31.29 | 20.23 | . | 20.36 | 8.33 |

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**Table 4.4. CI means of winter oat lines for individual genotypes in Castroville, TX, Baton Rouge, LA, Fargo, ND, and St. Paul, MN for 2010 and 2011.**

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | AVERAGE |
|---|---|---|---|---|---|---|---|---|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Fargo, ND | St. Paul, MN | |
| 1 | 833-99AB118 | 70.00 | 3.00 | 22.50 | 14.00 | 4.00 | 11.50 | 20.83 |
| 2 | Aurora | 75.00 | 80.00 | 40.00 | 80.00 | 100.00 | 50.00 | 70.83 |
| 3 | Bond | 75.00 | 100.00 | 35.00 | 55.90 | 100.00 | 29.00 | 65.82 |
| 4 | Brooks | 95.00 | 80.00 | 60.00 | 85.00 | 100.00 | 45.00 | 77.50 |
| 5 | Coker 242 | 70.00 | 40.00 | 38.50 | 45.00 | 80.00 | 38.00 | 51.92 |
| 6 | Coker 716 | 100.00 | 100.00 | 60.00 | 75.00 | 100.00 | 40.00 | 79.17 |
| 7 | Colberson | 80.00 | 80.00 | 32.25 | 75.00 | 100.00 | 38.50 | 67.63 |
| 8 | Corondo | 67.50 | 40.00 | 36.00 | 40.47 | 80.00 | 33.50 | 49.58 |
| 9 | Delair | 80.00 | 60.00 | 55.00 | 21.50 | 100.00 | 50.00 | 61.08 |
| 10 | DeSoto | 70.00 | 32.00 | 13.50 | 16.00 | 32.00 | 24.00 | 31.25 |
| 11 | Excel | 12.00 | 40.00 | 14.25 | 2.67 | 100.00 | 15.00 | 30.65 |
| 12 | FL0047-J9 | 15.00 | 0.00 | 6.75 | 0.00 | 3.00 | 7.50 | 5.38 |
| 13 | FL0115-J2 | 24.00 | 0.00 | 13.50 | 1.00 | 0.00 | 2.10 | 6.77 |
| 14 | FL0238BSB-22 | 3.00 | 0.00 | 17.25 | 0.00 | 0.00 | 10.50 | 5.13 |
| 15 | FL03001BSB-S7 | 26.00 | 40.00 | 43.00 | 3.00 | 48.00 | 25.50 | 30.92 |
| 16 | FL03129-Ab7 | 10.00 | 0.00 | 9.00 | 0.00 | 0.00 | 10.50 | 4.92 |
| 17 | FL03146BSB-S1-B-S1 | 10.00 | 0.00 | 7.65 | 0.00 | 0.00 | 5.25 | 3.82 |
| 18 | FL03167BSB-145 | 1.00 | 0.00 | 1.90 | 0.00 | . | 0.80 | Non-est |
| 19 | FL03167BSB-147 | 5.00 | 0.00 | 2.50 | 0.00 | 0.00 | 13.50 | 3.50 |
| 20 | FL03167BSBS-3 | 12.00 | 0.00 | 13.50 | 0.00 | 2.00 | 15.75 | 7.21 |
| 21 | FL03184-FLID-B-S1 | 42.50 | 0.00 | 7.50 | 0.00 | 0.00 | 6.00 | 9.33 |
| 22 | FL04155-S06-31-B-S1 | 1.10 | 0.00 | 3.60 | 0.00 | 0.00 | 0.65 | 0.89 |
| 23 | FL04178-FLID-B-S-2 | 2.00 | 0.00 | 6.00 | 0.00 | 4.00 | 7.50 | 3.25 |
| 24 | FL99084-J2 | 6.50 | 0.00 | 5.85 | 0.47 | 0.00 | 12.75 | 4.26 |
| 25 | FL99153FBS-45-1-B-S-B-S1-B-S1 | 0.20 | 0.00 | 12.00 | 0.00 | 0.00 | 9.00 | 3.53 |
| 26 | FL99212-D6 | 22.00 | 0.00 | 11.00 | 0.00 | 0.00 | 4.50 | 6.25 |
| 27 | Florida 167 | 75.00 | 8.00 | 60.00 | 40.00 | 21.00 | 34.00 | 39.67 |

**Table 4.4** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | AVERAGE |
|---|---|---|---|---|---|---|---|---|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Fargo, ND | St. Paul, MN | |
| 28 | Florida 500 | 68.00 | 60.00 | 60.00 | 0.07 | 80.00 | 45.00 | 52.16 |
| 29 | Floriland | 75.00 | 40.00 | 60.00 | 65.00 | 80.00 | 45.00 | 60.83 |
| 30 | HARRISON | 60.00 | 0.00 | 15.75 | 18.00 | 4.00 | 22.50 | 20.04 |
| 31 | HORIZON 201 | 0.20 | 0.00 | 4.35 | 39.53 | 0.00 | 6.00 | 8.35 |
| 32 | HORIZON LA976 | 0.20 | 0.00 | 4.65 | 0.00 | 0.00 | 2.70 | 1.26 |
| 33 | LA02012-S-B-139-S2-B-S2-B-S2 | 0.20 | 0.00 | 7.50 | 0.00 | 0.00 | 7.50 | 2.53 |
| 34 | LA02035-I-J1 | 16.00 | 0.00 | 4.65 | 0.00 | 0.00 | 6.75 | 4.57 |
| 35 | LA0210SBSBSBSB-S1 | 80.00 | 60.00 | 55.00 | 12.47 | 100.00 | 50.00 | 59.58 |
| 36 | LA03012SBSBSB-12 | 0.00 | 0.00 | 7.65 | 0.00 | 0.00 | 4.50 | 2.03 |
| 37 | LA03012SBSBSB-61 | 0.00 | 0.00 | 10.50 | 0.00 | 6.00 | 2.10 | 3.10 |
| 38 | LA03018SBSBSB-65-S1 | 24.00 | 0.00 | 13.50 | 0.00 | 0.00 | 9.00 | 7.75 |
| 39 | LA03040SBSBSB-83 | 60.00 | 0.00 | 31.50 | 1.40 | 4.00 | 9.00 | 17.65 |
| 40 | LA03046SBS7-B-S1 | 2.00 | 0.00 | 11.25 | 0.00 | 0.00 | 13.50 | 4.46 |
| 41 | LA03060SBSBSB-S1 | 8.00 | 0.00 | 43.00 | 0.00 | 32.00 | 38.00 | 20.09 |
| 42 | LA03063SBSBSB-6 | 6.10 | 0.00 | 3.00 | 0.00 | 0.00 | 6.00 | 2.52 |
| 43 | LA03063SBSBSB-S4 | 1.00 | 0.00 | 6.15 | 0.00 | 0.30 | 9.00 | 2.74 |
| 44 | LA03066SBS-L1 | 100.00 | 80.00 | 34.00 | 24.53 | 32.00 | 37.50 | 51.34 |
| 45 | LA04004SBSB-121 | 5.00 | 0.40 | 18.00 | 0.00 | 4.00 | 38.50 | 10.98 |
| 46 | LA04004SBSB-61-B-S1 | 11.00 | 0.00 | 22.50 | 2.50 | 4.00 | 27.00 | 11.17 |
| 47 | LA04014SBSB-39 | 3.00 | 0.00 | 7.50 | 0.00 | 8.00 | 27.00 | 7.58 |
| 48 | LA04018SBSB-181 | 0.20 | 0.00 | 13.50 | 3.00 | 0.00 | 5.25 | 3.66 |
| 49 | LA04018SBSB-86 | 2.10 | 0.00 | 9.00 | 0.00 | 0.00 | 9.00 | 3.35 |
| 50 | LA05006GSBS-7-S1 | 0.00 | 1.00 | 18.00 | 0.00 | 0.00 | 10.50 | 4.92 |
| 51 | LA06058SBS-32-S1 | 20.00 | 0.00 | 6.00 | 0.00 | 0.30 | 4.50 | 5.13 |
| 52 | LA06059SBS-84-S1 | 28.00 | 0.00 | 5.80 | 0.00 | 0.00 | 7.50 | 6.88 |
| 53 | LA604 | 2.00 | 4.00 | 4.50 | 0.00 | 3.00 | 11.55 | 4.18 |
| 54 | LA9339 | 20.00 | 4.00 | 31.50 | 4.00 | 8.00 | 15.00 | 13.75 |
| 55 | LA97006GSB-59-2-4-SBS1 | 2.00 | 0.00 | 3.00 | 0.00 | 0.00 | 13.50 | 3.08 |
| 56 | LA99016 | 0.00 | 0.00 | 7.50 | 0.00 | 0.00 | 3.00 | 1.75 |

**Table 4.4** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | AVERAGE |
|---|---|---|---|---|---|---|---|---|
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Fargo, ND | St. Paul, MN | |
| 57 | LA99017 | 0.00 | 0.00 | 6.75 | 0.40 | 0.00 | 15.15 | 3.72 |
| 58 | Lee | 77.50 | 60.00 | 36.00 | 89.53 | 100.00 | 45.00 | 68.01 |
| 59 | Osage | 75.00 | 60.00 | 45.00 | 7.00 | 100.00 | 34.50 | 53.58 |
| 60 | Ozark | 90.00 | 60.00 | 50.00 | 60.00 | 48.00 | 27.00 | 55.83 |
| 61 | PI260616-1 | 6.00 | 4.00 | 0.00 | 1.10 | 4.00 | 1.84 | 2.82 |
| 62 | Quincy Gray | 65.00 | 32.00 | 4.50 | 39.53 | 16.00 | 16.00 | 28.84 |
| 63 | Red Algerian | 55.00 | 20.00 | 27.00 | 14.00 | 80.00 | 35.00 | 38.50 |
| 64 | Rogers | 80.00 | 20.00 | 60.00 | 29.53 | 64.00 | 40.00 | 48.92 |
| 65 | Santa Fe | 70.00 | 100.00 | 60.00 | 55.00 | 100.00 | 43.00 | 71.33 |
| 66 | SECTARIAT LA495 | 85.00 | 40.00 | 60.00 | 21.00 | 80.00 | 42.50 | 54.75 |
| 67 | Simpson | 92.50 | 80.00 | 55.00 | 65.00 | 100.00 | 21.50 | 69.00 |
| 68 | Sure Grain | 70.00 | 8.00 | 35.00 | 0.50 | 32.00 | 16.50 | 27.00 |
| 69 | TAMO 405 | 12.00 | 0.00 | 15.75 | 0.00 | 0.00 | 6.00 | 5.63 |
| 70 | TAMO 406 | 3.00 | 0.00 | 7.25 | 0.00 | 0.00 | 14.50 | 4.13 |
| 71 | TAMO 606 | 70.00 | 24.00 | 12.00 | 2.50 | 4.00 | 19.50 | 22.00 |
| 72 | Tift | 60.00 | 60.00 | 55.00 | 0.00 | 40.00 | 33.50 | 41.42 |
| 73 | Trisparinia | 80.00 | 80.00 | 50.00 | 2.00 | 100.00 | 40.00 | 58.67 |
| 74 | Trophy | 6.00 | 0.00 | 13.50 | 0.00 | 8.00 | 15.00 | 7.08 |
| 75 | TX02U 7029 | 1.10 | 4.00 | 6.00 | 0.00 | 3.00 | 3.75 | 2.90 |
| 76 | TX02U 7047 | 9.50 | 0.00 | 11.25 | 0.00 | 0.00 | 7.35 | 4.68 |
| 77 | TX02U 7065 | 18.00 | 0.00 | 5.25 | 0.00 | 0.00 | 9.50 | 5.46 |
| 78 | TX02U 7097 | 5.00 | 0.00 | 4.35 | 0.00 | 0.00 | 7.50 | 2.81 |
| 79 | TX02U 7103 | 0.10 | 0.00 | 18.68 | 0.00 | 0.00 | 4.65 | 3.90 |
| 80 | TX02U 7104 | 0.00 | 0.00 | 4.50 | 0.00 | 0.00 | 12.00 | 2.75 |
| 81 | TX02U 7176 | 1.00 | 0.00 | 6.15 | 0.00 | 0.00 | 1.05 | 1.37 |
| 82 | TX02U 7181 | 0.00 | 0.00 | 9.00 | 0.00 | 0.00 | 2.00 | 1.83 |
| 83 | TX02U 7219 | 0.00 | 0.00 | 1.65 | 0.00 | 0.00 | 1.65 | 0.55 |
| 84 | TX02U 7227 | 0.20 | 0.00 | 4.80 | . | 0.00 | 1.70 | Non-est |
| 85 | TX02U 7237 | 11.00 | 0.00 | 9.00 | 0.00 | . | 3.75 | Non-est |

Table 4.4 *Continued*

| | | 2010 | | | 2011 | | | |
|---|---|---|---|---|---|---|---|---|
| ENTRY | GENOTYPE | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Fargo, ND | St. Paul, MN | AVERAGE |
| 86 | TX02U 7325 | 16.00 | 0.00 | 2.25 | 0.00 | 0.00 | 4.50 | 3.79 |
| 87 | TX02U 7443 | 20.00 | 0.00 | 4.50 | 0.00 | 0.00 | 3.75 | 4.71 |
| 88 | TX02U 7473 | 28.00 | 0.00 | 9.75 | 0.00 | 0.00 | 7.50 | 7.54 |
| 89 | TX02U 7479 | 0.00 | 0.00 | 0.90 | 0.00 | 0.00 | 3.00 | 0.65 |
| 90 | TX02U 7490 | 0.00 | 0.00 | 6.75 | 0.00 | 0.00 | 6.75 | 2.25 |
| 91 | TX02U 7518 | 2.00 | 1.00 | 3.75 | 0.00 | 0.00 | 6.45 | 2.20 |
| 92 | TX02U 7605 | 0.20 | 8.00 | 3.00 | 0.00 | 0.00 | 0.70 | 1.98 |
| 93 | TX02U 7651 | 0.00 | 0.00 | 9.00 | 0.00 | 0.00 | 2.75 | 1.96 |
| 94 | TX02U 7682 | 32.00 | 0.00 | 4.50 | 0.00 | 0.00 | 6.00 | 7.08 |
| 95 | TX05CS 347 1 | 0.50 | 0.00 | 13.50 | 0.00 | 0.00 | 6.00 | 3.33 |
| 96 | TX05CS 347 2 | 0.00 | 0.00 | 11.25 | 0.00 | 0.00 | 7.50 | 3.13 |
| 97 | TX05CS 542 | 50.00 | 0.00 | 7.50 | 0.00 | 0.00 | 9.00 | 11.01 |
| 98 | TX05CS 556 | 5.00 | 0.00 | 7.65 | 0.00 | 0.00 | 12.75 | 4.23 |
| 99 | TX07CS1039 | 12.00 | 4.00 | 6.15 | 0.00 | 0.00 | 5.25 | 4.57 |
| 100 | TX07CS1228 | 28.00 | 0.00 | 5.25 | 0.00 | 0.00 | 6.75 | 6.67 |
| 101 | TX07CS1268 | 20.00 | 0.00 | 18.75 | 1.00 | 4.00 | 10.13 | 8.98 |
| 102 | TX07CS1402 | 24.00 | 0.00 | 4.50 | 0.00 | 0.00 | 13.50 | 7.00 |
| 103 | TX07CS1564 | 20.00 | 0.00 | 9.00 | 0.00 | 0.00 | 7.50 | 6.08 |
| 104 | TX07CS1584 | 1.10 | 0.00 | 9.00 | . | 0.00 | 25.00 | Non-est |
| 105 | TX07CS1805 | 0.00 | 0.00 | 6.75 | 0.00 | 0.00 | 6.75 | 2.25 |
| 106 | TX07CS1832 | 0.00 | 0.00 | 9.00 | 0.00 | 0.00 | 20.00 | 4.83 |
| 107 | TX07CS1948 | 0.00 | 0.00 | 1.10 | 0.00 | 0.00 | 0.40 | 0.25 |
| 108 | TX07CS1965 | 0.00 | 0.00 | 1.50 | 0.00 | 0.00 | 0.35 | 0.31 |
| 109 | TX07CS1997 | 1.10 | 0.00 | 6.60 | 0.00 | 0.00 | 1.80 | 1.58 |
| 110 | TX07CS2001 | 5.00 | 0.00 | 11.25 | 0.00 | 0.00 | 7.84 | 4.02 |
| 111 | TX07CS2140 | 2.00 | 0.00 | 6.00 | 0.00 | 0.00 | 11.25 | 3.21 |
| 112 | TX07CS2201 | 0.15 | 0.00 | 9.75 | 0.00 | 0.00 | 9.00 | 3.07 |
| 113 | TX07CS2235 | 0.20 | 0.00 | 13.50 | 0.00 | 0.00 | 6.00 | 3.28 |
| 114 | TX07CS2350 | 0.15 | 0.00 | 7.50 | 0.00 | 0.00 | 9.00 | 2.78 |

**Table 4.4** *Continued*

| ENTRY | GENOTYPE | 2010 | | | 2011 | | | AVERAGE |
| | | Castroville, TX | Fargo, ND | St. Paul, MN | Baton Rouge, LA | Fargo, ND | St. Paul, MN | |
|---|---|---|---|---|---|---|---|---|
| 115 | TX07CS2609 | 0.00 | 0.00 | 10.50 | 0.00 | 0.00 | 3.75 | 2.38 |
| 116 | TX07CS2652 | 0.00 | 0.00 | 3.00 | 0.47 | 3.00 | 6.00 | 2.08 |
| 117 | TX07CS2765 | 0.10 | 0.00 | 6.00 | 0.00 | 4.00 | 3.60 | 2.28 |
| 118 | TX07CS2795 | 0.10 | 0.00 | 5.50 | 0.00 | 3.00 | 2.85 | 1.83 |
| 119 | Winter Fulghum | 75.00 | 80.00 | 60.00 | 75.00 | 80.00 | 28.50 | 66.42 |
| **CV%** | | 25.41 | . | 41.51 | 61.75 | . | 44.87 | 39.05 |
| **Grand Mean** | | 25.46 | 14.26 | 17.72 | 9.63 | 19.77 | 15.28 | 17.14 |
| **Range** | | 0 - 100.00 | 0 - 100.00 | 0 - 60.00 | 0 - 89.53 | 0 - 100.00 | 0.35 - 50.00 | 0.25 - 79.17 |
| **LSD** | | 12.81 | . | 14.93 | 12.58 | . | 13.70 | 5.97 |

**Variance component heritability**

Heritability is an estimate of the origin of variation, particularly the proportion of phenotypic variation to genetic variation (Brown and Caligari, 2008). A higher heritability value indicates greater breeding value and will ultimately be more useful in identifying QTL for crown rust resistance. In the spring oat panel, approximately 88% of the total phenotypic variance is estimated to be genetic in origin (Table 4.5). This is considered a high heritability value. For winter oats, approximately 90% of the phenotypic variance is estimated to be genetic in origin (Table 4.6).

**Table 4.5. Variance-component heritability for spring oat lines across all locations for 2010 and 2011.**

| Source of variation | DF | MS | $\sigma^2$ |
|---|---|---|---|
| Environment | 4 | 27934.51 | |
| Rep (Environment) | 5 | 890.52 | |
| Genotypes | 360 | 2404.28 | 2404.28 |
| Environment * Genotypes | 1431 | 295.32 | |
| Error | 1645 | 103.80 | |
| **Phenotypic variance** | | | 30634.11 |
| $h^2 = 0.88$ | | | |

**Table 4.6. Variance-component heritability for winter oat lines across all locations for 2010 and 2011.**

| Source of variation | DF | MS | $\sigma^2$ |
|---|---|---|---|
| Environment | 3 | 9335.81 | |
| Rep (Environment) | 4 | 355.16 | |
| Genotypes | 118 | 2854.68 | 2854.68 |
| Environment * Genotypes | 352 | 314.14 | |
| Error | 446 | 44.81 | |
| **Phenotypic variance** | | | 12504.63 |
| $h^2 = 0.90$ | | | |

**Repeatability**

Repeatability is a theoretical estimate of the upper limits of heritability indicating that selection for crown rust resistance is predictable within certain environments (Hakizimana et al., 2000). Higher repeatability values indicate that fewer measurements can be taken and that these measurements are capable of repetition over space or time (Falconer, 1988; Falconer and Mackay, 1996). Repeatability will be useful for the future work of this study because this value can help eliminate any testing environments in which oat lines do not perform consistently. Also this value indicates the quality of the information generated by data collection for 2010 and 2011. The higher the value, the more useful the data is in the ability to identify QTL for crown rust resistance.

For spring oat lines, repeatability was highest for Castroville, TX in 2010 with a value of 0.88. Repeatability was the lowest for Castroville, TX in 2011 with a value of 0.56. The repeatability values across the two years for Castroville, TX could be indicative of the large number of rust races found in this part of the country. Additionally, due to limited rainfall during 2011, crown rust infections took longer to establish in the crop, since crown rust relies on moisture for effective spread. St. Paul, MN revealed a repeatability value of 0.82 in 2010 and 0.61 in 2011. In Baton Rouge, LA in 2011, repeatability was estimated to be 0.64 (Table 4.7). Repeatability could not be calculated for the spring oat lines in Fargo, ND because only one rep was grown at this location.

**Table 4.7. Repeatability for spring oat lines in Baton Rouge, LA, Castroville, TX, and St. Paul, MN for 2010 and 2011.**

| Source of variation | DF | 2010 | | 2011 | | |
| | | Castroville, TX | St. Paul, MN | Baton Rouge, LA | Castroville, TX | St. Paul, MN |
| --- | --- | --- | --- | --- | --- | --- |
| Between genotypes | 1 | 715.05 | 187.88 | 358.08 | 119.54 | 165.08 |
| Within genotypes | 360 | 101.01 | 39.96 | 200.61 | 95.01 | 105.66 |
| $\sigma^2_P$ | | 816.06 | 227.84 | 558.69 | 214.55 | 270.73 |
| **Repeatability** | | 0.88 | 0.82 | 0.64 | 0.56 | 0.61 |

For winter oat lines, repeatability was the highest for Castroville, TX in 2010 with a rating of 0.96. The lowest repeatability is for St. Paul, MN in 2011 at 0.79. In 2010, the repeatability for St. Paul, MN was calculated as 0.84. Baton Rouge, LA in 2011 had the second highest repeatability value at 0.92 (Table 4.8). Repeatability could not be calculated for the winter oat lines in Fargo, ND because only one rep was grown at this location.

**Table 4.8. Repeatability for winter oat lines in Baton Rouge, LA, Castroville, TX, and St. Paul, MN for 2010 and 2011.**

| Source of variation | DF | 2010 | | 2011 | |
| | | Castroville, TX | St. Paul, MN | Baton Rouge, LA | St. Paul, MN |
| --- | --- | --- | --- | --- | --- |
| Between genotypes | 1 | 984.23 | 294.60 | 422.55 | 173.27 |
| Within genotypes | 118 | 41.86 | 54.07 | 35.36 | 47.02 |
| $\sigma^2_P$ | | 1026.09 | 348.67 | 457.91 | 220.29 |
| **Repeatability** | | 0.96 | 0.84 | 0.92 | 0.79 |

Crown rust measurements were highly heritable and repeatable. Heritability is necessary in order to guarantee that any resistance genes identified via association mapping will be carried on through future plant generations. Without high heritability, it would be difficult to ensure resistance for oat growers and breeders. Repeatability is also important in order to guarantee that resistance will be found in other locations within the genotypes featuring such resistance.

**Field observations vs. Assess ratings**

Three panels of oats (spring, winter and a core representation of each type of growth habit) were grown at four locations for two years. The four locations consist of Baton Rouge, LA, Castroville, TX, Fargo, ND, and St. Paul, MN. The spring oat panel consists of 360 breeder lines. The winter panel consists of 120 breeder lines. The core panel consisted of 108 lines of elite material designated by North American oat breeders. The spring and winter oat panels were evaluated for crown rust infection using traditional phenotypic note-taking methods. These methods included rating each plot based on crown rust severity and infection type. Severity refers to the percentage of the plot exhibiting crown rust symptoms. Infection type refers to the level of disease each plot is exhibiting. Infection types include resistant, moderately resistant, moderately susceptible, susceptible, or any combination thereof.

In addition to traditional phenotypic notes, pictures of each plot were obtained in Castroville for 2010. The photographs were of four representative flag leaves for each plot. These photographs were analyzed using Assess software (The American

Phytopathological Society), which generated an estimation for disease severity. The disease severity ratings obtained by the software were compared graphically to the traditional disease severity notes.

The software was only used for crown rust observations made in 2010 for Castroville, TX. A high correlation between the field observations and the Assess software ratings was found (Figure 4.1). In general, the software was aligned with the ratings obtained manually in the field. This correlation indicates the stability of the software for disease evaluation. However, due to certain limitations, the software may not be capable of entirely replacing human screening and traditional note-taking methods, but remains a valuable diagnostic tool nonetheless.
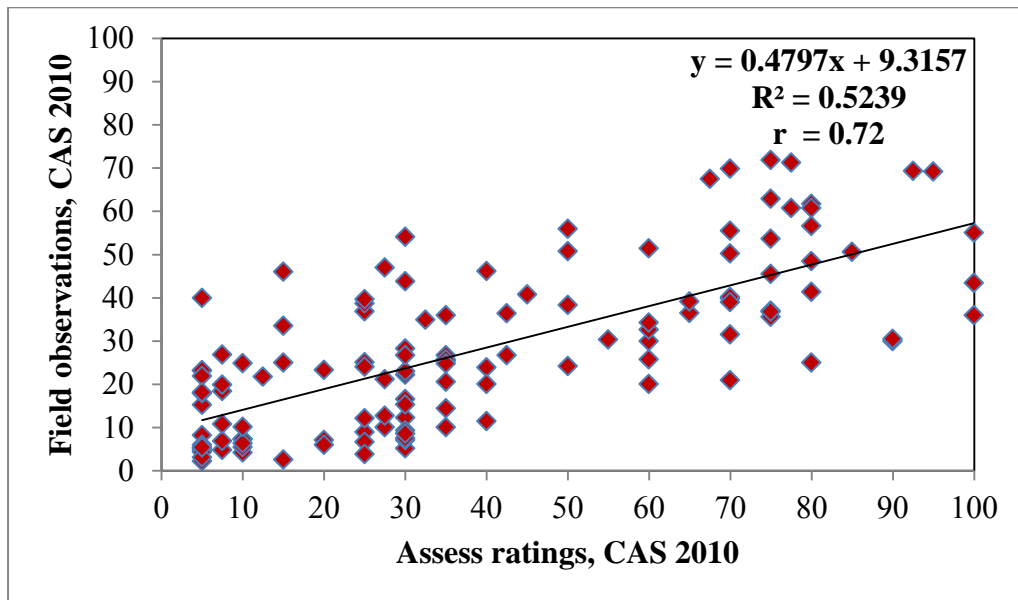


**Figure 4.1. Correlation between Assess software and manual disease ratings.**

**Spring vs. winter comparisons**

To compare the spring lines to the winter lines, the average coefficient of infection (CI) for all lines was calculated. This CI value was calculated by multiplying the numerical infection type ratings by the disease severity ratings to generate a quantitative measurement of disease. Severity ratings were based on a scale of 0-100%. Infection was classified as resistant, moderately resistant, moderately susceptible, susceptible, or any combination thereof. These infection types were assigned a numerical value on a scale of 0-1 for conversion and calculation of CI. The lower the CI value is, the more tolerant the line is to crown rust. On average, the winter lines performed better than the spring lines regarding rust susceptibility (Figure 4.2).
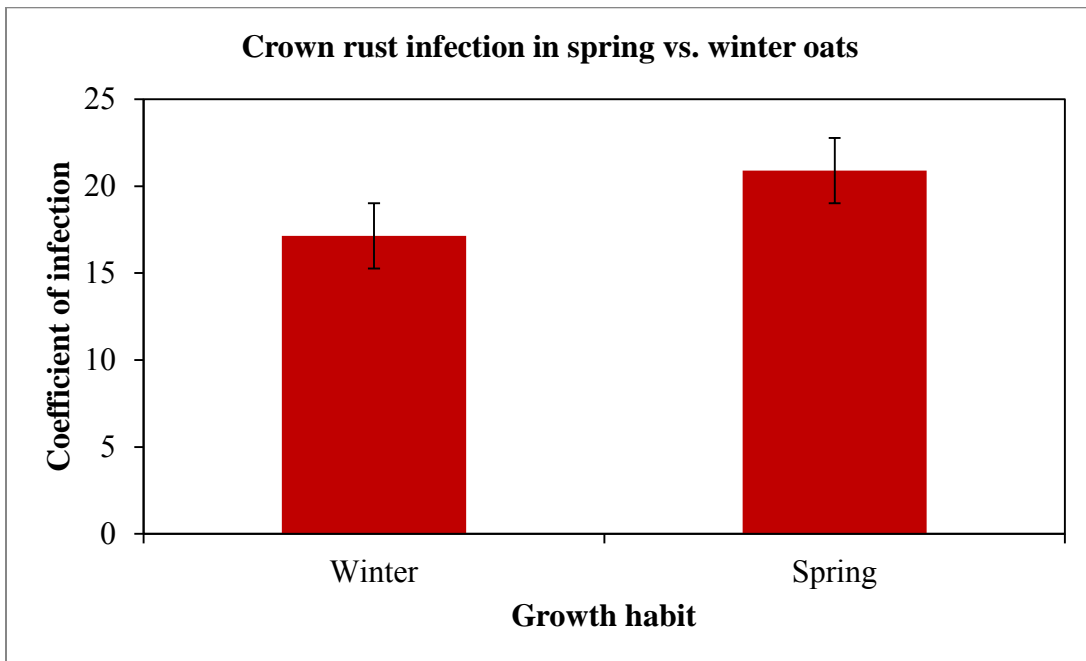


**Figure 4.2. The average CI for all winter lines in comparison to the average coefficient of infection of all the spring lines.**

The average CI was also evaluated according to the source of origin. Lines originating in Manitoba, Canada, Minnesota, North Dakota, Ottawa, Canada and Wisconsin performed the best in terms of crown rust resistance. The lines which performed the worst were those originating in Germany, Idaho, Missouri, Norway, Sweden and the United Kingdom. There was a large amount of variability across lines according to the source of origin (Figure 4.3).
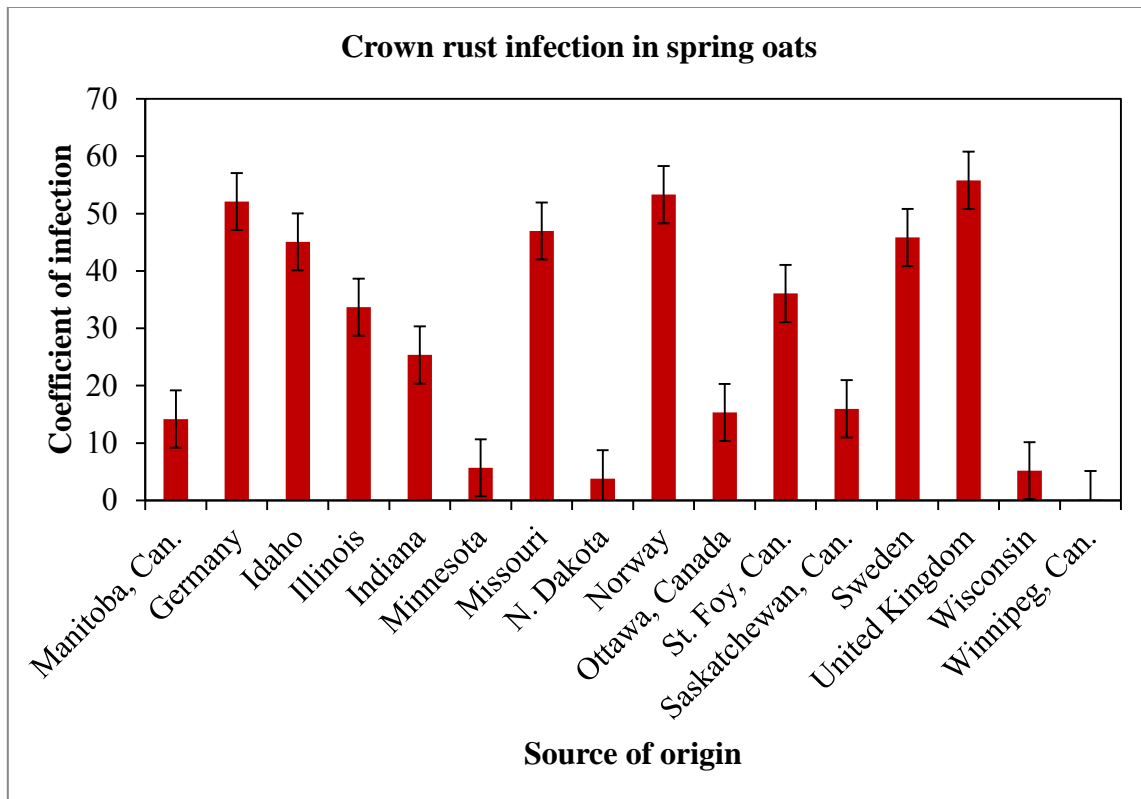


**Figure 4.3. The average CI for all spring lines originating from a given location.**

For winter oats, the lines originating in Brazil, Florida, Louisiana, and Texas performed the best in terms of crown rust resistance. The lines which were the most susceptible to crown rust were those originating in Argentina, Australia, Georgia and Virginia. Again, a large amount of variability across lines can be visualized when separated according to source of origin (Figure 4.4).
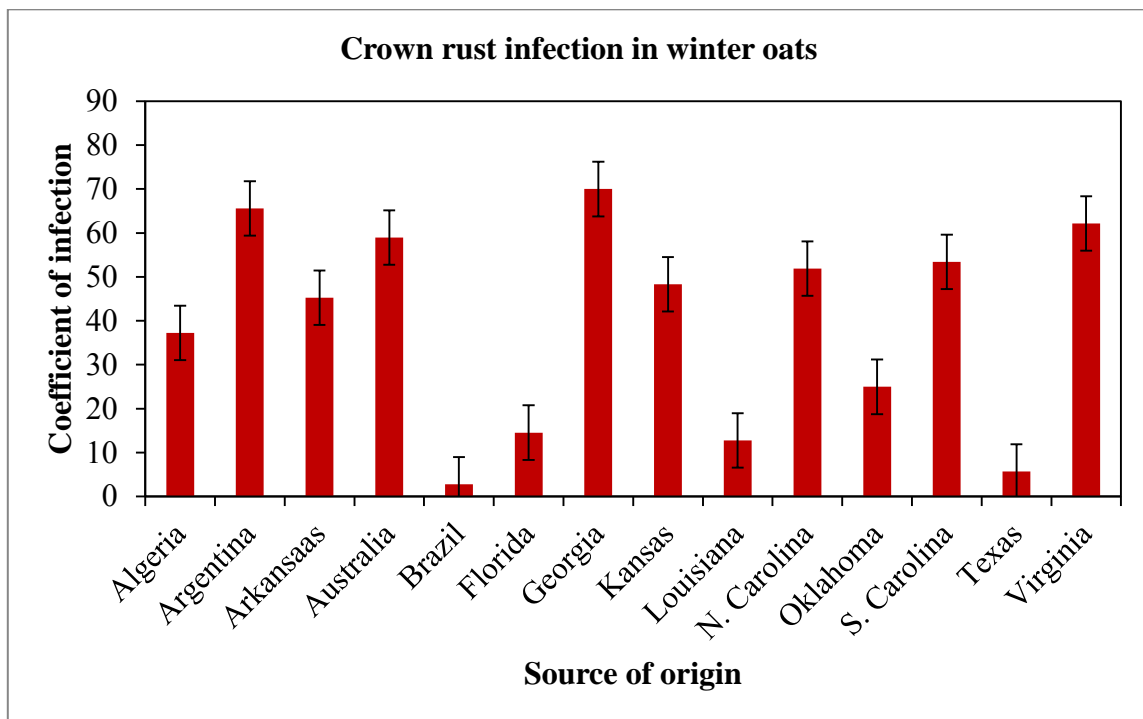


**Figure 4.4. The average CI for all winter lines originating from a given location.**

On average, the winter lines performed better than the spring lines in terms of crown rust resistance. Most of the winter lines grown in North America have been developed and released in Texas and Louisiana. These two states are located at the

forefront of the *Puccinia* pathway, where crown rust infections are consistently at their highest. It is necessary for breeders in these areas to place emphasis on resistance to crown rust. In areas where spring oats are more commonly grown, breeders may not feel the need to select for resistance to this pathogen since it is less of a problem for them. Other plant traits, such as yield or resistance to other diseases may outrank crown rust resistance making developed varieties more susceptible.

Of the winter oat lines, the Texas lines featured the highest and most consistent resistance to crown rust. It is necessary for the best-performing varieties to be crown rust resistant if grown in the Texas area, where there is likely a higher exposure to many races of rust than in other locations. Within the United States, the North Carolina and South Carolina oat lines performed the worst. This is understandable since crown rust is not a serious problem for the east coast area.

Within the spring oat lines, the best performing lines were found in Minnesota, North Dakota, and Wisconsin. These three states lie along the rust corridor, so breeders there focused on crown rust resistance, perhaps more so than breeders in places such as Idaho.

States in the rust corridor feature the best crown rust resistance. This type of resistance is expected as these genotypes are exposed to the most severe crown rust infections, and therefore, feature better natural resistance to the pathogen.

**GGE Biplot analysis**

GGE Biplot has proven a valuable statistical tool with many different uses, including such things as multi-environment testing, locations discriminating value and stability, and genotype-by-environment interaction. This tool allows for data to be analyzed graphically in an effective and convenient manner. Mathematically, a biplot is a graphical display of a two-way table that breaks a product matrix into its respective column and row vectors (Yan and Tinker, 2006). The numbers found on each of the biplot views refers to entry number of respective spring and winter genotypes, and can be found in Tables 4.5 and 4.6.

Figures 4.5 and 4.6 are used to determine discriminativeness versus representativeness of environments where crown rust testing was done. The lines connecting the test environments are referred to as environment vectors. A longer environmental vector is indicative of a more discriminative environment as determined by more variability measured in standard deviation units. An important component of this biplot view is the average-environment axis (AEA). The average environment is

represented by a small circle and is the average coordinate of all test environments. The AEA is the line which passes through the origin and the average environment. A test environment which has a smaller angle with the AEA is considered the most representative. A test environment which combines discriminativeness and representativeness is a good location for selecting genotypes that will be adapted over a large geographic area(Yan and Tinker, 2006). An environment which is discriminating, but not representative can be useful for selecting specifically adapted genotypes for a specific mega-environment, as well as for eliminating unstable genotypes (Yan and Tinker, 2006).

In Figure 4.5, 2011 Castroville, TX was ranked as the most discriminative environment for spring oat lines. The 2010 Castroville, TX environment was the most representative environment for spring oat lines as determined by proximity to the AEA. Castroville, TX was regarded as the most ideal testing environment because more races of rust are found in Texas than any other state in the United States.
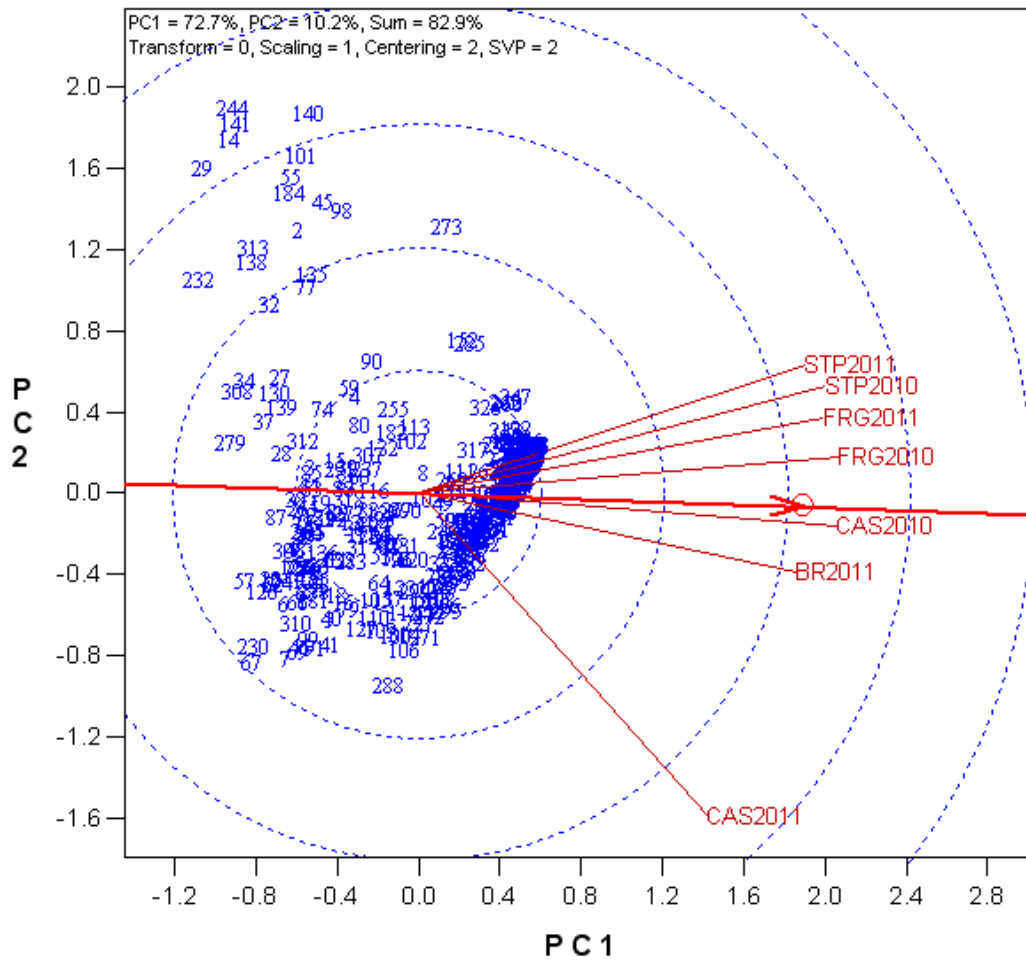
**Figure 4.5.** The discrimination and representativeness view of the GGE biplot to show the discriminating ability and representativeness of the test environments for spring oat lines.

In Figure 4.6, St. Paul, MN and Baton Rouge, LA for 2010 and 2011, respectively, were ranked as the most discriminative environments for winter oat lines. However, the differences in length for each environmental vector were minimal. The 2010 Castroville, TX and 2011 Fargo, ND environments were ranked as the most representative environments for winter oat lines.
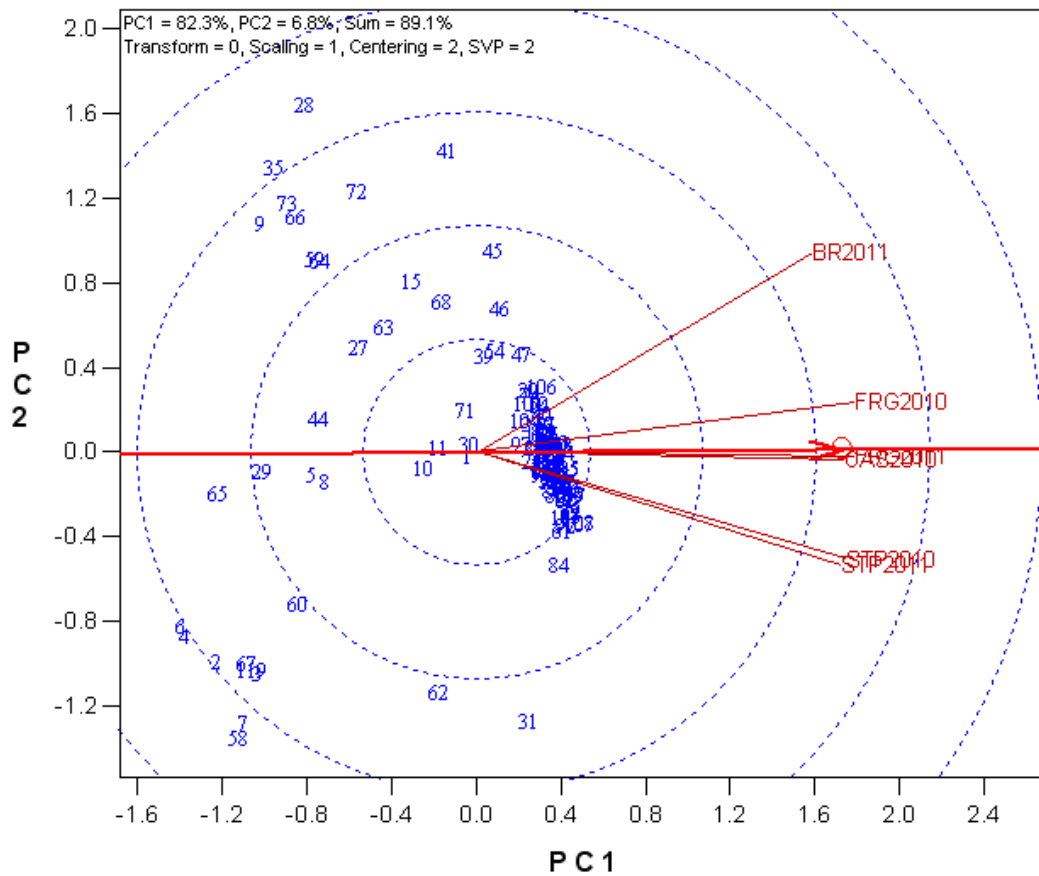
**Figure 4.6.** The discrimination and representativeness view of the GGE biplot to show the discriminating ability and representativeness of the test environments for winter oat lines.

Figures 4.7 and 4.8 demonstrate the relationships among test environments for spring and winter oats, respectively. Essentially this view is the same as the previous view without the AEA. The lines connecting the test environments are referred to as environment vectors. The cosine of the angle between two environments estimates correlation between these environments. The distance between two environments measures dissimilarity in discriminating genotypes.

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Figure 4.7 shows two distinct environment groups. The first contains all the environments except 2011 Castroville, TX, which comprises the second distinct group.
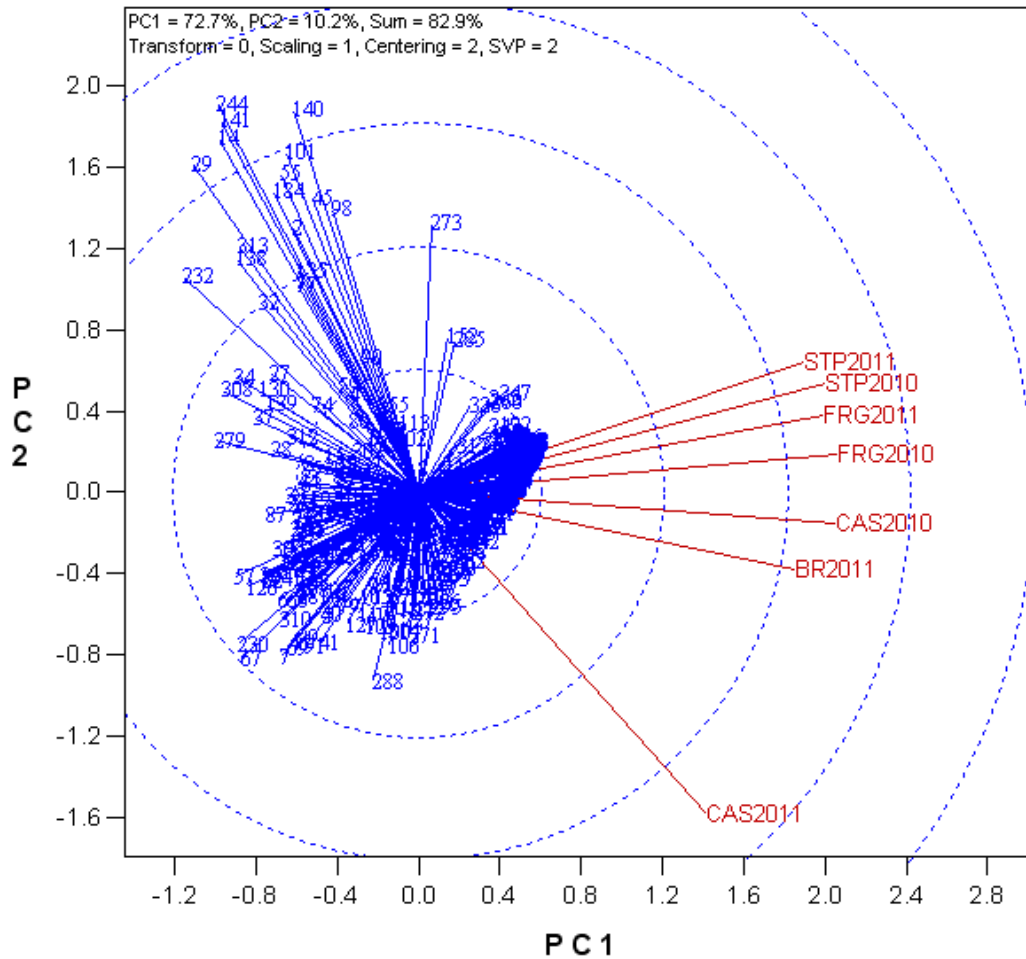


**Figure 4.7. The environment-vector view of the GGE biplot to show similarities among test environments in discriminating the spring genotypes.**

Figure 4.8 shows three environmental groupings, but is less distinct than shown for spring oat lines. The first group consists of 2011 Baton Rouge, LA. The second

group encompasses Fargo, ND for 2010 and 2011, and 2010 Castroville, TX.  The final

group consists of St. Paul, MN for both 2010 and 2011.
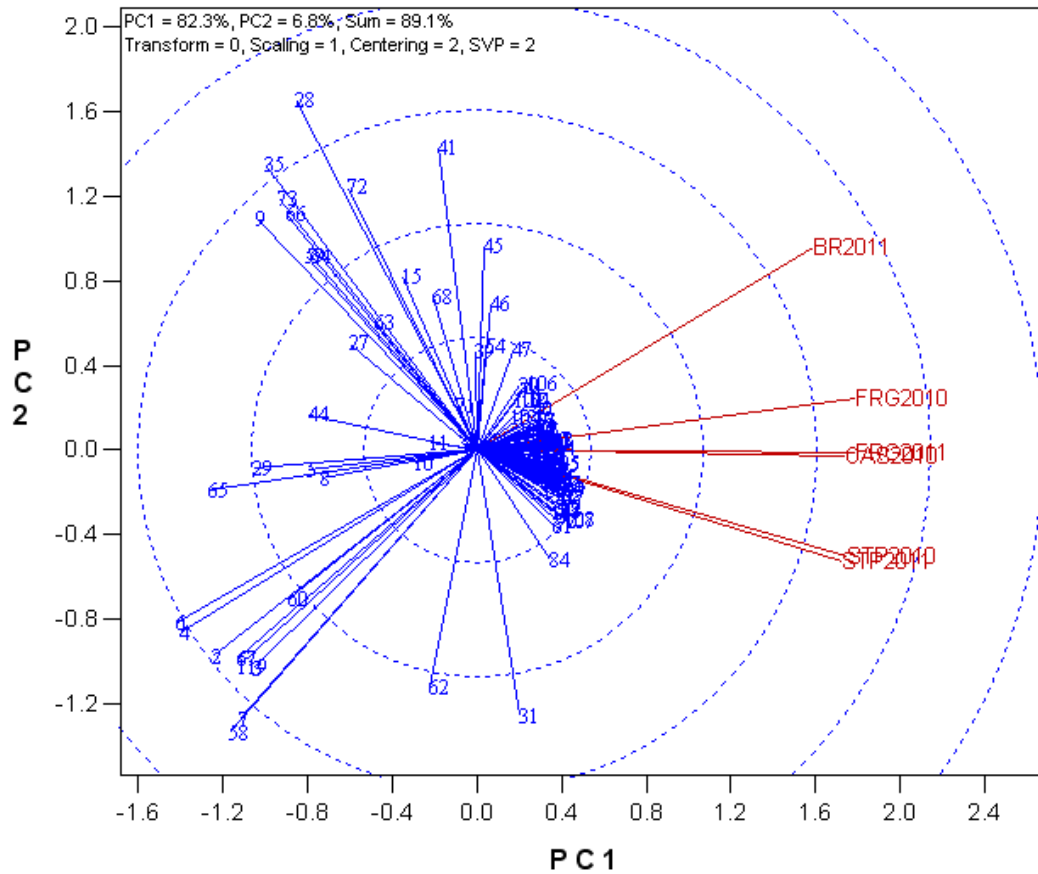


**Figure 4.8.   The environment-vector view of the GGE biplot to show similarities among test environments in discriminating the winter genotypes.**

Figures 4.9 and 4.10 depict the mean performance and stability of spring genotypes. The genotypes were evaluated on both performance and stability across environments. The red arrow points to better crown rust tolerance across environments; while the blue arrows indicate variability or decreased stability in either direction. The genotypes located to the right of the blue vertical line consistently had higher crown rust resistance across all locations. In Figure 4.9, 'Nudist' was the farthest on the negative side and was the most susceptible to crown rust, followed by '95Ab13050'. The genotypes '95Ab13050', 'OA1207-1', 'LIPOPLUS', '02Ab5836', 'Lennon', 'IL04-3664', 'OT3048', and 'SA070452' were among the most instable lines.

In Figure 4.10, 'Coker 716' was the farthest on the negative side and was the most susceptible to crown rust, followed by 'Brooks'. The genotypes 'Florida500', 'LA0210SBSBSBSB-S1', 'Tift', 'LA03060SBSBSB-S1', 'Horizon 201', 'Quincy Gray', and 'Lee' are among the most instable lines.
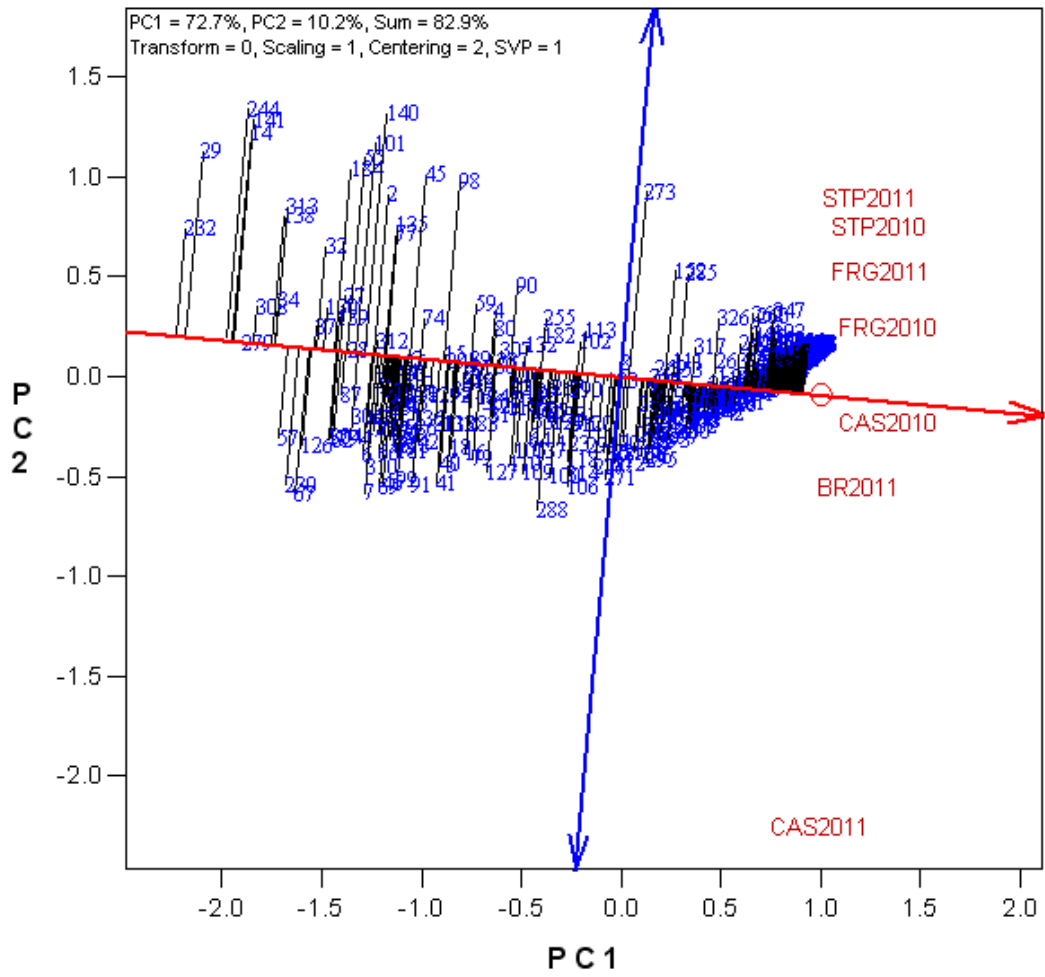
**Figure 4.9.** The average-environment coordination view to show the mean performance and stability of the spring genotypes.
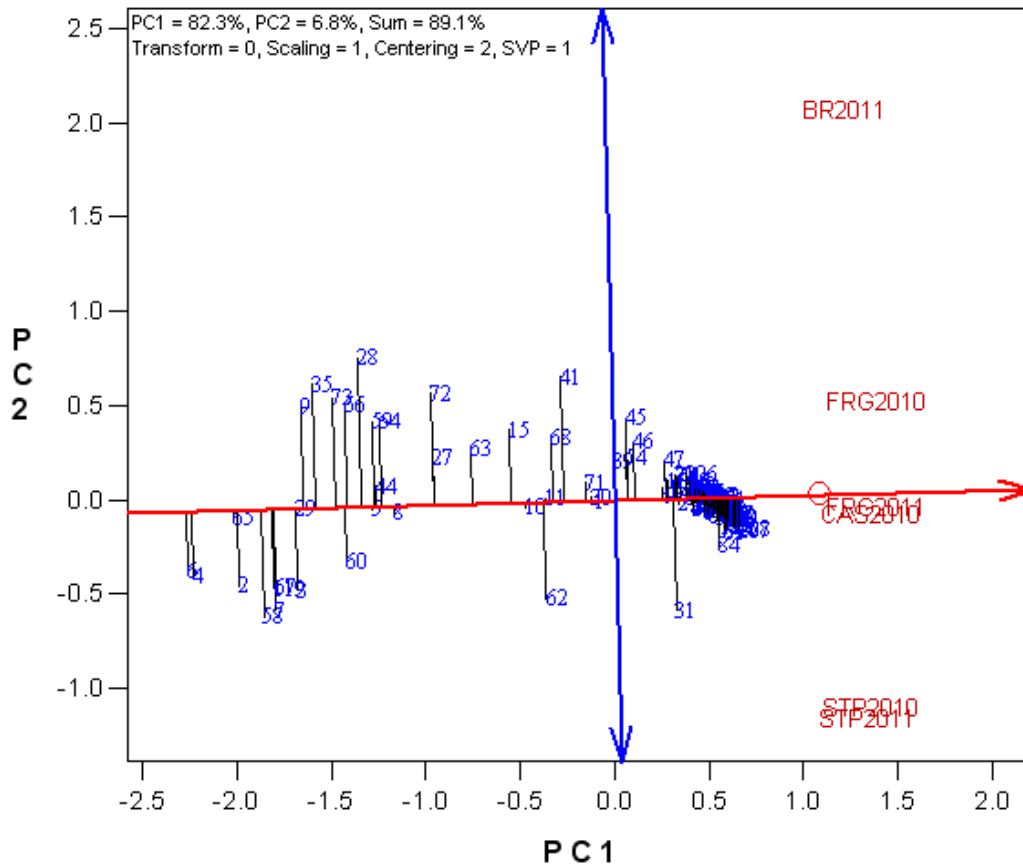
**Figure 4.10. The average-environment coordination view to show the mean performance and stability of the winter genotypes.**

One of the most attractive elements of biplot analysis is the which-won-where pattern of a G x E dataset. The polygon is drawn on genotypes that are the farthest away from the biplot origin in order to encompass all other genotypes within the polygon's parameters. Genotypes located on the vertices of the polygon performed either the best or the worst in multiple environments (Yan and Tinker, 2006). Figures 4.11 and 4.12 demonstrate which genotypes performed the best at each environment for spring and winter genotypes, respectively.

In Figure 4.11, 'Gere' did not perform well in any of the test environments. Other vertices indicating best or worst performance include 'Lennon', 'OT3048', and 'SA070452'. 'SA070452' performed the best in Castroville, TX for 2011.
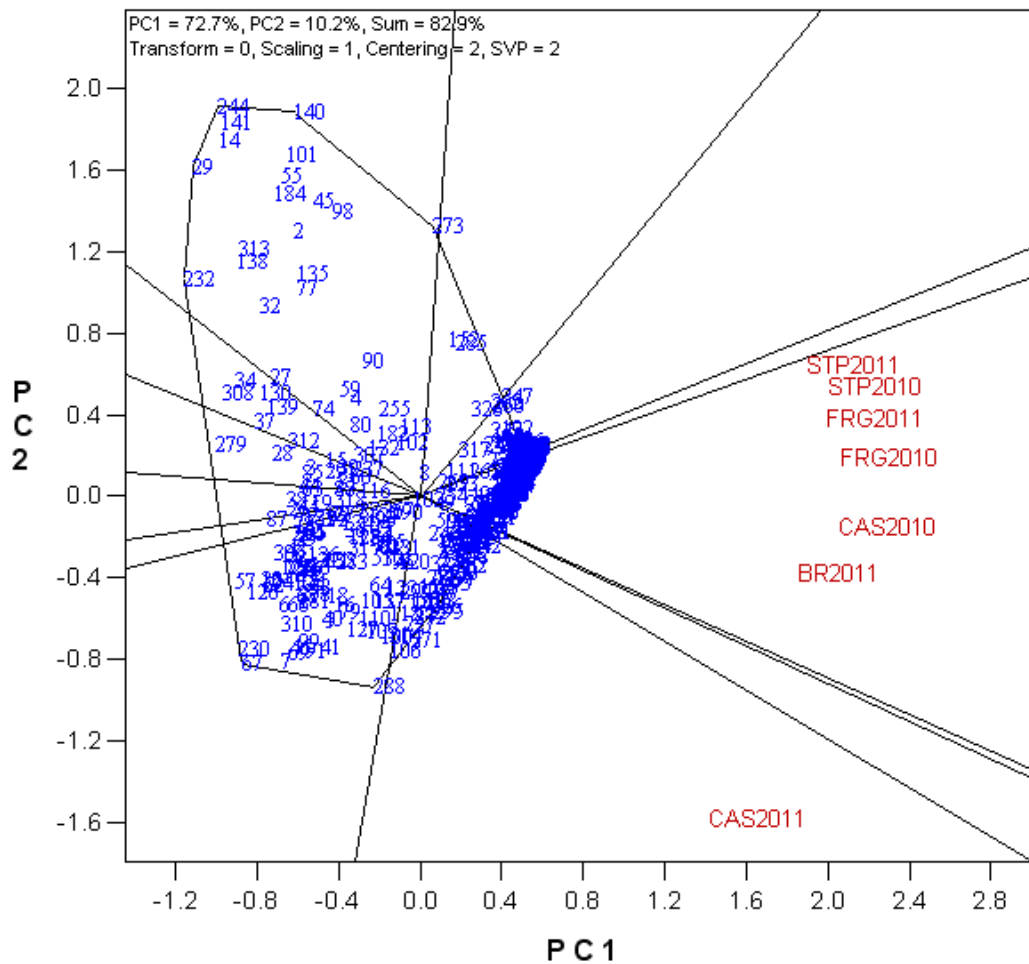


**Figure 4.11.** **The which-won-where view of the GGE biplot shows which spring genotypes performed best in which environments.**

In Figure 4.12, 'Coker 716', 'Brooks', and 'Lee' did not perform well in any of the test environments. Other vertices indicating best or worst performance include 'Florida 500', 'LA03060SBSBSB-S1' and 'HORIZON 201'. 'HORIZON 201' performed the best in St. Paul, MN for 2010 and 2011.



**Figure 4.12.** The which-won-where view of the GGE biplot shows which winter genotypes performed best in which environments.

**Table 4.9.  Correlations among locations for spring oats in 2010 and 2011 determined using CI means.**

|  | 2010 | | 2011 | | | |
|---|---|---|---|---|---|---|
|  | **Fargo, ND** | **St. Paul, MN** | **Baton Rouge, LA** | **Castroville, TX** | **Fargo, ND** | **St. Paul, MN** |
| Castroville, TX 2010 | 0.86 | 0.75 | 0.76 | 0.58 | 0.79 | 0.69 |
| Fargo, ND 2010 |  | 0.77 | 0.73 | 0.51 | 0.83 | 0.74 |
| St. Paul, MN 2010 |  |  | 0.67 | 0.45 | 0.78 | 0.84 |
| Baton Rouge, LA 2011 |  |  |  | 0.55 | 0.64 | 0.62 |
| Castroville, TX 2011 |  |  |  |  | 0.47 | 0.43 |
| Fargo, ND 2011 |  |  |  |  |  | 0.73 |

**Table 4.10.  Correlations among locations for winter oats in 2010 and 2011 determined using CI means.**

|  | 2010 | | 2011 | | |
|---|---|---|---|---|---|
| **Environment** | **Fargo, ND** | **St. Paul, MN** | **Baton Rouge, LA** | **Fargo, ND** | **St. Paul, MN** |
| Castroville, TX 2010 | 0.82 | 0.82 | 0.73 | 0.80 | 0.78 |
| Fargo, ND 2010 |  | 0.80 | 0.78 | 0.91 | 0.78 |
| St. Paul, MN 2010 |  |  | 0.66 | 0.84 | 0.85 |
| Baton Rouge, LA 2011 |  |  |  | 0.75 | 0.66 |
| Fargo, ND 2011 |  |  |  |  | 0.84 |

**Future work**

*Greenhouse studies*

A greenhouse study should be carried out to conduct single race screenings. The locations for greenhouses will be College Station, TX, Aberdeen, ID and St. Paul, MN. In these studies, seedlings of each genotype used in the field analysis should be grown and inoculated with pure strains of crown rust. Phenotypic notes should be taken using quantitative measurements paralleling those of the field trials. Additionally, photographs may also be taken and analyzed using Assess software. These studies will contribute to more robust phenotypes for association mapping.

*Genotypic work*

To complete the goals laid out in this study, it will be necessary to continue on with the genotypic analysis. This component of the research includes the generation of a comprehensive association map of the oat germplasm. Mapping of crown rust resistance will facilitate marker-assisted breeding via digital genotyping and genome-wide selection.

**Conclusions**

Highlights of this thesis include 1) significant differences across environments, within genotypes, and genotype-by-environment interactions; 2) high heritability and repeatability values for crown rust observations in spring and winter oat lines; 3) the use of Assess software as a helpful diagnostic tool; 4) performance of spring versus winter oat lines; 5) identification of an ideal location to screen for crown rust resistance in oats.

For both spring and winter oat lines, significant differences across environments and within genotypes were identified. Also, significant genotype-by-environment interactions were found using the output generated by SAS. This variability will contribute to the generation of a more effective oat map and the identification of significant QTL for crown rust resistance.

High heritability values will also be useful in identifying QTL for crown rust resistance. The heritability of crown rust resistance was 0.88 and 0.90 for spring and winter oat lines, respectively. These values indicate that approximately 88% and 90%, respectively, of the phenotypic variance associated with crown rust is genetic in origin.

High repeatability values indicate the predictability of crown rust disease performance of a given oat line within certain environments. The repeatability values for spring oat lines were calculated as 0.88 for Castroville, TX and 0.82 for St. Paul, MN in 2010, 0.64 for Baton Rouge, LA, 0.56 for Castroville, TX, and 0.61 for St. Paul, MN in 2011. For winter oats, the repeatability values were calculated as 0.96 for Castroville, TX and 0.84 for St. Paul, MN for 2010, 0.92 for Baton Rouge, LA and 0.79 for St. Paul, MN for 2011. Discrepancies between these values at the same location across years can be attributed to variety among *Puccinia* races or environmental effects, including amount of rainfall. Additionally, the component of human error cannot be ignored.

Assess software, Version 2.0 (The American Phytopathological Society) was used to corroborate disease severity ratings obtained via traditional note-taking methods. The software calculates the percentage of plant tissue exhibiting disease symptoms in comparison to the total plant tissue area by analyzing an image of four flag leaves

obtained from each plot. The software ratings were plotted against the disease severity ratings (percentage of infected plant tissue for a given plot) obtained manually in the field. A high correlation between these two types of ratings was found, indicating the helpfulness of this software as a diagnostic tool. Despite this high correlation, it is unlikely that such a software program will replace human beings as the sole means of collecting disease data. While a less objective disease rater, Assess has a number of limitations which contribute to a possible larger margin of error than human error. For example, the software cannot rate diseases whose symptoms are not visible as red-orange-brown in color. Also, the software can only be used to identify disease on plant tissue that is normally green in color. Due to such specific parameters, human beings will always be more flexible in their ability to identify and rate disease.

The spring oat lines were compared to the winter oat lines regarding crown rust infection. The CI values were calculated for each oat line by multiplying the severity ratings against the infection type numerical values. When the CI values for spring oats were compared to those of winter oats, the winter oat lines were shown to be more tolerant to crown rust than the spring oat lines. More of the winter oats are derived from locations along the *Puccinia* pathway, where crown rust resistance is an ideal and highly selected for trait. Spring oats are more commonly grown in areas where crown rust is less of a problem than for the winter oats, which means that other traits are given preference by breeders when developing a new oat variety.

Of the spring oat lines, those which featured higher tolerance to crown rust originated from Manitoba, Canada, Minnesota, North Dakota and Wisconsin. These

locations are found along the *Puccinia* pathway, which means they are generally exposed to the pathogen. The spring oat lines which were found to be the most susceptible to crown rust originated from Germany, Idaho, Missouri, Norway, Sweden, and the United Kingdom.

Of the winter oat lines, higher tolerance was found in lines originating in Brazil, Florida, Louisiana, and Texas. Louisiana and Texas lines are at the forefront of the *Puccinia* pathway, and lines in Texas are exposed to more races of *Puccinia* than any other state. Resistance to crown rust is necessary for lines developed in these two locations. As for Brazil and Florida, the humidity and moisture levels of these locations would contribute to an outbreak of crown rust, which may indicate why lines derived in these places have a higher tolerance to crown rust as well. The worst performing winter oat lines came from Argentina, Australia, Georgia, North Carolina, South Carolina and Virginia. Lines in states such as North and South Carolina are not exposed to severe crown rust infections, making this trait less important than perhaps other diseases.

Ultimately, through the use of GGE Biplot analysis, Castroville, TX was identified as the most representative and most ideal testing location of those locations used in this study. More races of *Puccinia* are found in this location which sits at the forefront of the *Puccinia* pathway. Castroville, TX features ideal humidity and temperatures for crown rust infection allowing for the best disease screening practices.

The phenotypic data obtained through this study is highly useful, however incomplete. The value of this data will increase greatly when paired with greenhouse studies and genotypic analysis. Together these components can be used to generate the

most comprehensive oat map to date.  This study will bring North American oat breeders one step closer to improving the oat germplasm through the development of new and improved oat varieties.  Better oat varieties will contribute to the competitiveness of oats as a sustainable food and feed crop in North American agriculture.

# CHAPTER V

# SUMMARY

Crown rust is the most severe pathogen impacting North American oats. Limited resistance to this pathogen creates a problem for oat growers who will likely suffer yield loss due to devastating infestations of *P. coronata*. In order to increase acreage of the oat crop with more durable resistance to crown rust, a more comprehensive oat map is needed.

To aid in the development of this oat map 702 lines of North American oat were grown and evaluated for susceptibility to crown rust at four locations for a total of two years. These lines represent spring and winter oat varieties, as well as 108 of the most commonly grown lines in Canada and the United States. The four locations, Castroville, TX, Baton Rouge, LA, Fargo, ND, and St. Paul, MN, were used to represent regions where winter and spring oats are commonly grown, respectively.

The results of this study indicate significant variation among the oat genotypes evaluated. This variability increases the likelihood that the molecular markers used in association mapping will identify useful QTL, thus producing a stronger map of the oat germplasm than currently exists. A stronger oat map will assist oat breeders in developing new varieties of oats with better tolerance to crown rust, contributing to the competitiveness of oats in North American agriculture.

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# APPENDIX

## A-1    PROC GLM code for individual location analysis in SAS; Spring

```
options nodate;
data spring;
input genotype $ source $ rep environment $ CI;
cards;
_001A1_24_2_4_1_3 INDIANA      1      BR2011        0
…
X9509_4      WISCONSIN   2      STP2011      6
;
title 'Individual Locations Spring';
proc sort data=spring; by environment rep;
proc glm;
class rep genotype;
model CI= rep genotype;
by environment;
lsmeans genotype / stderr;
means genotype / lsd lines;
run;
```

## A-2    PROC GLM code for individual location analysis in SAS; Winter

```
options nodate;
data winter;
input genotype $ source $ rep environment $ CI;
cards;
_833_99AB118        UNK_LOUISIANA      1    BR2011        16
…
Winter_Fulghum    VIRGINIA    2    STP2011    30
;
title 'Individual Locations Winter';
proc sort data=winter; by environment rep;
proc glm;
class rep genotype;
model CI= rep genotype;
by environment;
lsmeans genotype / stderr;
means genotype / lsd lines;
run;
```

## A-3    PROC GLM code for combined analysis in SAS; Spring

```
options nodate;
data spring;
input genotype $ source $ rep environment $ CI;
cards;
_001A1_24_2_4_1_3 INDIANA       1      BR2011        0
…
X9509_4      WISCONSIN   2      STP2011       6
;
title 'Combined analysis spring';
proc glm;
class environment rep entry;
model CI= environment rep(environment) entry
environment*entry;
means entry /lsd lines;
lsmeans entry;
run;
```

## A-4    PROC GLM code for combined analysis in SAS; Winter

```
options nodate;
data winter;
input genotype $ source $ rep environment $ CI;
cards;
_833_99AB118        UNK_LOUISIANA    1      BR2011        16
…
Winter_Fulghum    VIRGINIA   2      STP2011       30
;
title 'Combined analysis winter';
proc glm;
class environment rep entry;
model CI= environment rep(environment) entry
environment*entry;
means entry /lsd lines;
lsmeans entry;
run;
```

## A-5    PROC CORR code for Pearson Correlation in SAS; Spring

```
options nodate;
data spring;
input ENTRY      CAS2010     FRG2010     STP2010     BR2011
      FRG2011    STP2011     AVG;
cards;
1     24.00 8.00  11.25 1.10  0.60  8.00  13.50 9.49
…
361   0.00  20.00 3.75  0.00  0.00  32.00 9.00  9.25
;
proc corr; var CAS2010      FRG2010     STP2010     BR2011
      CAS2011    FRG2011     STP2011     AVG;
run;
```

## A-6    PROC CORR code for Pearson Correlation in SAS; Winter

```
options nodate;
data winter;
input ENTRY      CAS2010     FRG2010     STP2010     BR2011
      FRG2011    STP2011     AVG;
cards;
1     70    3     22.5  14    4      11.5 20.8333333
…
119   75    80    60    75    80     28.5 66.4166667
;
proc corr; var CAS2010      FRG2010     STP2010     BR2011
      CAS2011    FRG2011     STP2011     AVG;
run;
```