SCREENING BARLEY LINES FOR FORAGE PRODUCTION AND HESSIAN FLY RESISTANCE IN TEXAS ENVIRONMENTS

A Dissertation

by

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ABSTRACT

Barley (*Hordeum vulgare*) has been largely absent from Texas's cropping systems with no current public or private breeding program in the state since 2001. However, barley may become increasingly important due to a rapidly growing dairy industry, especially in the Texas Panhandle. For these dairies, barley may provide a more drought tolerant alternative as a cool season silage source compared to other small grains. This would be highly beneficial to the High Plains region due to the depletion of the Ogallala aquifer. Additionally, roughly 1.2 million hectares of small grains are grazed in Texas and barley may offer an alternative source of fall forage for beef cattle. Moreover, barley provides a less desirable host to insects such as Hessian fly (*Mayetiola destructor*), which can be devastating to wheat (*Triticum aestivum*). The Hessian fly is a major pest of small grains and can cause significant economic losses in some areas of Texas. Small grains intended for grazing are typically planted much earlier in the fall and hence are more vulnerable to Hessian fly damage. Consequently, finding resistant lines is of great importance. Therefore, the objectives of this study were to 1) Identify experimental barley lines with superior forage and silage production in Texas, 2) Screen barley lines for Hessian fly resistance, and 3) Conduct stability, repeatability, and heritability analysis on winter barley lines.

Lines examined in this study were previously screened and selected from 298 winter and facultative lines obtained from the Triticeae Coordinated Agricultural Project (TCAP) for adaptation to Texas environments based on disease resistance, vernalization requirements, and frost tolerance. All silage and Hessian fly field trials were laid out in an alpha lattice design with two replications. Forage and silage trials were conducted in College Station, McGregor, and Dimmitt, Texas, during the 2016 season and McGregor, Comanche, Brady, and Dimmitt in 2017. Hessian fly trials were located in McGregor in 2016 and McGregor and Brady in 2017.

Normalized difference vegetative index (NDVI) and plot height measurements in the fall indicated significant differences ($P<0.0005$) among barley lines at all environments except for NDVI in two out of six site years. Spring silage dry matter yields revealed significant differences ($P<0.05$) among barley lines in three out of four site-years. Several of the top yielding barley lines exceeded 15 tonnes per hectare in Comanche, Texas, which was the best producing environment for spring silage. The top producing barley line out-yielded the top commercial barley or wheat check by an average of 1.25 tonnes/hectare across the four locations. Large variation of Hessian fly field trial infestations prevented good separation between resistant and susceptible lines. In a subsequent growth chamber trial, 13% (18 of 140) of the barley lines showed potential resistance. Overall, only 6% (9 of 140) were rated as resistant across all field and growth chamber trials and only one line was found to have no flies in any trial. Biplot analysis revealed which lines were the most and least stable for fall forage and spring silage production across environments. Height in both forage and silage trials was found to be repeatable and heritable while NDVI was determined to be neither repeatable nor heritable.

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Contributors

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NOMENCLATURE

ANOVA	Analysis of Variance
GxE	Genotype-by-environment
NDVI	Normalized Difference Vegetation Index
TCAP	Triticeae Coordinated Agricultural Project
UVT	Uniform Variety Trials

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CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

Introduction

There has been little to no screening of new barley (*Hordeum vulgare*) germplasm in Texas since the closing of the Texas A&M barley breeding program in 2001. Recently, however, there has been a burgeoning interest for growing barley in the state. One reason is the need to provide forage for grazing the 11 million beef cattle and calves across the state which ranks first in cattle production in the nation (USDA-NASS, 2016). Currently, over two million hectares of land are used for forage, hay, haylage, and silage in Texas each year (USDA-NASS, 2016). Wheat (*Triticum aestivum*), corn (*Zea mays*), and other grasses are extensively used for these purposes, however, barley may be able a better alternative due to its tolerance of drought and alkaline soils (Anderson et al., 2012; Bornare et al., 2012). Additionally, barley can provide a better fall pasture than other small grains due to its rapid growth when planted early (Warrick et al., 2002). The expanding dairy industry in the High Plains creates another market opportunity for barley, particularly for silage. Currently, Texas ranks as the sixth largest dairy producing state in the country and is expected to continue growing as production gets closer to 400 million liters per month (Kieschnick, 2017). Barley can provide excellent silage quality if cut at the correct growth stage and studies have shown that steers fed barley silage produce similar or better gains than those fed corn or wheat silage respectively (Oltjen and Bolsen, 1980).

Hessian fly can have large detrimental effects on forage and grain production of certain small grains, but barley may provide better resistance compared to wheat. Due to its mild fall temperatures, Texas does not have a “fly-free” planting date (Morgan et al., 2005) and although delaying planting until the onset of cold temperatures can reduce infestations, resistant varieties are the most effective means of control (Ratcliffe, 1997). However, even with the identification of Hessian fly resistance genes and the use of marker assisted selection (MAS), genetic resistance is often overcome in six to eight years due to selection for virulent biotypes of Hessian fly (Garces-Carrera et al., 2014). Choice test studies have revealed that Hessian fly adults deposit fewer eggs and larva have lower survival rates on barley than on wheat (Chen et al., 2009a). Utilizing barley as a less preferred host may provide a better option for growers in some areas prone to Hessian fly infestation.

In Texas, any barley variety advanced for varietal release must have reliable forage production despite large variance in soils, rainfall, and biotic pressures across years and regions. Stable lines are ones that perform similarly across environments. Barley lines that are heavily influenced by environmental factors and unstable are excluded from consideration. An analysis for stability, repeatability, and heritability can provide beneficial information for selecting barley lines that are best adapted for Texas environments.

The main objective of this research is to identify new and superior barley lines for forage production in Texas environments. This research will access the Triticeae Coordinated Agriculture Project (TCAP), a comprehensive online database containing genotypic and phenotypic information on thousands of barley lines, to select lines that may be well suited to Texas' growing conditions. The specific objectives are to: 1) Identify winter and facultative barley lines with superior forage and silage production, 2) Screen winter and facultative barley lines for Hessian fly resistance, and 3) Conduct stability, repeatability, and heritability analysis on winter and facultative barley lines. The ultimate goal of these trials is to release one or more lines that are superior to other available commercial cultivars.

Barley Production, Types, and Uses

Due to its importance as a food crop for people and animals, as well as its role in brewing beer, barley grain production is expected to exceed 140 million metric tons in worldwide production in 2017 (USDA-FAS, 2017) making it the fourth most important grain crop (FAO, 2017). Such large production is due to barley's ability to grow in diverse environments. Since its domestication in the Fertile Crescent about 10,000 years ago, barley production has spread worldwide: from mountainous regions in the Himalayas and northern Scandinavia to the low lying regions around the Dead Sea (Badr et al., 2000; Bothmer et al., 2003). Just over three million metric tons are projected to be harvested in the United States this year, more than 80% of which is grown in the Northern Great Plains and Pacific Northwest states (UMN Extension, 2016). Currently, only about 10,000 hectares of winter barley are grown in Texas each year and 6,000 hectares of which are intended for grazing and forage purposes (USDA-FSA, 2017).

The type of barley produced is dependent on the area in which it is being grown and its intended end use. Spring barley dominates most of the acreage in the United States. Winter and facultative - cold tolerant varieties that require little or no vernalization (Kolar et al., 1990) - types are grown in some regions and commonly used as a cover crop to limit soil erosion and sequester carbon (UMN Extension, 2016). Malt production is the most economically desirable use for barley although malting quality standards are very strict. Two-row barley types are favored for malting although six-row types that meet quality standards are used extensively for this purpose in the U.S. and Mexico (OSU, 2006). Protein content between 11%-12.5% is ideal for malting barley (BMBRI, 2010) while protein levels greater than 12.5% are best for feed barley. Six-row types along with two-row types that do not meet malting quality standards are used for animal feed, which is the most common use for barley grain. On average, six-row types have higher protein content than two-row types although yield potential between the two are similar. Six-rowed varieties typically have more seed per head while two-rowed varieties produce more tillers per plant and have larger seed (OSU, 2006). The presence of awns can influence the end use of barley as well. Barley varieties include awned, awnless, awnletted (short awns), and hooded types. Awned and awnletted types are commonly used for malting or feed as they can reduce the amount of seed lost to consumption by animals or birds in the field. Awnless and hooded types are best suited for grazing as they do not produce awns which can be irritating to the mouths of animals. Besides being utilized for malting and as a feed source, research has shown that barley can also be used for biofuel production and decaying barley straw can be used to limit algae growth in waterways (Lemaux et al., 2011).

Barley as a Source of Forage and Silage

In addition to being grown for human consumption, many grains play an important role in providing a source of forage for livestock. Many small grains are used as cool-season forages or cover crops and since they are harvested in spring they can be double-cropped with summer crops such as sudangrass (*Sorghum x drummondii*), grain sorghum (*Sorghum bicolor*), or soybeans (*Glycine max*) (Vough, 2017). Barley in particular can produce greater forage quantities than other small grains in some regions due to its tolerance of soil salinity and drought (Bornare et al., 2012). Although many small grains provide a source of high quality forage, barley may provide the best option for fall grazing due to its rapid growth when planted early (Warrick et al., 2002). Forage variety trial research conducted annually by Texas A&M AgriLife Extension has shown that barley can produce biomass yields that are competitive with other small grains (TAMU AgriLife, 2017) Much research has also been conducted on intercropping barley with legumes such as peas (*Pisum sativum*) and faba beans (*Vicia faba*). Results have shown that intercropping with barley can increase forage dry matter yields and nutritive value (Strydhorst et al., 2008; Anderson et al., 2012) and may also allow for adequate yields of subsequent crops with reduced nitrogen fertilizer use (Scalise et al., 2015).

Barley cut for silage is commonly used for feeding dairy cows but may also be fed to beef cattle. Most of the literature on barley silage is from research facilities in Western Canada where barley is the primary source of silage due to the lack of heat units needed to grow corn. Although research has shown that corn and other grass silages may result in higher dairy cow milk production than barley silage (Burgess et al., 1973; Ahvenjarvi et al., 2006; Benchaar et al., 2014), barley can still be a beneficial source of silage. Barley also has greater water use efficiency than other small grains as one study showed that barley had 27% higher yield while using 9mm less water than wheat (Singh and Kumar, 1981). Greater water use efficiency, as well as greater drought tolerance, may allow barley to find a niche in semi-arid dryland environments or where irrigation becomes limited. Some producers are turning to sorghum silage as an alternative forage in areas of Texas and California where drought has been prevalent in recent years. However, large outbreaks of sugarcane aphids (*Melanaphis sacchari*) on sorghum in these areas may reduce acreage and barley may be able to fill this void.

The timing of cutting barley for ensiling is critical in order to optimize biomass yield and dairy cow milk production. Awnless varieties are generally used for forage or silage as mature awns can be irritating to the mouth of cattle (Anderson et al., 2012), but awned varieties can be used for silage if cut before or shortly after heading. The optimal silage harvest stage to maximize forage nutritive value for milk production can vary from mid-boot to mid-dough stage (Stallings, 1997; Jones et al., 2004). Researchers at the University of Saskatchewan believe this may be due to environmental interactions with lignin content in plant cells (Christensen, 2013).

The lower temperatures and longer day lengths in higher latitudes results in less lignification of plant cells allowing for a later harvest which results in increased biomass production while maintaining quality. When fed to beef cattle, research has shown that cattle fed barley silage had similar gains to those fed corn silage and significantly better than those fed wheat or oat (*Avena sativa*) silages (Sewell, 1993). Research conducted by Acosta et al. (1991) found apparent digestibility of 74.7% for dry matter, 75.4% for crude protein, and 70.8% for acid detergent fiber for barley silage cut at boot stage. Digestibility percentages were found to be lower for barley silage cut at the soft dough stage although milk production was not significantly affected. The effect of silage maturity on digestibility and milk yield in wheat (Arieli and Adin, 1994) and corn (Bal et al., 1997) silages has also been shown. Barley silage may have other specialty uses as well. A study conducted by Johannson et al. (2016) concluded that providing hens with access to barley silage reduced aggressive and feather-pecking behavior without negatively affecting egg production or quality, although other types of silage were not tested to determine if this was specific to barley.

Use of NDVI for Estimating Forage Production

Agricultural practices become more efficient as advances in technology become available to producers. One example is estimating pasture biomass and quality using the normalized difference vegetation index (NDVI). Measuring vegetation using reflectance readings has been studied using many tools such as handheld devices (Govaerts and Verhulst, 2010), unmanned aerial vehicles (UAV's) (Bendig et al., 2015), and satellite images (Weier and Herring, 2000). NDVI is calculated using the amount of reflectance of visible and near-infrared light (NDVI= (near infrared radiation- visible radiation)/ (near infrared radiation+ visible radiation)). As sunlight hits objects, certain wavelengths are absorbed while others are reflected. Chlorophyll in plant leaves strongly absorbs wavelengths of visible light (0.4-0.7µm) while the cell structure of leaves strongly reflects near-infrared light (0.7-1.1µm) (Weier and Herring, 2000). Therefore, the more plant biomass covering the land, the more these wavelengths are absorbed or reflected and NDVI is calculated based on these ratios.

While the usefulness of NDVI readings has been found to be dependent on landscape and season (Borowik et al., 2013), there is evidence to support its use for estimating biomass. Numerous studies have found NDVI to be correlated with biomass groundcover (Prabhakara et al., 2015; Flynn et al., 2008). Handheld and UAV-based NDVI measurement tools have already been used to predict biomass in barley and wheat (Bendig et al., 2015; Moges et al., 2006; Cabrera-Bosquet et al., 2011). Additionally, Goswami et al. (2015) found strong correlations between NDVI with biomass and leaf area index as well as evidence of saturation above a biomass of 100 g/m^2 across six plant species in Alaska. This indicates that applications of NDVI technology may be limited to, or at least most useful, when plants are at a young growth stage. As the field of remote sensing becomes better researched and more cost-effective, it will assist producers in estimating biomass for determining stocking rates in non-destructive methods and improve the efficiency of variety selection within breeding programs.

Significance of Hessian Fly in Small Grains Production

Hessian fly is a small insect belonging to the Cecidomyiidae family, which includes the sorghum midge, a serious pest of grain sorghum, and other gall midges (Stuart et al., 2008). Hessian fly feeds on wheat, rye, triticale, barley, and wild grasses. It is believed that the fly first reached the United States around the time of the Revolutionary War and was first identified in Texas in 1880 (Morgan et al., 2005). Hessian fly is now found in east, southeastern, and central Texas. Hessian fly usually has three to five generations per year in Texas and some pupae from each generation either aestivate (over-summer) or diapause (over-winter) to ensure species survival (Figure 1.1) (Morgan et al., 2005).

Injury to host plants is due to the larvae feeding on stem tissue using an effector-based strategy that is similar to ones used by plant-pathogenic organisms (Stuart et al., 2012). After hatching and moving down the leaf to within one or two centimeters of the base of the leaf, the Hessian fly larvae uses its microscopic mandibles to penetrate the cell wall and inject salivary fluid into the small punctures. In compatible interactions the epidermal and mesophyll sheath cells near the feeding site become nutritive feeding cells on which the larvae feeds whereas incompatible interactions result in the prevention of nutritive cell formation and ultimately the death of the larvae (Stuart et al., 2012). If successful, Hessian fly feeding results in stunted tillers and even tiller death in younger plants which negatively affects forage production and winter survivability. Additionally, large infestations of winter barley (>40% stems infested in spring) can lead to lodging and reduced grain quantity and quality (Buntin and Raymer, 1992). Wheat yield losses of 21 bushels/acre were reported in Alabama in 1985 and caused $20 million in losses from 1988 to 1989 in Georgia (Stuart et al., 2012).

Hessian fly is most effectively controlled using resistant varieties (Ratcliffe, 1997). Genetically resistant cultivars perhaps offer the best solution, however, this approach selects for Hessian fly biotypes that can overcome the resistance. Improving the durability of Hessian fly resistance genes (such as pyramiding *H* genes in wheat cultivars) is a common goal among breeding programs (Stuart et al., 2008). It has been determined that sixteen Hessian fly biotypes exist based on responses to a set of wheat resistance genes (Dubcovsky, 2016). Wheat has thirty-two resistance genes, but only five were found to be consistently effective against all biotypes (Chen et al., 2009b). Even if biotypes present in a certain area are known, it is not always known which resistance genes are present in commercial varieties. As a result, evaluating commercial varieties in field trials remains the best option for determining Hessian fly resistance. Screening trials often use the ratio of infested to non-infested plants to determine which varieties possess resistance, though percentages may vary slightly among trials. Generally, if 80% or more of the plants of a particular entry in a trial are scored as resistant, then that variety is considered resistant while those with less than 50% resistance are considered susceptible (Garces-Carrera et al., 2014; Chen et al., 2009b; Shukle et al., 2016). Those entries between 50-80% are described as moderately resistant. A slightly different approach was taken by Buntin et al. (1999) in which entries were considered resistant if the percentage of infested plants was not significantly ($P<0.1$) greater than zero. Another study on barley found highly resistant lines that invoked antibiosis which killed first instars (Buntin and Raymer, 1992). Antibiosis is an antagonistic relationship between two organisms in which one is negatively affected (Painter, 1951).

There is also evidence to support the use of less preferred host plants as a way of lowering Hessian fly damage if the cropping system allows. A choice test conducted by Chen et al. (2009a) found that Hessian fly adults deposited three times more eggs on wheat than barley or rice (*Oryza sativa*). Additionally, the average death rate of larvae on an apparently susceptible barley line was 60% compared to only 10% on a susceptible wheat cultivar. A study conducted by Harris et al. (2001) also found Hessian fly preferred wheat to barley and noted that similar observations were made in previous trials using different Hessian fly populations and cultivars. Therefore, the adoption of resistant barley lines in areas where Hessian fly is abundant could be very beneficial. A problem can arise over time, though, as the widespread planting of a select few resistant cultivars favor biotypes that can survive. Therefore, using genetically resistant cultivars or less preferred hosts may be overcome by virulent biotypes as selection pressure is increased.

Additional control tactics may be implemented with varying success. Applying systemic insecticides via seed treatments is one possibility but is only effective during early growth and tillering (Morrill and Nelson, 1975; Buntin and Hudson, 1991). Texas does not have a “fly-free” planting date like many other states to the north, but delaying planting until temperatures cool can substantially reduce infestations but may also result in loss of forage or yield potential (Buntin et al., 1992). Burial of small grains stubble after harvest, eliminating volunteer wheat, and crop rotation are other cultural control practices that may be implemented with limited success (Chapin, 2008).

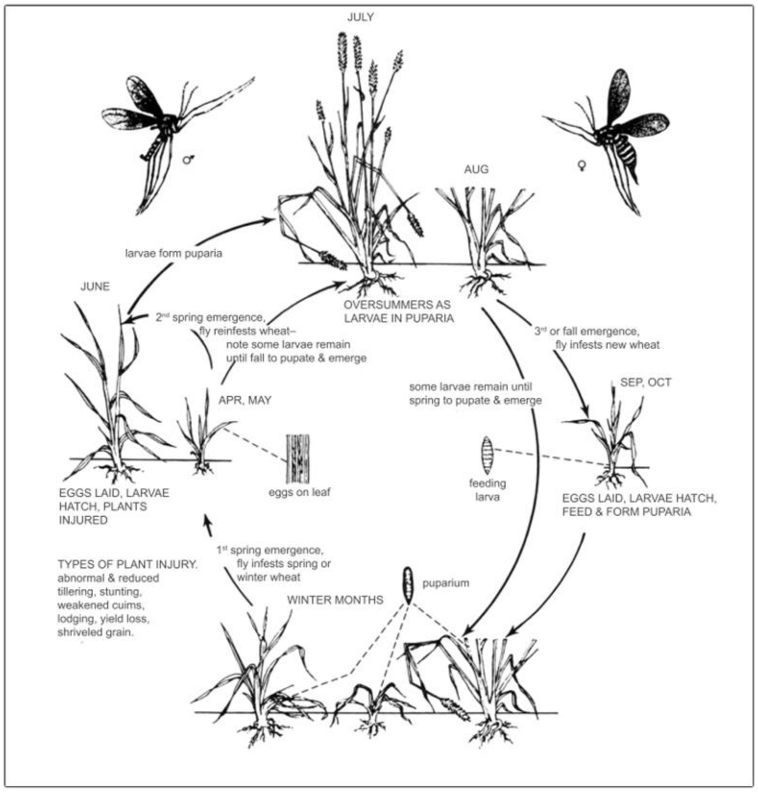

Figure 1.1 The Hessian fly life cycle. Reprinted from K.S. Pike et al. (1983).

Value of Conducting Stability, Repeatability, and Heritability Analysis

Without conducting proper statistical analysis, variety performance patterns for yield and other characteristics across environments may not be identified or fully understood. Broad sense heritability is the ratio of total genetic variance to total phenotypic variance ($H^2=V_G/V_P$). Repeatability is the ratio of variance between groups to the variance within groups plus the variance between groups. Plant breeders commonly use heritability and repeatability estimates to determine if there is sufficient genetic variation in the germplasm to allow for improvement of traits (which genetic population is most promising as a source of improved breeding material) and whether the same breeding procedure will be equally effective for improving all traits (Dudley and Moll, 1969). Additionally, heritability estimates can be used to compare gains from selection of different experimental designs and assist in constructing optimal breeding strategies (Holland et al., 2003).

Yield stability across environments is an essential component to any new variety and therefore stability analysis must be conducted. The way in which a genotype is affected by an environment (GxE-interaction) is the basic determinant of yield stability (Becker and Leon, 1988). The model $Y_{ij} = \mu_1 + \beta_1 I_j + \delta_{ij}$, developed by Eberhart and Russell (1965), can be used to estimate the stability of a variety where Y_{ij} is the variety mean at a specific environment, μ_1 is the variety mean over all environments, β_1 is the regression coefficient, I_j is the environmental index, and δ_{ij} is the deviation from regression. Many of these can be calculated using SAS (SAS Institute, Cary, North Carolina) or Agrobase (Agronomix, Winnipeg, Canada) statistical software. Biplots offer a way to visually interpret data and have been used to analyze agricultural data for forty years (Bradu and Gabriel, 1978). If sufficient data is available, mega-environments (groups of environments that produce similar results) as well as genotypes with high performance and stability within those environments can be identified using bi-plot analysis (Yan and Tinker, 2006). A previous study utilizing six years of wheat variety trial data containing 16 cultivars at 19 locations identified three mega-environments in Texas which corresponded to the High Plains, Rolling Plains, and Black Lands/ South Texas testing locations (Gerrish- Unpublished Data). Identifying locations which produce similar results can help reduce redundancy and conserve resources.

CHAPTER II

SCREENING BARLEY (*HORDEUM VULGARE*) LINES FOR FALL FORAGE AND SPRING SILAGE PRODUCTION IN TEXAS ENVIRONMENTS

Introduction

Texas is well known for its beef cattle and dairy industries which currently rank first and sixth in the nation respectively (USDA-NASS, 2016). Wheat (*Triticum aestivum*), corn (*Zea mays*), and other grasses are extensively used for grazing and ensiling in order to feed these animals. Land used for forage, hay, haylage, and silage exceeds two million hectares each year in Texas (USDA-NASS, 2016). As resources such as water become limited or more expensive, producers are searching for alternative crops that can produce equal amounts of biomass while requiring fewer inputs. Barley has the potential to fill this void. Currently, Texas producers only grow around 10,000 hectares of barley each year, a little over half of which is intended for forage purposes (USDA-FSA, 2017). However, barley may be able to replace cool-season crops such as wheat in some cropping systems due to having greater tolerance of drought and is the most tolerant of the cereal grains to saline and alkaline soils (Bornare et al., 2012; Anderson et al., 2012; Redmon, 2002).

Forage variety trial research conducted annually by Texas A&M AgriLife Extension has shown that commercial barley varieties can produce biomass yields that are competitive with other small grains (TAMU AgriLife, 2017). Small grains are commonly used as cool-season forages or cover crops in Texas since they are harvested in spring and can be double-cropped with summer annuals such as corn, grain sorghum (*Sorghum bicolor*), or soybeans (*Glycine max*) (Vough, 2017). Barley in particular may provide the best option for fall grazing due to its rapid growth when planted early (Warrick et al., 2002) and may be able to provide better resistance to certain insects which can cause severe damage in wheat. Planting small grains early in the fall can lead to greater Hessian fly (*Mayetiola destructor*) infestations which has caused significant economic losses in the past, particularly in wheat. Fall infestation results in tiller stunting or death which negatively affects forage production and winter survivability (Dubcovsky, 2016). Although Hessian fly can affect barley, studies have shown barley to be less preferred by Hessian fly adults for ovipositing eggs and larvae had lower survival rates compared to those deposited on wheat (Chen et al., 2009a; Harris et al., 2001). Similar to wheat, which commonly is used as a dual-purpose crop in Texas, barley that is grazed in the fall can be harvested in the spring for seed or ensiling purposes.

Normalized difference vegetation index (NDVI) has been used in many aspects of agronomic research. NDVI is calculated using the amount of reflectance of visible and near-infrared light (NDVI= (near infrared radiation - visible radiation)/ (near infrared radiation + visible radiation)). Certain wavelengths are absorbed while others are reflected when sunlight hits an object. Chlorophyll in plant leaves strongly absorbs wavelengths of visible light (0.4-0.7μm) while the cell structure of leaves strongly reflects near-infrared light (0.7-1.1μm) (Weier and Herring, 2000). Therefore, the more plant biomass covering the land, the more these wavelengths are absorbed or reflected and NDVI is calculated based on these ratios. Measuring vegetation using reflectance readings has been studied using many tools such as handheld devices (Govaerts and Verhulst, 2010), unmanned aerial vehicles (UAV's) (Bendig et al., 2015), and satellite images (Weier and Herring, 2000). Programs that analyze satellite images such as Climate FieldView (Climate, San Francisco, California) and MavRX (MavRX, San Francisco, California) are already being utilized by crop consultant agencies across the U.S. Midwest to assist farmers in management decisions. Although readings have been found to be dependent on landscape (Borowik et al., 2013), numerous studies have found NDVI to be correlated with biomass groundcover (Prabhakara et al., 2015; Flynn et al., 2008). Handheld and UAV-based NDVI measurement tools have already been used to predict biomass in barley and wheat (Bendig et al., 2015; Moges et al., 2006; Cabrera-Bosquet et al., 2010). However, Goswami et al. (2015) found evidence of NDVI saturation above a biomass of 100 g/m^2 across six plant species in Alaska indicating that applications of NDVI may be limited to, or at least most useful, when plants are at a young growth stage. This technology allows for a quick and non-destructive way in which to estimate variety biomass production in field trials.

Barley that is cut for silage is often used for feeding dairy cows. Corn is used as the main source of silage in most dairy regions, however, barley can still be a beneficial source of silage and is used extensively for this purpose in western Canada where they lack the heat units needed to grow corn. In Texas cropping systems, barley would most likely not replace corn silage, but would rather serve as a cool-season compliment to it. Research has shown that corn and other warm-season grass silages may result in higher dairy cow milk production than barley silage (Burgess et al., 1973; Ahvenjarvi et al., 2006; Benchaar et al., 2014), but this does not mean that barley is unusable as a forage source. The timing of cutting barley for ensiling is critical in order to optimize biomass yield and dairy cow milk production. The type of barley grown can play a part in this as mature awns can be irritating to the mouth of cattle (Anderson et al., 2012). Therefore, awnless varieties are generally used for this purpose, but if awned types are grown they should be cut before or shortly after heading. Examination of the optimal stage of cutting for milk production has been found to vary from mid-boot to mid-dough stage (Stallings, 1997; Jones et al., 2004) depending on location. Researchers at the University of Saskatchewan believe this may be due to environmental interactions with lignin content in plant cells (Christensen, 2013). The lower temperatures and longer day lengths in higher latitudes results in less lignification of plant cells allowing for a later harvest which results in increased biomass production while maintaining quality. In addition to dairies, barley silage can also be used for feeding beef cattle. Weight gain studies have shown that cattle fed barley silage had similar gains to those fed corn silage and significantly better gains than those fed wheat or oat (*Avena sativa*) silages (Sewell, 1993). Adapted barley varieties may have other specialty uses as well such as in the Texas poultry industry which ranks fifth in the nation (USDA-NASS, 2016). Johannson et al. (2016) concluded that providing hens with access to barley silage reduced aggressive and feather-pecking behavior without negatively affecting egg production or quality. Other types of silage were not tested in that study to determine if this was specific to barley.

The main objective of this study was to evaluate a set of winter and facultative advanced lines obtained from the Oregon State University barley breeding program through the Triticeae Coordinated Agriculture Project (TCAP) for fall forage and spring silage production in Texas environments. One or more barley lines identified as being superior in these categories to current cultivars using NDVI measurements, cutting data, and other phenotypic information such as leaf rust (*Puccinia hordei*) resistance and cold tolerance will be co-released and made available to Texas producers.

Materials and Methods

The screening locations used in this study were chosen due to their proximity to areas of dense cattle and/or dairy populations and therefore demand for forages is greatest (Figure 2.1). Silage evaluations took place at two locations for both the 2016 and 2017 growing seasons. In the first year, trials were located at the Texas A&M Research farm near College Station, TX (30°31’N 96°25’W) and Dimmitt, TX (34°30’N 102°31’W). Both locations were in an alpha lattice design with two replications of 116 entries and included commercial barley and wheat cultivar checks for comparison. The commercial cultivars in the trial were ‘Alba’, a six-row winter barley used for feed and malting, ‘Maja’, a six-row facultative barley used for feed and malting, and ‘TAM 304’, a widely adapted hard red winter wheat grown throughout Texas that can withstand grazing in a dual-purpose system and produce forage similar to other currently grown wheat cultivars. Plots were planted at a rate of 75 kilograms per hectare (kg ha^{-1}) on 19 cm row spacing at each location. College Station had 78.5 kg N ha^{-1} applied as liquid UAN (32-0-0) in early February and no irrigation was applied. Dimmitt had 70.6 kg N ha^{-1} applied as granular urea (46-0-0) prior to planting and had three applications of UAN (32-0-0) at 41.5 kg/ha applied via fertigation throughout the growing season. Approximately 12.7 centimeters (cm) of total irrigation were applied.

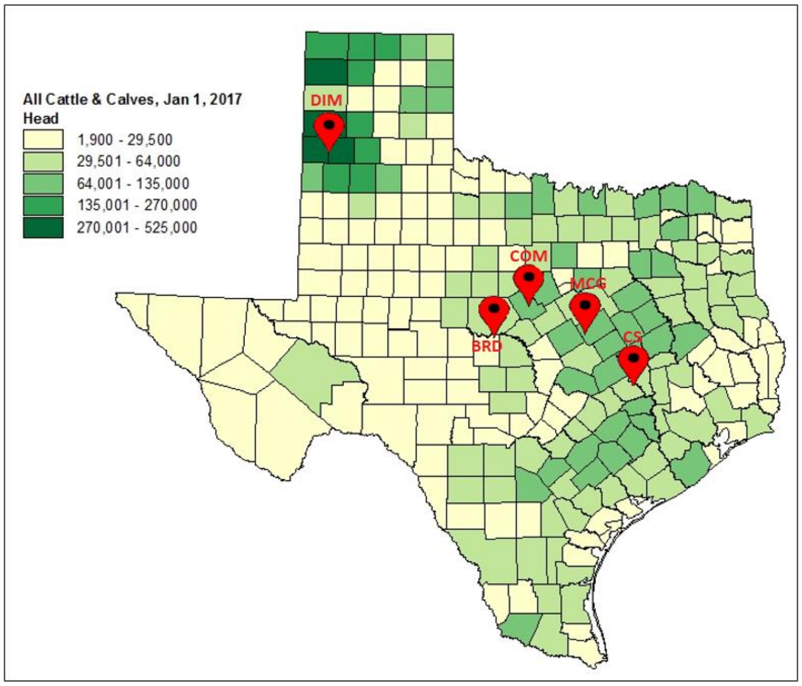

Figure 2.1 Map showing barley testing locations. CS= College Station, MCG= McGregor, CMN= Comanche, BRD= Brady, DIM= Dimmitt. Map adapted from the USDA-NASS (2017).

In the second year, trials were located near Comanche, TX (31°52’N 98°28’W) and Dimmitt, TX (34°31’ N 102°35’W). Both locations were in an alpha lattice design with two replications of 135 entries and included the same commercial cultivars with the addition of ‘Full Pint’, a two-row spring barley that is used primarily for malting. Plots were planted at a rate of 100 kg/ha at both locations. Comanche had 56 kg N ha^{-1} (UAN) applied in early February but irrigation amounts by the producer were not recorded. Dimmitt had 78.5 kg N ha^{-1} of nitrogen UAN applied in late March and no irrigation was applied.

All plots across both years were treated with Dividend Extreme Fungicide (Difenoconazole and Mefenoxam) and Cruiser 5FS Insecticide (Thiamethoxam) at the label rate (Syngenta, Basel, Switzerland). Plot size at all locations were 1.5 meters (m) x 4.5m except at Comanche where they were 1.5m x 6.0m. Plots in College Station were located on a Weswood silty clay soil which receives an average of 102 centimeters of rain each year. Plots in Comanche were located on a Pedernales loamy fine sand which receives an average of 82 centimeters of rain each year. Plots in Dimmitt were located on an Olton clay loam both years and receives an average of 50 centimeters of rain each year. Plant heights were taken just before harvest using a meter stick. Plots were harvested using a Haldrup 1500 forage harvester (Haldrup, Ilshofen, Germany) which has an onboard weigh system and 1.5 m header. Hand grab samples were taken from the harvester for each plot and quickly weighed to avoid water loss. The subsamples were then placed in a drying oven at 50°C for three days to ensure samples were thoroughly dried. Weights were taken again in order to determine dry matter percentages for each entry at time of harvest.

Early season forage production was estimated by measuring plot NDVI using a handheld Trimble Greenseeker Crop Sensor (Trimble, Sunnyvale, CA) and plant heights. These measurements were taken approximately two months after planting. In the first year, NDVI measurements were taken at McGregor, TX (31°22' N 97°27'W) as well as on the silage trial located in College Station. In the second year, NDVI measurements were taken at McGregor and Brady, TX (31°10' N 99°26'W) as well as on the silage trials located at Comanche and Dimmitt. Plots in McGregor and Brady were planted for a separate trial but contained the same entries as the other forage trials. The site at McGregor is primarily located on a Slidell silty clay and receives an average of 91cm of rain each year. The Brady site is primarily located on a Mereta clay loam and receives an average of 70cm of annual precipitation. Both trials at McGregor and the trial in Brady contained 140 entries that were in an alpha lattice design. All plots were planted at a rate of 75 kg/ha. NDVI measurements were typically taken between 10am-2pm on clear, sunny days in order to avoid any shade differences that may occur among entries due to clouds. Hand clippings were taken from a one meter row section of each plot in Brady and Dimmitt in the second year and dry matter weight was determined. The weight along with NDVI and height measurements were used to develop a prediction model that estimates biomass yield based on these two traits.

Statistical analysis was conducted using SAS 9.4 statistical software. PROC GLM was used for analysis of variance (ANOVA) and mean separation tests (Fisher's LSD) were conducted to determine differences among entries. PROC CORR was used to run a correlation analyses between NDVI readings and early season forage weight and PROC REG was used with a backward stepwise regression to develop the biomass prediction model.

Results

An ANOVA of the combined environments for fall forage height measurements (Table 2.1) revealed high significant differences ($P<0.0001$) among locations, replications within locations, entries, and the location*entry interaction. This indicates that genotypes were affected by the environment (Genotype-by-environment interaction commonly abbreviated GxE) and therefore entries were evaluated separately for each environment. An ANOVA for forage plot height at each environment (Table 2.2) showed high significant differences (P<0.001) among entries at all six environments. The average height of plants ranged from 11-27 cm across all trial sites with a grand mean of 16.4 cm.

An ANOVA for fall NDVI measurements (Table 2.3) found high significant differences (P<0.0001) among locations, replications within locations, and entries and also significant differences (P<0.05) for the GxE interaction. Entries were again evaluated for each environment and the ANOVA showed high significant differences (P<0.001) among entries at four of the six site-years (Table 2.4). The grand mean for fall forage NDVI was 0.58.

Table 2.1 Combined environment analysis of variance for barley fall plant height from 2016-2017.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
entry	113	9066.23	80.23	14.34	<.0001
loc	5	67128.81	13425.76	2399.09	<.0001
bloc(loc)	6	187.72	31.29	5.59	<.0001
loc*entry	563	8157.18	14.49	2.59	<.0001
Error	676	3783.03	5.6		
Corrected Total	1363	88509.27			

Loc= Location, Rep= Replications, DF= Degrees of Freedom

Table 2.2 Statistical summary for barley fall plant height (cm) at each environment and combined environment from 2016-2017.

	2016 CS	2016 MCG	2017 MCG	2017 CMN	2017 BRD	2017 DIM	Combined
Date	2/11/16	2/12/16	2/9/17	12/12/16	3/5/17	3/17/17	-
Mean	12.2	11.1	12.4	19.1	16.8	27.4	16.4
Min	5.1	6.4	7.6	11.4	10.2	17.8	5.1
Max	38.1	25.4	24.1	29.2	30.5	45.7	45.7
Maja[1]	10.8	7.6	10.2	21.0	14.6	21.6	14.3
Alba[1]	14.0	10.2	8.9	19.1	15.9	26.7	15.8
TAM 304[2]	8.9	8.9	8.9	14.0	21.6	34.3	16.1
LSD (0.05)	4.3	1.9	2.5	4.7	3.2	5.9	1.9
CV%	17.6	9.1	10.07	12.3	9.67	10.89	19.44
Significance	***	***	***	***	***	***	***

MSE= Mean square error, Mean=Average of all barley lines at that location, Min= Shortest barley line, Max= Tallest barley line, LSD= Least significant difference, CV%= Coefficient of variation, ***= P<0.001, CS= College Station, MCG= McGregor, CMN= Comanche, BRD= Brady, DIM= Dimmitt, 1= Barley commercial check, 2= Wheat commercial check.

Table 2.3 Combined environment analysis of variance for barley fall forage NDVI measurements from 2016-2017.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
loc	5	15.0775998	3.01551995	541.02	<.0001
rep(loc)	6	0.55266174	0.09211029	16.53	<.0001
loc*entry	503	3.21032275	0.00638235	1.15	0.0469
entry	116	12.3077651	0.10610142	19.04	<.0001
Error	754	4.20260227	0.00557374		
Corrected Total	1384	38.5985095			

Loc= Location, Rep= Replications, DF= Degrees of Freedom

Table 2.4 Analysis of variance for NDVI readings at each environment and combined environment for barley fall forage trials from 2016-2107.

	2016 CS	2016 MCG	2017 MCG	2017 CMN	2017 BRD	2017 DIM	Combined
Date	2/11/16	2/12/16	2/9/17	12/12/16	3/5/17	3/17/17	-
Mean	0.49	0.59	0.64	0.61	0.37	0.73	0.58
Min	0.35	0.5	0.25	0.41	0.24	0.59	0.24
Max	0.66	0.71	0.78	0.8	0.47	0.79	0.8
Maja^1	0.50	0.51	0.59	0.66	0.46	0.71	0.57
Alba^1	0.57	0.65	0.58	0.57	0.42	0.76	0.59
TAM 304^2	0.51	0.55	0.69	0.52	0.31	0.61	0.53
LSD (0.05)	-	0.07	0.06	-	0.07	0.07	0.06
CV	12.4	5.89	4.86	10.37	9.61	4.86	13
Significance	NS	***	***	NS	***	***	***

MSE= Mean square error, Mean=Average of all barley lines at that location, Min= Lowest NDVI reading, Max= Highest NDVI reading, LSD= Least significant difference, CV%= Coefficient of variation, NS= No significance, ***= $P<0.001$, CS= College Station, MCG= McGregor, CMN= Comanche, BRD= Brady, DIM= Dimmitt, 1= Barley commercial check, 2= Wheat commercial check.

In hopes of finding one or a few lines that demonstrated high fall forage production across all environments, barley lines were ranked based on plant heights and NDVI readings. A combined ranking was developed for each line at each location and the average ranking across environments was found in order to easily compare the performance of all entries. Table 2.5 (Full listing in Appendix B-1) shows the top fifteen barley lines and the commercial cultivars based on their average ranking across all environments.

Table 2.5 The top fifteen ranked barley lines compared to commercial cultivars based on their average rank across six Texas environments for height and NDVI measurements from 2016-2017.

Name	2016 CS	2016 MCG	2017 CMN	2017 MCG	2017 BRD	2017 DIM	Average
MW09S4080_001	37	61	17	4	3	3	21
06OR_91	15	8	46	21	5	45	23
2011_F5_32_1	3	37	23	8	28	49	25
MW10S4120_008	27	25	2	19	38	52	27
2011_F5_9_2	6	11	64	55	15	35	31
08OR_30	23	40	35	12	33	47	32
2011_F5_121_2	80	21	43	13	4	39	33
2011_F5_47_1	22	10	5	25	81	58	34
06OR_41	11	34	99	31	29	6	35
2011_F5_136_1	19	54	38	9	89	5	36
2011_F5_64_1	13	18	8	68	108	4	37
2011_F5_96_2	12	59	63	39	51	32	43
2011_F5_88_3	40	43	9	70	60	36	43
MW10S4118_003	26	17	77	44	78	20	44
2011_F5_5_1	9	45	48	77	54	31	44
Alba*	7	33	87	129	45	34	56
Full Pint*	123	91	74	61	61	22	72
Maja*	60	125	47	123	16	128	83
TAM 304**	74	115	127	93	105	76	98

*= Barley commercial cultivar, **= Wheat commercial cultivar, CS= College Station, MCG= McGregor, CMN= Comanche, BRD= Brady, DIM= Dimmitt, Full listing found in appendix B-1

The ANOVA for hand clipped dry matter yield found no significant differences ($P<0.05$) among entries at either location (Table 2.6) although significant differences ($P<0.1$) were found among entries at both locations. The plots at Dimmitt were collected a couple weeks after those taken at Brady resulting in much greater biomass yields. Pearson Correlation Coefficients found a highly significant correlation ($P<0.0001$; $R^2=0.52$) between NDVI values and hand clipped weights (Table 2.7; Figure 2.2).

Table 2.6 Analysis of variance for one meter row hand clipped dry matter yields (g) of barley lines taken at Brady and Dimmitt in 2017.

	2017 BRD	**2017 DIM**
Entry (MSE)	17.77	119.5
Residual (MSE)	13.11	91.81
Mean	11.83	29.43
Min	3.75	12.1
Max	25.05	50.55
LSD (0.05)	-	-
CV%	30.62	32.56
Significance	NS	NS

MSE= Mean square error, Mean=Average of all barley lines at that location, Min= Lowest dry weight yield, Max= Highest dry weight yield, CV%= Coefficient of variation, NS= No significance, BRD= Brady, DIM= Dimmitt

Table 2.7 The Pearson Correlation Coefficient for the correlation between NDVI and hand clipped weight for a one meter row section taken at Brady and Dimmitt in 2017.

Pearson Correlation Coefficients	**NDVI**
Weight	0.71969 <.0001

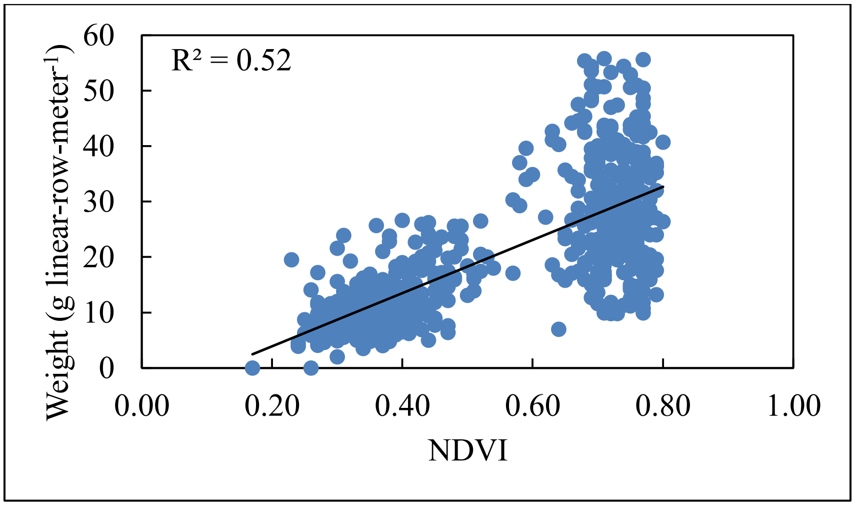

Figure 2.2 The correlation between NDVI and one meter row hand clipped dry matter yields (g) of barley lines taken at Brady and Dimmitt in 2017.

Using hand clipped weights along with NDVI and height measurements, the prediction model Yield= (47.385*NDVI)+(0.398*Height) was developed. Since measurements were taken late in the season after canopy closure had occurred, the samples at Dimmitt were excluded from development of the model. When this model using just the data collected from Brady was used to predict yields, an R^2=0.37 was found for the correlation between predicted yields and actual yields (Figure 2.3).

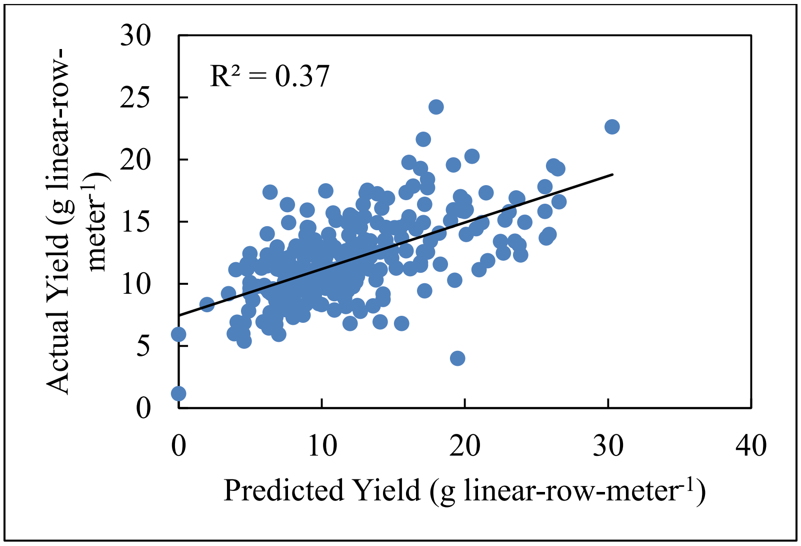

Figure 2.3 The correlation between predicted and actual dry matter yield of barley lines at Brady and Dimmitt using a prediction model.

A combined environment ANOVA of plant height for spring silage trials revealed high significant differences ($P<0.001$) among locations, replications within locations, location*entry interaction, and entries (Table 2.8). When an ANOVA was conducted for each environment (Table 2.9), high significant differences ($P<0.001$) were found for all four environments. Average heights ranged from 50-86cm across locations with a grand mean of 62.8cm.

Table 2.8 Combined environment analysis of variance for barley plant height taken at silage harvest from 2016-2017.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
entry	113	33239.64	294.16	9.1	<.0001
loc	3	156310.5	52103.5	1612.2	<.0001
bloc(loc)	4	723.15	180.79	5.59	0.0002
loc*entry	339	31920.98	94.16	2.91	<.0001
Error	452	14607.47	32.32		
Corrected Total	911	236801.73			

Loc= Location, Rep= Replications, DF= Degrees of Freedom

Table 2.9 Analyses of variance for plant height (cm) at each environment and combined environment for barley spring silage trials from 2016-2017.

	2016 CS	2016 DIM	2017 CMN	2017 DIM	Combined
Date	4/7/16	5/12/16	4/6/17	5/4/17	-
Mean	49.9	57.6	85.5	59.3	62.8
Min	22.9	40.6	50.8	40.6	22.9
Max	76.2	76.2	116.8	73.7	116.8
Maja[1]	31.8	58.4	80.0	53.3	55.9
Alba[1]	56.7	53.3	80.0	62.2	63.8
TAM 304[2]	59.7	58.4	92.7	63.5	68.6
LSD (0.05)	10.8	6.4	12.4	5.7	5.6
CV%	10.79	5.53	7.27	4.87	9.05
Significance	***	***	***	***	***

MSE= Mean square error, Mean=Average of all barley lines at that location, Min= Shortest barley line, Max= Tallest barley line, LSD= Least significant difference, CV%= Coefficient of variation, ***= P<0.001, CS= College Station, CMN= Comanche, DIM= Dimmitt

Levene's test for homogeneity of variance revealed heterogeneity of variance for spring silage percent dry matter. In order to correct this, the data collected at Comanche were dropped from analysis and resulted in homogeneity of variance. After dropping the Comanche data, a combined environment ANOVA of silage percent dry matter found high significant differences among locations, location*entry interaction, and entries while no differences (P<0.05) were found for replications within environments (Table 2.10). The ANOVA for silage percent dry matter at each environment found significant differences (P<0.05) among entries at one environment and high significant differences (P<0.001) at the other three (Table 2.11). Average percent dry matter was found to range from 19.5-38.6% across environments with a grand mean of 29.7%.

Table 2.10 Combined environment analysis of variance for barley spring silage percent dry matter from 2016-2017.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
entry	113	3296.9	29.2	4.09	<.0001
loc	2	46883.1	23441.6	3282.1	<.0001
rep(loc)	3	122.9	40.9	5.7	0.0008
loc*entry	226	3260	14.4	2	<.0001
Error	339	2421.2	7.1		
Corrected Total	683	55984.2			

Loc= Location, Rep= Replications, DF= Degrees of Freedom

Table 2.11 Analyses of variance for percent dry matter at each environment and combined environment for barley spring silage trials from 2016-2017.

	2016 CS	2016 DIM	2017 CMN	2017 DIM	Combined
Date	4/7/16	5/12/16	4/6/17	5/4/17	-
Mean	22.86	19.54	38.02	38.61	27.01
Min	18.46	15.77	26.85	32.33	15.77
Max	38.48	28.31	59.25	47.22	47.22
Maja^1	28.1	21.6	46.3	42.1	34.5
Alba^1	20.2	16.6	44.5	39.3	30.2
TAM 304^2	23.3	22.6	38.0	46.5	32.6
LSD (0.05)	4.13	4.41	9.94	5.13	3.04
CV%	9.03	11.27	13.14	6.67	9.89
Significance	***	***	*	***	***

MSE= Mean square error, Mean=Average of all barley lines at that location, Min= Lowest dry matter percentage, Max=Highest dry matter percentage, LSD= Least significant difference, CV%= Coefficient of variation,*=P<0.05, ***= P<0.001, CS= College Station, CMN= Comanche, DIM= Dimmitt

The combined environment ANOVA for silage dry matter yield revealed high significant differences ($P<0.01$) among locations, replications within locations, location*entry interaction, and entries (Table 2.12). When silage dry matter yield was analyzed at each location (Table 2.13), no differences ($P<0.05$) among entries were found at Dimmitt 2017 while significant differences ($P<0.05$) were found at 2016 College Station and 2016 Dimmitt and high significant differences ($P<0.001$) at Comanche 2017. The average dry matter yield ranged from 2.4-10.2 tonnes per hectare (t ha^{-1}) with a grand mean across all environments of 5.3 t/ha.

Table 2.12 Combined environment analysis of variance for barley spring silage dry matter yield from 2016-2017.

Source	DF	Sum of Squares	Mean Square	F Value	Pr >
entry	113	512.45	4.53	3	<.0001
loc	3	8477.69	2825.9	1869.37	<.0001
bloc(loc)	4	31.26	7.81	5.17	0.0004
loc*entry	339	1044.37	3.08	2.04	<.0001
Error	449	678.75	1.51		
Corrected Total	908	10759.13			

Loc= Location, Rep= Replications, DF= Degrees of Freedom

Table 2.13 Analyses of variance of dry matter yield (t/ha) at each environment and combined environment for barley spring silage trials from 2016-2017.

	2016 CS	2016 DIM	2017 CMN	2017 DIM	Combined
Date	4/7/16	5/12/16	4/6/17	5/4/17	-
Mean	2.4	2.8	10.2	5.7	5.3
Min	0.5	0.6	3.4	0.2	0.2
Max	5.9	6.3	17.6	8.4	17.6
Maja^1	1.2	3.2	10.6	4.9	5.0
Alba^1	3.3	2.3	8.9	5.8	5.1
TAM 304^2	3.7	3.0	12.3	5.7	6.2
LSD (0.05)	1.4	1	3.6	-	1.2
CV%	28.14	18.26	17.79	12.99	27.56
Significance	*	*	***	NS	***

MSE= Mean square error, Mean=Average of all barley lines at that location, Min= Lowest dry matter yield, Max=Highest dry matter yield, LSD= Least significant difference, CV%= Coefficient of variation, NS= No significance, *=$P<0.05$, ***= $P<0.001$, CS= College Station, CMN= Comanche, DIM= Dimmitt

In order to identify one or more entries that performed well at all four testing sites, the barley lines were ranked based on silage dry matter yield at each location. An average ranking was then determined to compare the overall performance of entries as shown in Table 2.14. This table displays the top fifteen (Full listing in Appendix B-2) ranked barley lines and the commercial cultivars tested in this trial.

Table 2.14 The fifteen highest ranked spring silage producing barley lines compared to commercial cultivars based on their average performance across environments from 2016-2017.

Name	**2016 CS**	**2016 DIM**	**2017 CMN**	**2017 DIM**	**Average**
OKARS 474	31	23	4	2	15
MW09S4076_002	15	32	1	15	16
2011_F5_9_2	56	3	29	23	28
2011_F5_47_3	8	52	34	17	28
MW10S4118_003	16	18	37	41	28
OR108	42	31	8	37	30
OR103	73	25	5	16	30
OR76	49	15	20	38	31
06OR_41	18	40	6	59	31
2011_F5_96_2	43	71	7	6	32
OKARS 452	86	4	11	28	32
2011_F5_23_1	10	27	49	45	33
TAM 304**	7	35	25	66	33
08OR_30	32	8	89	10	35
OR813	45	12	54	36	37
PO71DH_87	82	20	40	9	38
Alba*	22	100	106	54	71
Maja*	114	21	92	124	88

*= Barley commercial cultivar, **= Wheat commercial cultivar, CS= College Station, CMN= Comanche, DIM= Dimmitt, Full listing found in appendix B-2

Discussion

Early season forage height and NDVI measurements were taken to help estimate the amount of biomass produced by each entry at a particular location. Despite consistently taking measurements 2-2.5 months after planting, winter temperatures and rainfall drastically influenced the amount of early season growth and forage present at the time measurements were collected. These measurements are not intended to compare environments, but rather detect relative differences among entries. General observations can be made, however, about why the values at certain environments were higher or lower than others. NDVI values were found to vary due to a number of biotic (leaf rust) and abiotic (frost damage) stresses. College Station had the lowest mean NDVI values, most likely due to high disease pressure such as leaf rust and barley yellow dwarf virus (*Luteovirus*). On the other hand, Dimmitt had the highest NDVI values and averaged 0.73 which indicates that canopy closure had occurred in most entries. This can lead to NDVI saturation as observed by Goswami et al. (2015) and is easily seen in Figure 2.2 where NDVI values are correlated to the hand clipping dry weight yields. In this figure, two distinct groupings can be seen which corresponds to the two locations where sampling occurred: Brady, where most NDVI values range from about 0.15-0.55 and Dimmitt, where most NDVI values range from about 0.55-0.80. The saturation of NDVI values as seen in this figure reinforces the belief that NDVI is limited to early growth stages of plant growth and cannot successfully be used to estimate biomass once canopy closure has occurred.

Although the ANOVA for plant height revealed high significant differences among entries at all six environments and the ANOVA for NDVI revealed high significant differences among entries at four of six environments, it does not indicate which barley lines were better than others. Table 2.5 summarizes relative differences among entries and how they compare with commercial cultivars. The top performing barley line for early season forage, ‘MW09S4080_001’, was one of the top five barley lines in half of the trials conducted. However, even this line indicates the significance of genotype-by-environment (GxE) interaction on these barley lines as it was ranked 61st in McGregor the first year and 4th the second year. McGregor had a very mild winter in the first year but experienced a few days of very cold temperatures in the second year which resulted in leaf yellowing and tiller death in some lines. This most likely played a large role in the rank improvement of this line from one year to the next. Conducting stability analyses can help to better understand how different lines perform across environments. These barley lines proved to be competitive for fall forage production as they all had a better overall average than the wheat and barley commercial cultivars.

Although the ANOVA for one meter row hand clipped dry matter yields did not show significant differences between entries, this information along with the height and NDVI measurements were used to make a biomass prediction model. Height and NDVI measurements can be taken much quicker than clipping methods and therefore the development of a model using these two traits in order to estimate biomass would be very beneficial. When implemented, the prediction model yielded an R^2=0.37 for the correlation between predicted yield and actual yield. This value is fairly low and accuracy may have been increased if biomass clippings had been taken earlier in the season before canopy closure had occurred at Dimmitt. Since the prediction model was not able to provide a higher correlation than NDVI values alone (R^2=0.52 in Figure 2.2), NDVI and height measurements were used to rank early season forage production. Nevertheless, the data from these trials provided valuable information for determining the top early season forage producing barley lines.

There was a large range in maturity rates among the barley lines tested in this experiment which made it difficult to cut all the entries at the optimal period for spring silage using a single cutting. This led to the overestimation of plant height and percent dry matter of the early maturing barley entries than would be expected if harvested at the correct time. Entries at

Comanche were the tallest with some barley lines exceeding one meter in height. Entries at College Station were the shortest, most likely due to disease pressure and vernalization issues at that location. Percent dry matter was over 50% for some entries at Comanche indicating that those entries had already began to desiccate and were harvested too late. The combination of these factors led to Comanche producing the highest dry matter yields out of all locations. The average yield at this location was almost double any other location tested for spring silage and the highest yielding barley line was over 17 t/ha. The yields at this location demonstrate that barley can produce large quantities of biomass for spring silage and that this may be an ideal environment in Texas for growing barley.

Similar to the results of the early season forage trials, the significant and high significant differences found by conducting ANOVA for dry matter yield does not show which barley lines had the highest yields. Table 2.14 summarizes the top fifteen highest producing spring silage barley lines and commercial cultivars across the four testing environments. ‘OKARS 474’ was the highest producing spring silage line and was ranked in the top five at two of the four testing sites. Again the GxE effects could be seen across environments as no barley line was among the top ten producing lines at all locations. The wheat check, ‘TAM 304’, was the 13th highest producing entry tested but was not one of the top five producing lines at any location. This demonstrates that the barley lines tested are competitive for spring silage production compared to other commercial cultivars.

Conclusion

Small plot forage trials can be labor intensive but remain the best way for screening lines for biomass production. However, NDVI and height measurements can be used to estimate biomass semi-reliably in a quick and nondestructive method. These measurements were used to estimate early season forage production of barley lines in this experiment and a biomass prediction model was developed. Significant differences ($P<0.05$) were found amongst entries for spring silage dry matter yields at three out of four environments. The top producing early season forage and spring silage barley lines were identified at each environment. Some lines were found to have very competitive biomass production compared to other commercial barley and wheat cultivars. Although some barley lines performed well at many locations, the best adapted lines will need to be determined for each environment. Several of the lines that showed potential for total forage production were entered into the statewide Texas A&M AgriLife Extension forage variety trials for further testing.

CHAPTER III

SCREENING BARLEY (*HORDEUM VULGARE*) LINES FOR HESSIAN FLY (*MAYETIOLA DESTRUCTOR*) RESISTANCE IN TEXAS ENVIRONMENTS

Introduction

Small grains are extensively used as a cool-season forage source for feeding beef and dairy cattle in Texas. Almost 1.1 million hectares of winter wheat (*Triticum aestivum*) were used for grazing or forage production across the state last year (USDA-FSA, 2017). However, small grains such as wheat, rye (*Secale cereale*), triticale (*Triticosecale*), and barley are particularly prone to Hessian fly infestation when planted early for fall grazing. This insect belongs to the Cecidomyiidae family which includes other gall midges and acquired its name from the belief that it was brought over from Europe by Hessian soldiers in wheat straw used for bedding during the Revolutionary War. It was first identified in Texas in 1880 and is now found in east, southeastern, and central Texas (Lidell and Schuster, 1990). The Hessian fly has three to five generations per year and some pupae from each generation either aestivate (over-summer) or diapause (over-winter) to ensure species survival (Pike et al., 1983).

Plant injury is due to the larvae feeding on stem tissue using an effector-based strategy that is similar to ones used by plant-pathogenic organisms (Stuart et al., 2012). After hatching and moving down the leaf to within one or two centimeters of the base of the leaf, the Hessian fly larvae uses its microscopic mandibles to penetrate the cell wall and inject salivary fluid into the small punctures. In compatible interactions the epidermal and mesophyll sheath cells near the feeding site become nutritive feeding cells on which the larva feeds whereas incompatible interactions result in the prevention of nutritive cell formation and ultimately the death of the larva (Stuart et al., 2012). Successful Hessian fly feeding results in stunted tillers and even tiller death in younger plants which negatively affects forage production and winter survivability. Large economic losses can occur in dual purpose systems where small grains crops are grazed in the fall and harvested for seed in the spring. Wheat yield losses of 1412 kg ha^{-1} bushels/acre were reported in Alabama in 1985 and caused $20 million in losses from 1988 to 1989 in Georgia (Stuart et al., 2012).

Although Hessian fly is most effectively controlled in wheat using resistant varieties (Ratcliffe, 1997), this approach selects for Hessian fly biotypes that can overcome the resistance. Improving the durability of Hessian fly resistance genes (such as pyramiding *H* genes in wheat cultivars) is a common goal among breeding programs (Stuart et al., 2008). It has been determined that sixteen Hessian fly biotypes exist based on responses to a set of wheat resistance genes (Dubcovsky, 2016). Wheat has thirty-two resistance genes, but only five were found to be consistently effective against all Hessian fly populations in Texas, Oklahoma and Kansas (Chen et al., 2009b). Virulence assays can identify which resistant genes are still effective against Hessian fly populations (Garces-Carrera et al., 2014). However, it is not always known which resistance genes are present in commercial varieties. As a result, evaluating commercial varieties in field trials is often the only means of determining Hessian fly resistance. Virulence assays define resistant plants as those having only dead larvae and use the ratio of resistant to susceptible plants within a line (variety) to determine which are described as resistant. Generally, if 80% or more of the plants of a particular entry in a trial are rated as resistant, then that variety is considered resistant while entries with less than 50% resistant plants are considered susceptible (Garces-Carrera et al., 2014; Chen et al., 2009b; Shukle et al., 2016). Those entries between 50-80% are described as moderately resistant. Buntin et al. (1999) considered entries resistant if the percentage of infested plants was not significantly ($P<0.1$) greater than zero.

Outbreaks of Hessian fly attacking wheat are well documented (Stuart et al., 2012; Harris et al., 2010; Smiley et al., 2003) whereas reports of Hessian fly damage on barley are much less common. However, losses can be significant as high infestation of winter barley (>40% stems infested in spring) can lead to lodging and reduced grain quantity and quality (Buntin and Raymer, 1992). Hessian fly causes similar damages in barley as it does wheat, and resistance in barley is attributed to antibiosis in that first instar larvae fail to establish feeding sites and die (Olembo et al. 1966). Antibiosis is an antagonistic relationship between two organisms in which one is negatively affected (Painter, 1951). It is believed that this mechanism is operating in both winter wheat and barley resistant cultivars (Gallun, 1972).

The search for resistance to Hessian fly in barley began as early as 1916 (McColloch and Salmon) during a resistance screening of several small grains. Later, Hill et al. (1952) screened over 5,100 barley varieties across five years at two locations and discovered seven that had low plant infestations and were believed to be highly resistant at both test sites. Three of these varieties were used in a subsequent study conducted by Olembo et al. (1966) for a genetic analysis of resistance to Hessian fly in barley. They also found the three varieties to be highly resistant to infestation and additionally concluded that the plant stunting reaction and the ability of the larvae to survive on the plant were not completely associated as it was in wheat. Despite this work, Starks and Webster (1985) and Lamiri et al. (2001) reported that resistant barley cultivars were not commercially available. No recent documentation of Hessian fly resistant barley lines in commercial production were found.

Studies have also shown barley to be a less preferred host plant than wheat for Hessian fly. A choice test conducted by Chen et al. (2009a) found that Hessian fly adults deposited three times more eggs on wheat than barley or rice (*Oryza sativa*). Additionally, the average death rate of larvae on an apparently susceptible barley line was 60% compared to only 10% on a susceptible wheat cultivar. A study conducted by Harris et al. (2001) also found Hessian fly preferred wheat to barley for oviposition and noted that similar observations were made in previous trials using different Hessian fly populations and cultivars. Therefore, the adoption of resistant barley lines in areas where Hessian fly is abundant could be very beneficial. A problem can arise over time, though, as the widespread planting of a few resistant cultivars can select for virulent biotypes and lead to crop damage. Consequently, genetically resistant cultivars or less preferred hosts may be overcome by virulent biotypes as selection pressure is increased and resistant varieties should be used in conjunction with other management practices that limit Hessian fly survival such as crop rotation and tillage.

Materials and Methods

Advanced barley breeding lines were obtained from the Oregon State University breeding program through the Triticeae Coordinated Agricultural Project (TCAP). These lines were evaluated for Hessian fly resistance in field trials located in areas previously found to have high infestations of Hessian fly in wheat. In the first year, trials were planted on November 24, 2015 near McGregor, TX (31°22'N 97°27'W) and near Greenville, TX, however the latter trial was lost due to rain shortly after planting. In the second year, one trial was again located near McGregor, TX and planted on November 21, 2016 while another was located near Brady, TX (31°10'N 99°26'W) and planted on October 25, 2016. Barley lines were planted in an alpha lattice design with two replications of 140 entries. Plots were planted at a rate of 73 kilograms per hectare (kg/ha) on 19 cm row spacing and seeds were treated with Dividend Extreme Fungicide (Difenoconazole and Mefenoxam) (Syngenta, Basel, Switzerland) at the label rate. Plot size at all locations were 1.5 meters x 4.5 meters. Hessian fly infestations were determined from plant samples collected from a 0.67 meter-row area within the center three rows of each plot in May during plant ripening (Feekes 11). Plants were pulled out of the ground to avoid loss of pupae at the base of plants and kept in cool storage (4°C) until processing. Susceptibility of barley lines was determined by dissecting barley tillers and counting the number of Hessian fly pupae found. Two to three tillers from each of four plants were dissected for a total of ten tillers per plot. Samples were also taken using the same sampling techniques from the Texas A&M AgriLife hard red winter wheat uniform variety trial (UVT) which was located in the same field during the second year of evaluations in McGregor. This trial was planted on November 21, 2016 and seed was treated with an insecticide seed treatment, Cruiser 5FS Insecticide (Thiamethoxam) (Syngenta, Basel, Switzerland), while the barley seed in the barley trial was not treated with an insecticide.

In order to apply greater insect pressure, the barley and winter wheat lines were also screened for Hessian fly resistance in a growth chamber trial. Wheat plants were collected from a field heavily infested with Hessian fly near Hillsboro, TX (31°57’1”N 97°11’02”W). Plants were in the grain fill stage and most of the Hessian fly were in the puparium stage but the plants were around 60% moisture which helped avoid desiccation of puparia during the storage period. Stem samples were pulled out of the ground and left to dry inside a greenhouse for one day to allow free moisture to evaporate. Stems were then bundled together, wrapped in newspaper, and packed into cardboard boxes and placed in cool storage (4°C) with high humidity for 180 days to break diapause. Following this, the infested wheat stems were placed in a growth chamber which was kept at 21°C and 60% humidity with twelve hours of light per day. The infested tillers were sprayed to simulate a rainfall event and then misted as needed throughout the remainder of the experiment to prevent them from drying out. On the same day as the infested wheat stems were placed in the growth chamber, 140 barley entries as well as a resistant (Duster) and susceptible (Fannin) wheat checks were planted in three replications in a 56cm x 30cm x 10cm (LxWxH) plastic planting trays consisting of 72 cells each. Six trays were used in total for planting this trial. Two seeds were planted per cell and spacing between cells was about 1cm in any direction. Additionally, three replications of 40 winter wheat varieties (29 of which were also in the McGregor UVT field trial) were planted in a similar manner. The winter wheat entries consisted mostly of commercial cultivars as well as some Texas A&M advanced breeding lines. Entries of both trials were laid out in a randomized complete block design (RCDB) and none of the seed was treated with an insecticide. The trays were placed in a greenhouse until they reached the 1.5 leaf stage (about 12 days after planting) at which time they were moved into the growth chamber that contained the infested wheat tillers. Ten days later, eggs could be seen on the adaxial leaf surface of most plants and the infested wheat tillers that had contained the Hessian fly puparium were removed. The seedlings were left in the growth chamber for another fourteen days and then each plant was dissected and the number of live larvae and puparium were counted.

PROC GLM was used for analysis of variance (ANOVA) for the mean number of flies found per plot (10 tillers) in field trials and per seedling in the growth chamber experiment. A mean separation test (Fisher's LSD) was then used to separate entries into one of two categories. Entries found not to be significantly different ($P<0.05$) than zero were rated as resistant while those that were significantly different were rated as susceptible. Hessian fly infestations of barley and wheat plots were also compared.

Results

The combined environment ANOVA for Hessian fly pupae per tiller of field trials revealed significant differences ($P<0.05$) for location*entry and high significant differences

($P<0.0001$) among locations, replications, and entries (Table 3.1). Since the location*entry (genotype-by-environment) interaction was found to be significant, resistance was determined for each environment. The ANOVA for Hessian fly pupae per tiller found significant differences ($P<0.05$) among barley entries at two of the three field screening trials as well as for the winter wheat UVT screening in McGregor (Table 3.2). The mean number of Hessian flies in the barley trials ranged from 0.11-0.24 and was less than the mean number of 0.74 per tiller in the wheat trial. Using Fisher's LSD, 92% and 95% of lines were rated as resistant for barley trials in McGregor 2016 and Brady 2017, respectively., In comparison, 85% of hard red winter wheat varieties in the adjacent trial were rated as resistant at the McGregor 2017 site while no ratings were given for the barley lines due to the lack of statistical significance among entries.

The ANOVA for Hessian fly larvae per tiller in the growth chamber screening revealed significant differences ($P<0.05$) among entries for both the barley and winter wheat trials (Table 3.3). Using Fisher's LSD, 15% of the barley lines and 2% of the winter wheat cultivars were rated as resistant. Six percent of the barley lines were rated as resistant in all three environments and only one barley line, '2011_F5_4_2', had no Hessian fly in any field or growth chamber trial (Table 3.4 and full listing of lines in Appendix B-3). The lone resistant winter wheat cultivar was 'LCS Chrome' (Appendix B-4).

Table 3.1 Combined environment analysis of variance for Hessian fly pupae per tiller found in barley field trials at McGregor and Brady from 2016-2017.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
loc	2	2.62	1.31	21.29	<.0001
rep(loc)	3	1.41	0.47	7.61	<.0001
loc*entry	268	20.40	0.08	1.24	0.027
entry	139	20.35	0.15	2.38	<.0001
Error	406	24.99	0.06		
Corrected Total	818	69.44			

Loc= Location, Rep=Replications.

Table 3.2 Analysis of variance for Hessian fly pupae per tiller for barley and winter wheat plots at each environment from 2016-2017.

		Barley		W. Wheat
Source	2016 MCG	2017 MCG	2017 BRD	2017 MCG
Mean	0.11	0.24	0.18	0.74
Min	0	0	0	0
Max	1.3	1.9	2.7	3.3
LSD (0.05)	0.36	-	0.57	1.53
Resistant	120	-	133	22
Susceptible	10	-	7	4
Significance	*	NS	*	*

MCG=McGregor, BRD= Brady, Mean= Average of all barley lines at that location, Min=Lowest average number of Hessian fly pupae in a barley line, Max= Highest average number of Hessian fly pupae in a barley line, LSD= Least Significant Difference, Resistant= Number of lines rated as resistant, Susceptible=Number of lines rated as susceptible, *= P<0.05, NS= No Significance

Table 3.3 Analysis of variance for Hessian fly pupae per tiller for barley and winter wheat seedlings in a growth chamber screening.

Source	Barley	W. Wheat
Mean	2.26	7.63
Min	0	1
Max	12	19.5
LSD (0.05)	0.53	1.77
Resistant	18	1
Susceptible	122	39
Significance	*	*

Mean= Average of all lines, Min=Lowest average number of Hessian fly pupae, Max= Highest average number of Hessian fly pupae, LSD= Least Significant Difference, Resistant= Number of lines rated as resistant, Susceptible=Number of lines rated as susceptible, *= P<0.05, NS= No Significance

Table 3.4 The TCAP barley lines that were rated as resistant to Hessian fly in all three screening environments from 2016-2017.

Name	MCG 2016	Brady 2017	Growth Chamber	Grand Mean
2011_F5_4_2	0.00	0.00	0.00	0.00
08OR_48	0.00	0.10	0.00	0.03
OKARS 474	0.00	0.15	0.33	0.16
OR76	0.00	0.00	0.50	0.17
OKARS 248	0.00	0.00	0.50	0.17
2011_F5_64_1	0.00	0.05	0.50	0.18
2011_F5_121_5	0.00	0.15	0.50	0.22
2011_F5_91_1	0.00	0.25	0.50	0.25
2011_F5_88_3	0.00	0.35	0.50	0.28

MCG=McGregor, BRD= Brady, Grand Mean= Average number of Hessian fly pupae per tiller in the three environments

Discussion

The combined environment analysis of field trials for Hessian fly counts revealed a significant genotype by environment interaction. This is not surprising as virulence patterns in wheat have been shown to greatly vary even across relatively short geographic distances (Chen et al., 2009b) as well as from one year to the next. It is believed that this is due to differences in biotype composition which is a result of planting wheat with different resistant genes in different geographic areas (Chen et al., 2009b). Therefore, the resistance of barley lines in this experiment were determined for each environment.

In the barley field trials, most of the pupae found in the tiller samples were located at the second or third nodes indicating that these were spring infestations rather than fall infestations. Higher infestation levels may have resulted if the trial had been planted earlier in the fall instead of the traditional planting date for grain production. Hessian fly pressure on the barley lines in the field trials was low as the highest average number of pupae per tiller was 0.24 at McGregor in 2017 and no physical damage such as stunting, lodging or undeveloped seed heads was observed at any location. Additionally, the high field variability masked separation of entries that only had a few flies and resulted in very few lines being considered susceptible. While pressure was much greater on the hard red winter wheat which had an average of 0.74 Hessian fly pupae per tiller with visible lodging in some plots, high amounts of variability still limited the number of cultivars determined to be susceptible. Higher insect pressure in the growth chamber trial resulted in much greater success discriminating between resistant and susceptible lines. The average number of pupae per tiller was much higher for both barley and winter wheat at 2.26 and 7.63, respectively.

Nine of the 140 barley lines were found to be resistant in the McGregor 2016, Brady 2017, and growth chamber trials and one of these lines did not contain any Hessian fly in any trial. It is possible, but not likely, that some lines with no Hessian fly may have escaped infestation. These results suggest that these nine lines would provide the best protection against Hessian fly at those locations (Brady and McGregor). Additionally, barley lines at McGregor in 2017 as well as those in the growth chamber were found to have much lower Hessian fly infestations than the winter wheat entries in the same environment. In both of these trials, the overall average number of Hessian fly pupae per tiller were found to be about three times greater in wheat than in barley, which is the same ratio reported by Chen et al. (2009a) in a choice test trial.

Conclusion

Until molecular markers associated with Hessian fly resistance genes are developed in barley, field and growth chamber screenings will remain the best way for determining resistance. In this experiment, low insect pressure and high variability in field screenings prevented the identification of many susceptible lines. The growth chamber screening provided much higher pressure than field trials which resulted in greater infestations of susceptible entries. Due to this, it was easier to separate resistant lines from susceptible ones than in the field trials. Overall, barley was found to have much lower Hessian fly infestation than winter wheat. Therefore, barley may be especially useful to Texas producers who plant small grains early for grazing cattle in the fall which makes them more vulnerable to Hessian fly infestation.

CHAPTER IV

STABILITY, HERITABILITY, AND REPEATABILITY ANLYSES ON A SET OF BARLEY (*HORDEUM VULGARE*) LINES GROWN FOR FORAGE PRODUCTION IN TEXAS ENVIRONMENTS

Introduction

Texas is a very diverse state as environmental factors such as rainfall, average temperature, and soil type greatly vary across regions. Crops such as wheat (*Triticum aestivum* L.) and cotton (*Gossypium hirsutum*) which are grown statewide must, therefore, have regionally adapted cultivars that are best suited for each location. Additionally, environmental effects on genotypes such as freezing temperatures or drought can change from year to year at the same location. Plant breeders rely on a set of analytical tools while selecting varieties that are best suited for certain regions. Without conducting proper statistical analysis, variety performance patterns for yield and other characteristics may not be identified or fully understood. Stability, heritability, and repeatability are a few of the tests commonly conducted by breeders to help understand genotype-by-environment (GxE) interactions.

Cultivars intended to transcend more than one environment must demonstrate yield stability not only across regions but also from one year to the next. The way in which a genotype is affected by an environment is the basic determinant of yield stability (Becker and Leon, 1988). The model $Y_{ij} = \mu_1 + \beta_1 I_j + \delta_{ij}$, developed by Eberhart and Russell (1965), can be used to estimate the stability of a variety where Y_{ij} is the variety mean at a specific environment, μ_1 is the variety mean over all environments, β_1 is the regression coefficient, I_j is the environmental index, and δ_{ij} is the deviation from regression. This can be quickly calculated using Agrobase Gen II (Agronomix, Winnipeg, Canada) statistical software. Bi-plots offer a way to visually interpret data and have been used to analyze agricultural data for forty years (Bradu and Gabriel, 1978). If sufficient data is available, mega-environments (groups of environments that produce similar results) as well as genotypes with high performance and stability within those environments can be identified using bi-plot analysis (Yan and Tinker, 2006). A previous study utilizing six years of wheat variety trial data containing 16 cultivars at 19 locations identified three mega-environments in Texas which corresponded to the High Plains, Rolling Plains, and Black Lands/ South Texas testing locations (Gerrish- Unpublished Data). Identifying locations which produce similar results can help reduce redundancy and conserve resources.

Plant breeders commonly use heritability and repeatability estimates to determine if there is sufficient genetic variation in the germplasm to allow for improvement of traits (which genetic population is most promising as a source of improved breeding material) and whether the same breeding procedure will be equally effective for improving all traits (Dudley and Moll, 1969). Heritability is the ratio of total genetic variance to total phenotypic variance. Heritability on an entry-mean basis is described by Fehr (1987) as: $h^2= \sigma^2_g/(\sigma^2_e/rt+ \sigma^2_{ge}/t+ \sigma^2_g)$ where h^2 is heritability, σ^2_g is genetic variance, σ^2_e is experimental error, r is number of replications, t is number of test environments, and σ^2_{ge} is genotype-by-environment interaction. Heritability estimates can be used to compare gains from selection of different experimental designs and assist in constructing optimal breeding strategies (Holland et al., 2003). Repeatability is a measurement of the ability of a genotype to repeat trait expression over time or space (Roman et al., 2000). This can help differentiate between superior genotypes that perform well from one year to the next and those that perform well due to some transient environmental condition (Laviola et al., 2013). Repeatability can set the upper limit for heritability (if defined and measured properly) which can be very useful as estimates of heritability cannot always be obtained (Dohm, 2002).

Wheat is grown on over two million hectares across Texas each year. Not only does it provide a source of grain which is utilized in a wide range of products, but also serves as a source of forage for grazing livestock. It has been proposed that barley may be able to replace wheat in some cropping systems due to having greater tolerance to drought and saline soils (Bornare et al., 2012). Additionally, although many small grains provide a source of high quality forage, barley may provide the best option for fall grazing due to its rapid growth when planted early (Warrick et al., 2002). However, planting small grains early for grazing purposes can leave them vulnerable to greater Hessian fly (*Mayetiola destructor*) infestations which results in higher tiller mortality and reduced biomass yield. Nevertheless, barley has been shown to provide greater resistance to this insect. A choice test conducted by Chen et al. (2009a) found that Hessian fly adults deposited three times more eggs on wheat than barley or rice (*Oryza sativa*). Additionally, the average death rate of larvae on an apparently susceptible barley line was 60% compared to only 10% on a susceptible wheat cultivar. Therefore, the main objective of this study was to conduct stability, heritability, and repeatability analyses on a set of winter and facultative barley lines that were screened for early season forage and spring silage production in Texas environments.

Materials and Methods

The screening locations used in this study were chosen due to their proximity to areas of dense cattle and/or dairy populations and greater demand for forages. Silage evaluations took place at two locations for both the 2016 and 2017 growing seasons. In the first year, trials were located at the Texas A&M Research farm near College Station, TX (30°31’N 96°25’W) and

Dimmitt, TX (34°30’N 102°31’W). Both locations were laid in an alpha lattice design with two replications of 116 entries and included commercial barley and wheat cultivar checks for comparison. The commercial cultivars in the trial were ‘Alba’ (PI 672535) (Graebner et al., 2014), a six-row winter barley used for feed and malting, ‘Maja’ (PI 184884), a six-row facultative barley used for feed and malting, and ‘TAM 304’ (PI 655234) (Rudd et al., 2015), a widely adapted hard red winter wheat grown throughout Texas that can withstand grazing in a dual-purpose system and produce forage similar to other currently grown wheat cultivars. Plots were planted at a rate of 75 kilograms per hectare (kg ha^{-1}) on 19 cm row spacing at each location. College Station had 78.5 kg N ha^{-1} applied as liquid UAN (32-0-0) in early February and no irrigation was applied. Dimmitt had 70.6 kg N ha^{-1} applied as granular urea (46-0-0) prior to planting and had three applications of UAN (32-0-0) at 41.5 kg N ha^{-1} applied via fertigation throughout the growing season. Approximately 12.7 centimeters (cm) of total irrigation were applied.

In the second year, trials were located near Comanche, TX (31°52’N 98°28’W) and Dimmitt, TX (34°31’ N 102°35’W). Both locations were in an alpha lattice design with two replications of 135 entries and included the same commercial cultivars with the addition of ‘Full Pint’, a two-row spring barley that is used primarily for malting. Plots were planted at a rate of 100 kg ha^{-1} at both locations. Comanche had 56 kg N ha^{-1} (UAN) applied in early February but irrigation amounts by the producer were not recorded. Dimmitt had 78.5 kg N ha^{-1} of UAN applied in late March and no irrigation was applied.

All plots across both years were treated with Dividend Extreme Fungicide (Difenoconazole and Mefenoxam) and Cruiser 5FS Insecticide (Thiamethoxam) at the label rate (Syngenta, Basel, Switzerland). Plot size at all locations were 1.5 meters (m) x 4.5m except at

Comanche where they were 1.5m x 6.0m. Plots in College Station were located on a Weswood silty clay soil which receives an average of 102 centimeters of rain each year. Plots in Comanche were located on a Pedernales loamy fine sand which receives an average of 82 centimeters of rain each year. Plots in Dimmitt were located on an Olton clay loam both years and receives an average of 50 centimeters of rain each year. Plant heights were taken just before harvest using a meter stick. Plots were harvested using a Haldrup 1500 forage harvester (Haldrup, Ilshofen, Germany) which has an onboard weigh system and 1.5 m header. Hand grab samples were taken from the harvester for each plot and quickly weighed to avoid water loss. The subsamples were then placed in a drying oven at 50°C for three days to ensure samples were thoroughly dried. Weights were taken again in order to determine dry matter percentages for each entry at time of harvest.

Early season forage production was estimated by measuring plot normalized difference vegetation index (NDVI) using a handheld Trimble Greenseeker Crop Sensor (Trimble, Sunnyvale, CA) and plant height. These measurements were taken approximately two months after planting. In the first year, NDVI measurements were taken at McGregor, TX (31°22' N 97°27'W) as well as on the silage trial located in College Station. In the second year, NDVI measurements were taken at McGregor and Brady, TX (31°10' N 99°26'W) as well as on the silage trials located at Comanche and Dimmitt. Both trials at McGregor and the trial in Brady contained 140 entries that were laid in an alpha lattice design. All plots were planted at a rate of 75 kg ha^{-1}. NDVI measurements were typically taken between 10am-2pm on clear, sunny days in order to avoid any shade differences that may occur among entries due to clouds.

Only entries that were tested in both years were included in these analyses. Statistical analysis was conducted using several analytical software programs. Data was organized in

Microsoft Excel (Microsoft, Redmond, WA) and repeatability values were estimated from the variance component output produced by Agrobase Gen II. Bi-plot software (Yan and Hunt, 2002) was used to determine the stability of lines as well as which lines were best suited for each environment. Agrobase Gen II (Agronomix, Winnipeg, Canada) was used to calculate heritability and Eberhart-Russell stability estimates.

Results

The "which wins where or which is best for what" bi-plot is used to evaluate genotype stability as well as determine which genotypes are best suited for a certain environment. Since NDVI was the primary measurement of fall forage yield, bi-plot analysis was conducted on NDVI values. In Figure 4.1, entries are divided by a red line which represents the average value; values that appear above the line are above average while those below the line are below average. Values also increase moving from left to right. Entries are connected to the average line with a blue line which indicates the stability of that genotype across all of the testing environments. Those that are close to the red line are more stable than those that appear far from it. Due to the large number of entries, it is difficult to identify some lines in the middle section of the figure. However, it does allow for genotypes that perform very well or very poorly to be recognized. Entries 67, '2001_F5_88_3', and 59, '2011_F5_59_2', had the highest NDVI values and were stable across environments while entries 91, 'MW10S4116_004', and 90, 'MW10S4116', had low NDVI values and were also unstable. The full set of entry numbers and corresponding lines can be found in Table 4.1.

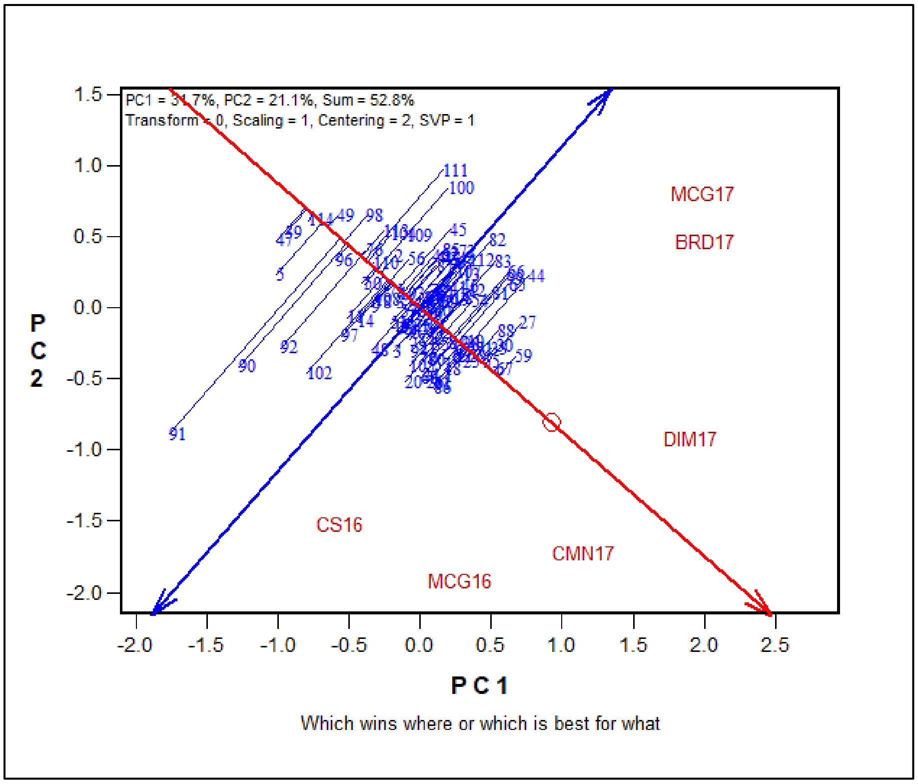

Figure 4.1 GGE bi-plot showing each entries mean NDVI performance and stability. BRD17= Brady 2017, CMN17= Comanche 2017, CS= College Station 2016, DIM17= Dimmitt 2017, MCG 16= McGregor 2016, MCG17= McGregor 2017.

In Figure 4.2, the outermost entry numbers are connected and those that appear at the vertex of two lines are either the best performing genotype for a certain environment or did not perform well in any environment. Environments which appear close together produced similar NDVI values. In this figure, entries 44, '2011_F5_36_2', 66, '2011_F5_83_1', and 65, '2011_F5_76_4', were among the barley lines with the highest NDVI values for the 'MCG17' and 'BRD17' environments while entries 59, '2011_F5_59_2', and 67, '2011_F5_88_3', had the highest NDVI values for the 'DIM17' environment. Entries 47, '2011_F5_4_2', and 29, '2011_F5_121_4', were among the barley lines that were not suited for any environment.

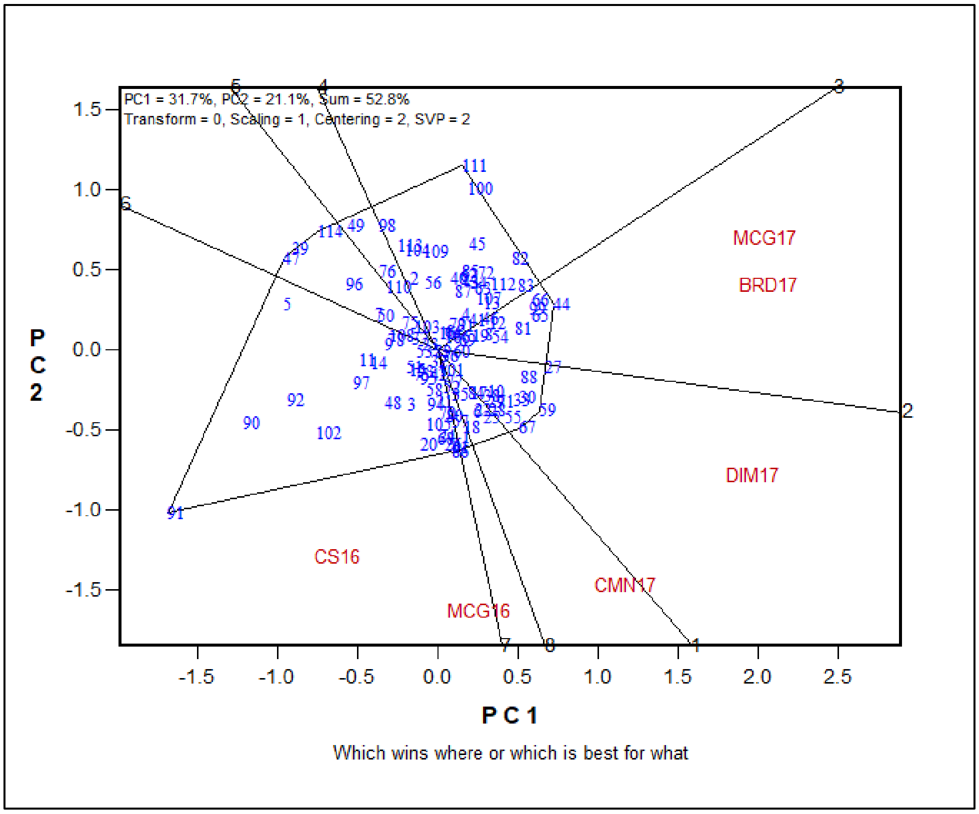

Figure 4.2 GGE bi-plot showing the best and poorest performing entries for NDVI at each test environment. Testing locations in red, entries in blue. BRD17= Brady 2017, CMN17= Comanche 2017, CS= College Station 2016, DIM17= Dimmitt 2017, MCG 16= McGregor 2016, MCG17= McGregor 2017.

When conducting the Eberhart-Russell stability analysis, a good line has a large mean, a beta close to one, and a small deviation from beta. For example, in the stability analysis for fall forage height (Table 4.1), lines ‘2011_F5_96_4’ and ‘08OR_44’ had a high mean indicating they had high yield potential and also had a beta close to ‘1.0’ and a relatively low deviation from beta indicating they were stable across environments. The barley line ‘2011_F5_59_1’ had a low deviation which demonstrated that it was stable across environments, but also had a low mean and therefore had low yield potential. Barley line ‘MW10S4118_001’ had a high yield potential but also had a very high deviation from beta indicating it was unstable across environments.

Table 4.1 Eberhart-Russell stability analysis for fall forage height (cm) measurements in order from tallest to shortest mean taken at College Station, McGregor, Brady, Comanche, and Dimmitt from 2016-2017.

Entry	Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
95	MW10S4120_008	25.3	0.788	5.158
92	MW10S4118_001	24.7	0.828	81.867
48	2011_F5_47_1	24.3	0.805	3.071
97	MW10S4122_005	24.1	1.086	31.236
89	MW09S4080_001	23.4	1.481	19.302
91	MW10S4116_004	23.0	1.014	78.070
93	MW10S4118_003	22.7	1.104	26.076
3	06OR_91	22.4	1.500	13.780
96	MW10S4122_001	21.7	0.834	42.851
42	2011_F5_32_1	21.6	0.677	4.379
39	2011_F5_22_3	21.2	0.390	6.699
47	2011_F5_4_2	21.1	0.648	2.059
94	MW10S4118_004	21.1	0.207	9.259
51	2011_F5_5_1	20.9	0.711	3.217
40	2011_F5_23_1	20.3	0.597	15.121
107	OR813	20.1	1.258	11.703
49	2011_F5_47_3	19.9	0.501	7.434
5	07OR_3	19.5	0.586	5.985
74	2011_F5_96_4	18.8	0.951	3.464
61	2011_F5_64_1	18.7	1.206	2.719
102	OR103	18.0	0.584	3.672
73	2011_F5_96_2	17.8	0.840	0.849
10	08OR_30	17.8	1.462	4.737
68	2011_F5_9_2	17.6	1.318	2.065
90	MW10S4116_003	17.5	0.677	10.771
1	06OR_41	17.4	0.878	6.685
106	OR76	17.4	1.170	17.860
11	08OR_44	17.3	0.977	3.464
109	OR818	17.1	1.243	1.486
101	OR101	17.1	1.240	3.073
9	07OR_8	16.9	1.128	3.207
50	2011_F5_48_1	16.9	1.038	1.627
52	2011_F5_50_1	16.9	0.977	3.449
38	2011_F5_136_1	16.8	1.067	3.731
36	2011_F5_132_1	16.8	1.063	1.347
113	PYT211_6	16.7	0.921	9.020
41	2011_F5_27_1	16.7	1.146	5.018
110	OR91	16.7	0.952	2.381

Table 4.1 Continued

Entry	Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
27	2011_F5_121_2	16.6	1.059	3.499
35	2011_F5_131_1	16.5	0.788	4.224
98	OBADV11_13	16.4	0.664	6.707
31	2011_F5_124_1	16.3	1.006	1.156
105	OR108	16.3	0.989	0.720
75	2011_Short_11	16.3	0.803	3.617
20	2011_F5_109_1	16.3	0.802	9.026
12	08OR_48	16.2	1.195	5.588
15	08OR_81	16.2	1.025	0.279
66	2011_F5_83_1	16.2	0.985	3.228
14	08OR_73	16.1	0.881	1.580
76	2011_Short_12	16.1	1.150	11.536
114	TAM 304	16.1	1.503	19.049
7	07OR_6	16.0	1.096	2.536
67	2011_F5_88_3	16.0	0.942	4.309
103	OR104	16.0	0.933	5.107
30	2011_F5_121_5	16.0	1.134	3.133
28	2011_F5_121_3	15.8	0.733	1.090
24	2011_F5_119_1	15.8	1.128	2.148
26	2011_F5_121_1	15.8	1.027	10.177
80	Alba	15.8	0.985	3.310
55	2011_F5_56_1	15.7	1.056	4.302
21	2011_F5_112_1	15.5	1.042	3.703
57	2011_F5_57_2	15.5	0.991	6.080
78	2011_Short_16	15.3	0.923	1.134
59	2011_F5_59_2	15.3	1.033	0.710
53	2011_F5_52_2	15.2	0.773	6.760
56	2011_F5_56_3	15.2	1.299	1.732
69	2011_F5_90_5	15.2	0.811	5.084
112	PO71DH_87	15.1	1.254	4.892
19	2011_F5_108_1	15.0	1.095	1.654
25	2011_F5_120_3	15.0	0.979	1.510
108	OR815	15.0	0.643	2.239
44	2011_F5_36_2	14.9	1.143	3.419
77	2011_Short_13	14.9	0.737	14.410
32	2011_F5_126_1	14.8	0.965	0.406
81	OKARS 216	14.8	1.510	9.848
29	2011_F5_121_4	14.8	0.928	0.346
65	2011_F5_76_4	14.7	1.127	6.887
72	2011_F5_95_1	14.7	0.825	1.698

Table 4.1 Continued

Entry	Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
86	OKARS 474	14.7	0.927	4.003
33	2011_F5_126_2	14.7	0.938	4.229
99	OBADV11_29	14.6	1.056	2.877
37	2011_F5_134_3	14.6	0.891	0.608
46	2011_F5_37_3	14.6	0.776	0.071
4	07OR_21	14.5	1.118	1.542
71	2011_F5_91_2	14.5	1.105	2.210
62	2011_F5_66_3	14.4	0.809	0.074
64	2011_F5_76_1	14.4	1.061	5.584
17	2011_F5_105_3	14.4	0.911	16.720
104	OR106	14.4	0.858	3.472
87	Maja	14.3	0.839	6.115
8	07OR_63	14.3	1.069	5.559
54	2011_F5_55_1	14.3	0.857	3.822
84	OKARS_242	14.3	1.169	4.316
43	2011_F5_35_2	14.2	1.105	1.175
88	MW09S4076_002	14.2	1.414	4.946
13	08OR_53	14.2	0.590	3.343
79	2011_Short_8	14.2	0.552	2.222
2	06OR_43	14.1	0.748	0.576
6	07OR_59	14.0	0.919	4.004
60	2011_F5_60_2	14.0	1.054	2.498
22	2011_F5_112_3	14.0	0.904	4.311
23	2011_F5_113_2	14.0	0.804	2.871
70	2011_F5_91_1	13.9	0.623	3.588
100	OBADV11_31	13.8	1.095	1.479
34	2011_F5_129_1	13.8	1.100	1.912
111	PO71DH_104	13.7	1.083	0.913
63	2011_F5_72_3	13.4	0.942	0.221
18	2011_F5_106_1	13.2	0.857	0.711
45	2011_F5_37_1	13.0	0.863	0.548
16	2011_F5_105_1	13.0	0.641	0.134
83	OKARS 248	12.8	1.031	1.070
85	OKARS 452	12.7	0.963	4.697
58	2011_F5_59_1	12.6	0.747	0.060
82	OKARS_249	12.1	0.928	3.053
	Grand mean = 16.426	R-squared = 0.8295		C.V. = 15.09%

*= Barley check, **= Wheat check, C.V.= Coefficient of Variation.

As in the previous table, Table 4.2 shows the stability of the barley lines for fall forage NDVI values across environments. The stability values for all lines are small indicating a lack of stability. This is confirmed by the low repeatability values.

Table 4.2 Eberhart-Russell stability analysis for fall forage NDVI values in order from highest to lowest mean taken at College Station, McGregor, Brady, Comanche, and Dimmitt from 2016-2017.

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
08OR_30	0.63	-0.464	0.004
MW09S4076_002	0.63	-0.191	0.021
2011_F5_121_2	0.63	-0.320	0.015
2011_F5_59_2	0.62	-0.286	0.019
2011_F5_88_3	0.62	-0.299	0.015
2011_F5_126_2	0.62	-0.026	0.034
2011_F5_56_1	0.62	-0.377	0.02
2011_F5_9_2	0.62	-0.508	0.007
2011_F5_119_1	0.61	-0.271	0.018
2011_F5_121_1	0.61	-0.121	0.028
2011_F5_136_1	0.61	-0.160	0.021
2011_F5_64_1	0.61	-0.292	0.016
OKARS 474	0.61	-0.285	0.025
2011_F5_120_3	0.61	-0.311	0.013
2011_F5_121_4	0.61	-0.136	0.024
2011_F5_121_5	0.61	-0.297	0.025
OKARS_242	0.61	-0.330	0.02
2011_F5_109_1	0.61	-0.237	0.022
2011_F5_121_3	0.61	-0.212	0.024
06OR_41	0.61	-0.298	0.017
2011_F5_91_1	0.60	-0.327	0.012
07OR_59	0.60	-0.442	0.011
08OR_53	0.60	-0.240	0.017
2011_F5_106_1	0.60	-0.302	0.025
OKARS 216	0.60	-0.347	0.01
2011_F5_59_1	0.60	-0.449	0.008
2011_F5_91_2	0.60	-0.377	0.013
2011_F5_112_3	0.60	-0.248	0.022
2011_Short_13	0.60	-0.269	0.017
OR108	0.59	-0.410	0.009
2011_F5_32_1	0.59	-0.199	0.019

Table 4.2 Continued

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
2011_F5_36_2	0.59	-0.022	0.031
2011_F5_57_2	0.59	-0.106	0.029
2011_F5_72_3	0.59	-0.373	0.006
2011_F5_76_4	0.59	0.017	0.039
2011_F5_83_1	0.59	-0.005	0.027
Alba	0.59	-0.486	0.007
06OR_91	0.59	-0.375	0.013
2011_F5_108_1	0.59	-0.160	0.022
2011_F5_37_3	0.59	-0.271	0.01
OKARS 248	0.59	-0.197	0.022
MW10S4120_008	0.59	-0.183	0.022
2011_F5_132_1	0.59	-0.256	0.012
PO71DH_87	0.59	-0.116	0.02
2011_F5_105_3	0.59	-0.026	0.037
OR813	0.59	-0.026	0.027
OBADV11_29	0.59	-0.201	0.02
2011_F5_112_1	0.58	-0.146	0.023
2011_F5_27_1	0.58	-0.203	0.019
2011_F5_76_1	0.58	-0.222	0.013
MW10S4118_004	0.58	-0.229	0.025
2011_F5_126_1	0.58	-0.279	0.017
2011_F5_90_5	0.58	-0.164	0.021
OR101	0.58	-0.108	0.022
08OR_48	0.58	0.010	0.026
2011_F5_47_1	0.58	-0.146	0.027
2011_F5_52_2	0.58	-0.117	0.021
07OR_63	0.58	-0.327	0.014
2011_F5_131_1	0.58	-0.152	0.023
2011_F5_50_1	0.58	-0.154	0.022
MW09S4080_001	0.58	0.061	0.033
2011_F5_113_2	0.58	-0.170	0.018
2011_F5_35_2	0.58	-0.203	0.014
2011_F5_60_2	0.58	-0.398	0.008
2011_F5_96_2	0.58	-0.121	0.023
2011_Short_8	0.58	-0.295	0.01
MW10S4118_003	0.58	-0.213	0.018
OR104	0.57	-0.301	0.009
2011_F5_124_1	0.57	-0.190	0.02
2011_F5_55_1	0.57	-0.105	0.033
2011_F5_96_4	0.57	-0.105	0.02

Table 4.2 Continued

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
Maja	0.57	-0.330	0.007
2011_F5_105_1	0.57	-0.325	0.016
07OR_21	0.57	-0.063	0.023
OKARS 452	0.57	-0.393	0.02
2011_F5_48_1	0.57	-0.279	0.011
OR91	0.57	-0.194	0.016
2011_F5_5_1	0.57	-0.258	0.015
OKARS_249	0.57	-0.346	0.021
2011_F5_134_3	0.56	-0.246	0.015
2011_Short_16	0.56	-0.099	0.022
07OR_8	0.56	-0.444	0.015
2011_F5_66_3	0.56	-0.378	0.013
2011_F5_95_1	0.56	-0.193	0.017
2011_Short_11	0.56	-0.142	0.018
OR818	0.56	-0.375	0.005
MW10S4122_005	0.56	-0.158	0.023
OR815	0.56	-0.089	0.026
08OR_81	0.56	-0.266	0.021
2011_F5_23_1	0.56	-0.200	0.031
2011_F5_129_1	0.55	-0.110	0.024
07OR_6	0.55	-0.233	0.014
2011_F5_56_3	0.55	0.041	0.03
06OR_43	0.55	-0.235	0.02
08OR_73	0.55	-0.164	0.022
2011_F5_37_1	0.55	-0.086	0.021
OBADV11_31	0.55	-0.214	0.015
MW10S4118_001	0.55	-0.453	0.011
2011_Short_12	0.54	-0.202	0.014
OR103	0.54	-0.294	0.027
OR106	0.54	-0.328	0.013
TAM 304	0.53	-0.245	0.016
08OR_44	0.53	-0.449	0.012
PO71DH_104	0.53	-0.210	0.018
07OR_3	0.52	-0.384	0.008
MW10S4122_001	0.52	-0.319	0.015
PYT211_6	0.52	-0.165	0.025
OBADV11_13	0.51	-0.275	0.021
2011_F5_22_3	0.51	-0.190	0.018
MW10S4116_003	0.51	-0.380	0.026
MW10S4116_004	0.51	-0.502	0.044

Table 4.2 Continued

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
2011_F5_47_3	0.50	-0.192	0.02
2011_F5_4_2	0.49	-0.178	0.016
OR76	0.48	-0.200	0.017
Grand mean = 0.576		R-squared = 0.0742	C.V. = 12.77%

*= Barley check, **= Wheat check, C.V.= Coefficient of Variation.

Table 4.3 shows the Eberhart-Russell stability estimates for spring silage heights. Lines such as ‘2011_F5_96_4’ and ‘OR76’ had high means, beta values close to one, and relatively low deviations from beta indicating they were stable across environments. Conversely, entries such as ‘2011_F5_36_2’ and ‘2011_F5_72_3’ had low means, beta values far from one, and high deviations from beta so would be considered to have low yield potential and low stability across environments.

Table 4.3 Eberhart-Russell stability analysis for spring silage height (cm) measurements in order from tallest to shortest taken at College Station, Comanche, and Dimmitt from 2016-2017.

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
MW09S4076_002	81.1	1.502	22.181
06OR_41	75.9	1.374	70.276
MW10S4120_008	75.6	0.863	103.453
MW10S4118_003	74.6	0.815	53.822
MW10S4116_003	73.7	0.658	94.282
OR103	73.3	1.176	41.201
OR76	73.2	1.195	7.076
2011_F5_96_2	72.2	1.099	49.119
2011_F5_96_4	72.1	0.923	7.556
MW10S4118_001	71.9	0.581	69.989
06OR_91	71.4	0.519	4.665
MW10S4116_004	71.1	0.653	107.588
OR813	71.1	0.859	4.340
MW09S4080_001	70.8	0.641	58.906
MW10S4122_005	70.8	0.917	82.455

Table 4.3 Continued

Name	**Mean**	**Regression Coefficient (Beta)**	**Deviation from Regression (S^2)**
08OR_44	70.5	1.284	6.306
OR108	70.5	1.279	11.383
08OR_30	69.1	0.591	2.726
MW10S4122_001	68.6	0.725	16.349
TAM 304	68.6	1.032	8.492
2011_F5_131_1	68.3	0.834	41.403
2011_F5_5_1	68.3	0.542	38.731
2011_Short_12	68.3	1.189	3.651
2011_Short_16	68.3	0.873	3.310
OKARS 474	67.9	1.142	3.864
2011_Short_11	67.6	0.934	7.802
08OR_73	67.2	1.224	3.451
2011_F5_32_1	67.2	0.538	35.571
MW10S4118_004	67.0	0.625	77.429
OKARS 452	66.8	1.560	0.652
2011_Short_13	66.7	1.095	3.932
06OR_43	66.5	1.307	93.570
2011_F5_109_1	66.5	0.973	12.888
2011_F5_120_3	66.4	1.050	10.732
2011_F5_9_2	66.4	0.986	8.933
2011_F5_4_2	66.2	0.727	71.973
PO71DH_104	66.2	1.901	13.745
OR101	65.6	1.242	11.331
08OR_81	65.2	1.421	1.409
2011_F5_47_3	64.8	0.932	3.856
2011_F5_91_2	64.6	1.204	2.496
2011_F5_91_1	64.5	0.782	28.916
PO71DH_87	64.5	1.138	28.244
OR91	64.3	1.060	4.384
07OR_21	63.8	1.002	3.697
Alba	63.8	0.676	21.945
2011_F5_121_1	63.5	1.032	8.492
2011_F5_23_1	63.5	0.932	3.856
2011_F5_59_1	63.5	0.728	18.361
2011_F5_64_1	63.5	0.728	18.361
PYT211_6	63.5	1.222	1.772
2011_F5_132_1	63.3	0.726	10.376
OR818	63.3	1.261	4.634
OKARS_242	63.2	0.932	7.634
2011_F5_76_1	63.2	0.836	17.824

Table 4.3 Continued

Name	**Mean**	**Regression Coefficient (Beta)**	**Deviation from Regression (S^2)**
07OR_8	63.0	1.124	5.759
2011_F5_121_5	63.0	1.310	9.500
OKARS 216	63.0	1.295	15.953
2011_F5_47_1	62.5	0.436	71.693
2011_F5_121_4	62.5	0.850	14.234
2011_F5_22_3	62.5	0.539	74.990
OR815	62.5	1.546	90.568
OBADV11_13	62.2	1.027	5.481
07OR_59	62.2	1.332	37.729
OBADV11_29	61.8	1.274	2.986
2011_F5_90_5	61.6	1.391	5.328
2011_Short_8	61.6	0.843	12.439
07OR_6	61.3	0.756	18.652
2011_F5_95_1	61.0	1.391	10.326
2011_F5_134_3	60.8	1.055	13.679
07OR_63	60.6	1.279	58.785
2011_F5_136_1	60.3	0.766	2.534
2011_F5_126_2	60.0	0.800	65.528
2011_F5_59_2	59.9	1.199	11.980
07OR_3	59.7	0.689	1.783
2011_F5_112_1	59.7	0.760	1.713
2011_F5_50_1	59.7	1.007	9.259
2011_F5_121_2	59.7	1.207	22.534
2011_F5_60_2	59.7	0.642	12.967
2011_F5_119_1	59.5	0.904	0.964
2011_F5_112_3	59.4	1.179	17.980
2011_F5_126_1	59.4	0.739	28.992
2011_F5_124_1	59.1	0.888	10.420
2011_F5_56_3	59.1	1.150	23.740
OR104	58.9	1.121	0.151
2011_F5_113_2	58.4	0.896	7.975
08OR_48	58.3	1.299	7.734
2011_F5_121_3	57.8	0.794	17.723
2011_F5_48_1	57.5	0.751	1.069
2011_F5_76_4	57.5	1.237	37.866
2011_F5_108_1	57.3	0.989	17.339
2011_F5_83_1	57.2	0.857	48.090
OR106	57.2	1.370	2.190
2011_F5_106_1	56.5	0.994	47.131
2011_F5_37_3	56.5	0.820	4.328

Table 4.3 Continued

Name	**Mean**	**Regression Coefficient (Beta)**	**Deviation from Regression (S^2)**
2011_F5_57_2	56.4	0.911	13.079
2011_F5_129_1	56.2	1.219	4.691
2011_F5_105_1	56.2	1.060	33.349
2011_F5_56_1	56.2	0.788	128.783
2011_F5_27_1	55.9	0.987	10.734
2011_F5_66_3	55.9	0.956	30.183
2011_F5_88_3	55.9	0.589	11.358
Maja	55.9	1.204	67.377
OKARS 248	55.6	1.674	2.049
08OR_53	54.9	1.328	6.643
OKARS_249	54.6	1.553	59.226
2011_F5_35_2	54.3	1.165	13.288
OBADV11_31	54.0	0.693	0.773
2011_F5_52_2	53.3	0.879	13.884
2011_F5_37_1	52.4	1.196	10.958
2011_F5_72_3	52.4	0.385	49.077
2011_F5_105_3	52.1	0.998	83.818
2011_F5_36_2	51.0	0.889	27.802
2011_F5_55_1	49.8	0.987	29.067
Grand mean = 62.915		R-squared = 0.9135	C.V. = 8.43%

*= Barley check, **= Wheat check, C.V.= Coefficient of Variation.

Levene's test for homogeneity of variance revealed heterogeneity of variance (P<0.03) for spring silage percent dry matter. In order to correct this, the data collected at Comanche were dropped from analysis and resulted in homogeneity of variance (P<0.95). After dropping the Comanche data values, Eberhart-Russell stability estimates were determined (Table 4.4). Barley lines 'MW10S4122_001' and 'MW10S4118_003' as well as the checks 'TAM 304' and 'Maja' had high means, beta values close to one, and relatively low deviations from beta. Barley lines 'OBADV11_29' and '2011_F5_56_1' had low means, beta values far from one, and relatively high deviations from beta.

Table 4.4 Eberhart-Russell stability analysis for spring silage percent dry matter in order from highest to lowest taken at College Station and Dimmitt from 2016-2017.

Name	**Mean**	**Regression Coefficient (Beta)**	**Deviation from Regression (S^2)**
MW10S4120_008	36.82	0.8652	43.076
MW09S4080_001	33.76	0.8486	9.693
MW10S4118_001	32.63	0.8069	15.691
MW10S4122_001	32.57	0.9118	0.632
MW10S4122_005	30.82	0.6595	18.006
TAM 304	30.76	1.3283	3.284
Maja	30.61	1.0203	1.291
MW10S4116_004	30.55	0.9429	1.768
MW10S4118_003	30.55	0.9642	3.718
06OR_91	30.19	1.2023	2.326
08OR_30	30.14	1.4222	8.776
2011_Short_11	30.09	1.4567	1.56
2011_Short_12	29.67	0.9569	10.206
2011_F5_32_1	29.43	1.4644	24.568
2011_F5_52_2	29.19	1.4706	3.381
07OR_6	29.10	0.7288	49.975
2011_Short_16	29.02	1.1696	1.028
OKARS 474	28.98	1.0454	4.291
2011_F5_9_2	28.79	1.2317	31.696
08OR_81	28.67	1.0701	2.866
OKARS 216	28.60	0.9522	2.215
OR818	28.57	1.2983	2.589
OKARS 452	28.56	0.9995	4.738
2011_F5_105_1	28.41	0.4986	125.549
OR76	28.29	1.0207	6.856
MW10S4118_004	28.27	1.0528	3.199
2011_F5_48_1	28.16	1.1651	2.065
2011_F5_5_1	28.07	1.2746	2.974
MW09S4076_002	28.06	1.0105	7.889
OKARS 248	27.93	1.105	0.151
OKARS_242	27.91	1.1683	15.798
OKARS_249	27.89	1.2719	13.223
2011_F5_47_1	27.88	1.1486	3.407
2011_F5_36_2	27.86	1.2544	5.738
08OR_73	27.76	0.6817	3.157
OR813	27.72	1.0968	5.163
2011_F5_47_3	27.64	1.3264	3.297
2011_F5_55_1	27.63	0.9128	1.996
07OR_8	27.58	1.2209	3.694

Table 4.4 Continued

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
2011_F5_96_4	27.55	1.2267	6.854
2011_F5_72_3	27.47	1.137	1.676
OR101	27.44	1.0363	2.641
PO71DH_104	27.28	1.0366	0.689
2011_F5_23_1	27.22	1.0356	0.704
2011_F5_66_3	27.19	1.1115	2.727
06OR_43	27.18	0.8596	1.359
OR106	27.18	1.1717	3.395
2011_F5_64_1	27.15	1.2691	3.548
2011_F5_109_1	27.07	0.6042	3.223
2011_F5_35_2	27.07	1.1579	3.439
2011_F5_126_2	27.05	0.8075	28.857
2011_F5_50_1	27.00	1.1334	3.467
2011_F5_112_1	26.86	0.6737	14.446
2011_Short_13	26.83	1.1461	2.902
07OR_21	26.76	0.9929	3.578
2011_F5_121_2	26.68	0.7648	1.547
PO71DH_87	26.67	0.7683	1.131
2011_F5_22_3	26.66	1.1301	3.302
PYT211_6	26.61	0.845	3.981
2011_F5_113_2	26.56	0.9609	2.916
07OR_3	26.52	1.031	2.832
OR103	26.52	0.7789	3.522
OR91	26.52	0.883	2.895
2011_F5_37_1	26.39	0.9321	0.016
06OR_41	26.34	1.1141	3.758
OR104	26.26	0.8866	3.567
2011_Short_8	26.24	0.9449	7.279
2011_F5_124_1	26.16	0.5345	3.719
2011_F5_56_1	26.15	0.8432	16.267
2011_F5_27_1	26.08	1.0156	1.768
08OR_53	26.06	0.9834	3.371
2011_F5_76_4	26.03	1.0748	3.556
2011_F5_37_3	25.96	1.0766	1.869
2011_F5_90_5	25.96	1.0744	1.2
OR108	25.90	1.2428	1.164
2011_F5_83_1	25.85	1.0282	3.707
OBADV11_29	25.83	0.8025	12.863
2011_F5_136_1	25.81	1.087	3.671
OBADV11_31	25.78	1.1811	3.621

Table 4.4 Continued

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
MW10S4116_003	25.76	0.759	3.674
2011_F5_4_2	25.70	0.9615	3.066
2011_F5_95_1	25.70	0.9226	1.331
OBADV11_13	25.68	0.854	3.409
2011_F5_126_1	25.63	1.1011	1.469
2011_F5_108_1	25.61	0.7995	3.462
08OR_48	25.57	0.8256	0.151
07OR_63	25.52	0.9641	2.487
2011_F5_56_3	25.46	0.9473	0.524
Alba	25.36	1.2017	3.665
2011_F5_60_2	25.32	0.9335	3.581
2011_F5_121_5	25.13	1.0285	0.021
2011_F5_57_2	25.08	1.0081	3.572
OR815	25.02	0.8485	2.683
2011_F5_96_2	24.92	0.9487	0.711
2011_F5_106_1	24.89	0.7994	1.919
08OR_44	24.88	0.8025	1.145
2011_F5_131_1	24.88	1.0177	3.187
2011_F5_132_1	24.88	0.9807	3.672
2011_F5_112_3	24.86	0.9985	2.831
2011_F5_91_1	24.85	0.9291	1.443
2011_F5_121_4	24.81	0.7583	2.902
2011_F5_59_2	24.78	1.0033	3.109
2011_F5_91_2	24.74	1.053	0.417
2011_F5_119_1	24.72	0.9011	6.575
2011_F5_129_1	24.67	0.8092	4.664
2011_F5_120_3	24.53	1.0145	0.361
2011_F5_105_3	24.46	0.8111	4.028
07OR_59	24.27	1.1283	3.568
2011_F5_134_3	24.16	0.8474	3.672
2011_F5_88_3	24.02	0.9261	1.246
2011_F5_76_1	23.83	0.867	2.89
2011_F5_59_1	23.75	1.0055	1.503
2011_F5_121_3	23.61	0.7794	0.96
2011_F5_121_1	23.53	1.0551	3.637

Grand mean = 27.014 R-squared = 0.9684 C.V. = 10.10%

*= Barley check, **= Wheat check, C.V.= Coefficient of Variation.

“Which wins where and which is best for what” bi-plots were created for spring silage dry matter yield. In Figure 4.3 (which is interpreted the same as Figure 4.1), entries 86, ‘OKARS 474’, and 33, ‘2011_F5_126_2’, were high yielding but a little unstable while entries 68, ‘2011_F5_9_2’, and 88, ‘MW09S4076_002’, were also high yielding and very stable across the four testing environments. On the other hand, entries 67, ‘2011_F5_88_3’, and 16, ‘2011_F5_105_1’, were the lowest yielding entries. In Figure 4.4 (which is interpreted the same as Figure 4.2), entry 81, ‘OKARS 216’, was the best performing barley line for the ‘DIM17’ environment and entries 89, ‘MW09S4080_001’, and 92, ‘MW10S4118_001’, were the best performing lines in the ‘CS16’ environment. Entries 68, ‘2011_F5_9_2’, 86, ‘OKARS 474’, and 33, ‘2011_F5_126_2’, were among the top yielding barley lines for the ‘COM17’ and ‘DIM16’ environments.

The Eberhart-Russell stability estimates for spring silage dry matter yields revealed that the barley lines ‘2011_F5_9_2’ and ‘MW10S4118_003’ had high means, beta values close to one, and low deviations from beta while entries such as ‘2011_F5_36_2’ and ‘2011_F5_37_3’ had low means, beta values far from one, and high deviations from beta (Table 4.5).

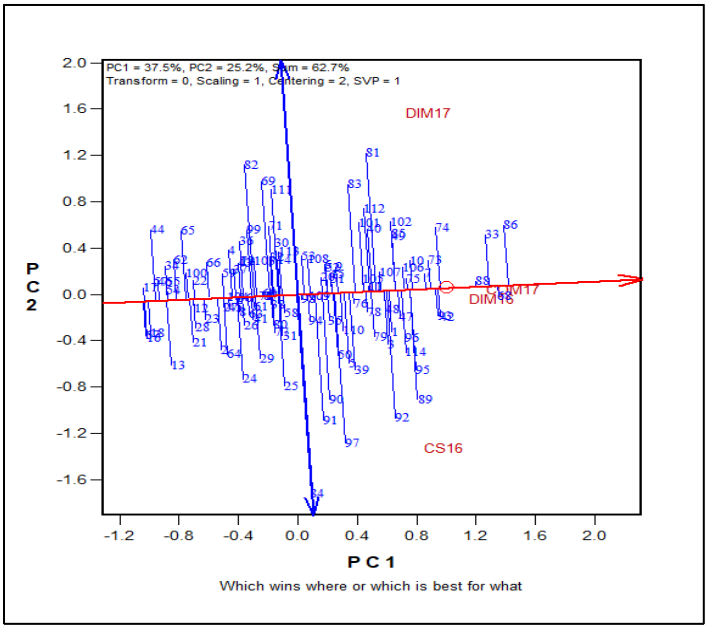

Figure 4.3 GGE bi-plot showing each entries mean silage dry matter yield and stability. BRD17= Brady 2017, CMN17= Comanche 2017, CS= College Station 2016, DIM17= Dimmitt 2017, MCG 16= McGregor 2016, MCG17= McGregor 2017.

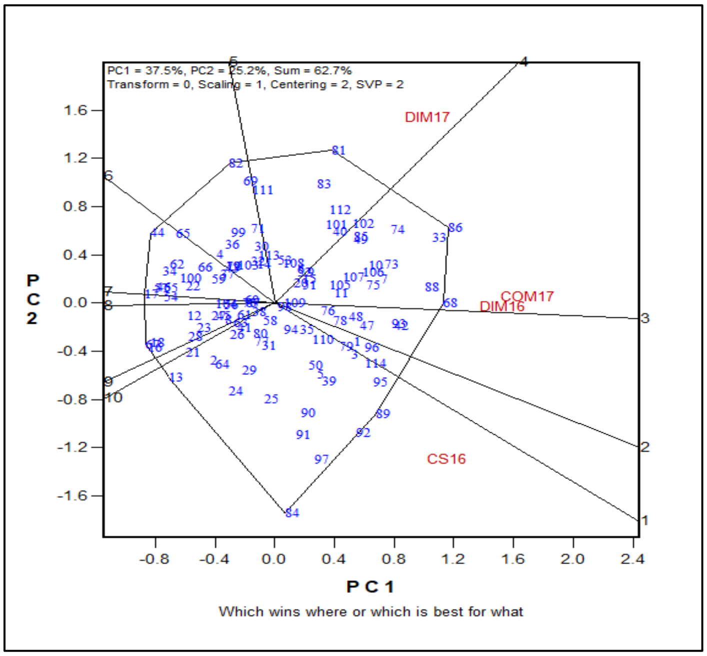

Figure 4.4 GGE bi-plot showing the best and poorest performing entries for silage dry matter yield at each test environment. Testing locations in red, entries in blue. BRD17= Brady 2017, CMN17= Comanche 2017, CS= College Station 2016, DIM17= Dimmitt 2017, MCG 16= McGregor 2016, MCG17= McGregor 2017.

Table 4.5 Eberhart-Russell stability analysis for spring silage dry matter yields in order from highest to lowest taken at College Station, Comanche, and Dimmitt from 2016-2017.

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
OKARS 474	7.1	1.5638	0.392
MW09S4076_002	6.9	1.4918	0.184
2011_F5_9_2	6.6	1.2149	0.275
2011_F5_96_2	6.5	1.3671	0.276
2011_F5_4_2	6.5	1.4505	0.786
MW10S4118_003	6.4	1.2482	0.127
2011_F5_96_4	6.4	1.2806	0.728
MW10S4118_001	6.3	1.1821	2.270
MW10S4120_008	6.3	1.1772	0.713
07OR_3	6.3	1.5434	1.942
2011_F5_47_3	6.3	1.4462	0.626
2011_F5_126_2	6.2	1.163	0.522
TAM 304	6.2	1.1735	0.223
2011_Short_16	6.1	1.362	0.014
06OR_41	6.1	1.2104	0.057
OR76	6.1	1.2867	0.474
2011_F5_23_1	6.1	1.5281	0.011
MW09S4080_001	6.1	1.0234	0.538
2011_F5_47_1	6.0	1.0976	0.185
2011_F5_32_1	6.0	0.9341	0.701
2011_Short_11	6.0	1.1969	0.561
OR103	6.0	1.2854	0.668
2011_F5_22_3	5.9	1.1463	0.328
08OR_81	5.9	1.4587	0.235
OKARS 248	5.9	1.4254	0.511
08OR_44	5.8	1.2705	0.227
2011_F5_48_1	5.8	1.2085	0.216
OKARS 216	5.8	1.2589	0.203
07OR_6	5.8	1.0561	0.018
07OR_59	5.8	1.4375	0.268
2011_Short_12	5.8	1.3707	0.858
06OR_91	5.8	0.9363	0.509
2011_F5_131_1	5.7	1.1654	0.296
MW10S4122_005	5.7	0.9974	1.394
MW10S4122_001	5.7	0.9187	0.584
07OR_8	5.7	1.2897	0.573
OR108	5.7	1.0822	0.769
OR91	5.7	1.2304	0.119
OKARS_242	5.7	1.2193	4.276

Table 4.5 Continued

Name	Mean	Regression Coefficient (Beta)	Deviation from Regression (S^2)
OR813	5.7	1.0195	0.687
2011_Short_8	5.6	0.9308	0.650
08OR_30	5.6	0.8173	0.530
OKARS 452	5.6	1.0518	0.095
PO71DH_87	5.6	1.0887	0.390
OBADV11_13	5.6	1.2655	0.503
OR818	5.6	1.2391	0.546
OR101	5.5	1.0502	0.376
PO71DH_104	5.5	1.3973	0.692
MW10S4116_004	5.5	0.9092	0.471
2011_Short_13	5.5	1.3054	0.036
MW10S4118_004	5.4	1.0563	0.639
OR815	5.4	1.2226	0.390
2011_F5_50_1	5.4	1.0582	0.691
2011_F5_91_2	5.4	1.2643	0.744
MW10S4116_003	5.3	0.8141	0.316
2011_F5_52_2	5.3	1.1486	0.567
2011_F5_91_1	5.3	1.1956	0.644
2011_F5_121_5	5.3	1.1219	0.636
2011_F5_5_1	5.3	0.6916	0.518
PYT211_6	5.3	1.1312	0.762
2011_F5_90_5	5.3	1.171	0.033
OR106	5.1	1.3652	0.211
2011_F5_109_1	5.1	0.8062	0.548
2011_F5_120_3	5.1	0.8391	0.456
2011_F5_27_1	5.1	1.1767	0.201
Alba	5.1	0.8322	0.259
OKARS_249	5.1	1.2262	0.024
08OR_73	5.0	0.9935	0.598
Maja	5.0	1.124	0.116
2011_F5_95_1	5.0	1.0375	0.675
2011_F5_119_1	5.0	0.8563	0.238
2011_F5_35_2	4.9	0.9778	0.533
2011_F5_121_1	4.9	0.8827	0.665
2011_F5_59_2	4.9	1.0458	0.709
08OR_48	4.9	1.2256	0.579
OR104	4.9	0.984	0.574
2011_F5_64_1	4.9	0.7868	0.447
2011_F5_60_2	4.9	0.8237	0.637
2011_F5_37_1	4.8	0.9928	0.763

Table 4.5 Continued

Name	**Mean**	**Regression Coefficient (Beta)**	**Deviation from Regression (S^2)**
OBADV11_29	4.8	0.9116	0.125
2011_F5_59_1	4.8	0.516	0.566
06OR_43	4.8	0.9513	0.628
07OR_21	4.7	0.8683	0.235
2011_F5_121_4	4.6	0.5592	0.589
OBADV11_31	4.6	0.9311	0.354
08OR_53	4.6	1.1087	0.145
07OR_63	4.6	0.7399	0.639
2011_F5_56_3	4.6	0.7577	0.552
2011_F5_132_1	4.6	0.583	1.646
2011_F5_136_1	4.6	0.5217	0.120
2011_F5_108_1	4.5	0.7143	0.003
2011_F5_134_3	4.5	0.778	0.218
2011_F5_76_1	4.5	0.5711	0.381
2011_F5_121_2	4.5	0.7328	0.581
2011_F5_112_3	4.5	0.8714	0.548
2011_F5_124_1	4.5	0.482	0.319
2011_F5_76_4	4.4	0.878	0.088
2011_F5_126_1	4.4	0.4797	0.925
2011_F5_129_1	4.4	0.9328	0.480
2011_F5_112_1	4.3	0.691	0.710
2011_F5_72_3	4.3	0.4028	0.166
2011_F5_121_3	4.2	0.6098	0.503
2011_F5_83_1	4.2	0.5911	0.494
2011_F5_113_2	4.2	0.5628	0.337
2011_F5_105_1	4.2	0.6007	0.531
2011_F5_57_2	4.1	0.765	0.270
2011_F5_66_3	4.1	0.6417	0.439
2011_F5_55_1	4.0	0.6462	0.059
2011_F5_106_1	4.0	0.5652	0.391
2011_F5_56_1	3.9	0.4915	0.694
2011_F5_37_3	3.9	0.4334	1.429
2011_F5_105_3	3.9	0.6153	0.092
2011_F5_36_2	3.7	0.4826	2.054
2011_F5_88_3	3.7	0.3876	0.064
Grand mean = 5.251		R-squared = 0.9669	C.V. = 23.76%

*= Barley check, **= Wheat check, C.V.= Coefficient of Variation.

Tables 4.6 and 4.7 show repeatability and heritability estimates for fall forage height and NDVI values, respectively. In these tables, mean values for each entry as well as the grand mean, coefficient of variation (C.V.), least significant differences (LSD), and repeatability estimates are shown for each environment. The overall heritability estimate for all locations is shown as well. Repeatability estimates ranged from 0.39-0.87 for fall forage height and from 0.09-0.65 for fall forage NDVI values across the six testing environments. Heritability estimates were 0.51 for fall forage height and 0.00 for fall forage NDVI values.

Table 4.6 Repeatability and heritability estimates for fall forage height (cm) taken at College Station, McGregor, Brady, Comanche, and Dimmitt from 2016-2017.

Name	2016 CS	2016 MCG	2017 MCG	2017 COM	2017 BRD	2017 DIM	Average
06OR_41	13.34	10.16	16.51	16.51	19.69	27.94	17.36
06OR_43	10.80	10.80	10.16	15.88	13.97	22.86	14.08
06OR_91	15.24	12.70	19.05	21.59	25.40	40.64	22.44
07OR_21	8.26	8.89	10.16	19.05	13.97	26.67	14.50
07OR_3	19.69	12.07	17.15	20.96	21.59	25.40	19.48
07OR_59	8.26	9.53	8.89	19.69	14.61	22.86	13.97
07OR_6	12.07	10.16	10.16	20.96	14.61	27.94	15.98
07OR_63	8.26	11.43	9.53	14.61	13.97	27.94	14.29
07OR_8	13.97	10.16	12.70	19.69	14.61	30.48	16.94
08OR_30	11.43	10.80	12.70	20.32	15.88	35.56	17.78
08OR_44	13.34	12.70	12.07	17.15	19.05	29.21	17.25
08OR_48	10.80	8.89	12.70	22.23	13.34	29.21	16.20
08OR_53	10.80	8.89	14.61	17.78	12.70	20.32	14.18
08OR_73	13.34	9.53	12.70	20.32	15.24	25.40	16.09
08OR_81	12.07	10.80	11.43	19.05	15.88	27.94	16.20
2011_F5_105_1	8.26	10.16	11.43	15.24	12.70	20.32	13.02
2011_F5_105_3	8.26	8.89	9.53	24.13	13.97	21.59	14.40
2011_F5_106_1	9.53	8.89	8.26	14.61	15.24	22.86	13.23
2011_F5_108_1	8.89	9.53	10.16	19.69	15.24	26.67	15.03
2011_F5_109_1	15.24	.	10.16	20.32	11.43	24.13	16.26
2011_F5_112_1	12.07	9.53	10.16	20.96	13.34	26.67	15.46
2011_F5_112_3	9.53	8.89	9.53	20.32	12.70	22.86	13.97
2011_F5_113_2	10.16	7.62	10.16	17.15	17.15	21.59	13.97
2011_F5_119_1	10.16	10.16	9.53	19.05	17.78	27.94	15.77

Table 4.6 Continued

Name	2016 CS	2016 MCG	2017 MCG	2017 COM	2017 BRD	2017 DIM	Average
2011_F5_120_3	11.43	9.53	8.89	18.42	16.51	25.40	15.03
2011_F5_121_1	10.16	9.53	11.43	24.13	13.97	25.40	15.77
2011_F5_121_2	9.53	11.43	12.07	19.69	19.05	27.94	16.62
2011_F5_121_3	12.07	10.80	12.07	19.69	17.15	22.86	15.77
2011_F5_121_4	12.07	9.53	10.16	17.78	13.97	25.40	14.82
2011_F5_121_5	8.89	11.43	12.07	19.05	15.24	29.21	15.98
2011_F5_124_1	12.07	10.80	12.70	19.69	14.61	27.94	16.30
2011_F5_126_1	9.53	9.53	11.43	18.42	14.61	25.40	14.82
2011_F5_126_2	7.62	9.53	12.07	19.69	15.24	24.13	14.71
2011_F5_129_1	7.62	7.62	11.43	15.88	13.34	26.67	13.76
2011_F5_131_1	12.07	13.34	13.34	15.24	18.42	26.67	16.51
2011_F5_132_1	12.07	9.53	12.70	20.96	17.78	27.94	16.83
2011_F5_134_3	9.53	9.53	10.80	17.15	16.51	24.13	14.61
2011_F5_136_1	12.07	10.80	13.97	20.96	13.97	29.21	16.83
2011_F5_22_3	20.32	14.61	22.23	20.96	23.50	25.40	21.17
2011_F5_23_1	16.51	15.88	21.59	15.88	22.86	29.21	20.32
2011_F5_27_1	8.89	10.80	13.97	21.59	15.88	29.21	16.72
2011_F5_32_1	20.96	14.61	19.05	22.23	23.50	29.21	21.59
2011_F5_35_2	10.80	8.26	8.26	17.78	13.34	26.67	14.19
2011_F5_36_2	10.16	8.89	10.80	19.69	12.07	27.94	14.93
2011_F5_37_1	9.53	8.26	9.53	15.88	12.07	22.86	13.02
2011_F5_37_3	12.07	9.53	10.16	17.15	15.88	22.86	14.61
2011_F5_4_2	20.32	15.88	18.42	20.96	21.59	29.21	21.06
2011_F5_47_1	20.32	19.69	22.86	26.67	22.23	34.29	24.34
2011_F5_47_3	13.97	19.05	19.05	18.42	22.23	26.67	19.90
2011_F5_48_1	12.07	10.16	13.34	21.59	16.51	27.94	16.94
2011_F5_5_1	19.69	14.61	16.51	24.13	22.23	27.94	20.85
2011_F5_50_1	12.07	10.80	12.70	22.86	16.51	26.67	16.94
2011_F5_52_2	13.34	10.16	10.80	21.59	12.70	22.86	15.24
2011_F5_55_1	7.62	10.16	13.34	17.15	13.34	24.13	14.29
2011_F5_56_1	8.89	11.43	10.16	20.96	15.88	26.67	15.67
2011_F5_56_3	9.53	8.89	10.16	18.42	13.97	30.48	15.24
2011_F5_57_2	10.16	10.80	10.16	22.23	13.97	25.40	15.45
2011_F5_59_1	9.53	9.53	8.26	13.34	13.34	21.59	12.60
2011_F5_59_2	10.16	10.16	10.16	18.42	16.51	26.67	15.35
2011_F5_60_2	9.53	9.53	8.26	14.61	15.24	26.67	13.97
2011_F5_64_1	12.07	12.70	13.34	23.50	19.05	31.75	18.74
2011_F5_66_3	10.80	9.53	12.07	15.24	14.61	24.13	14.40
2011_F5_72_3	10.16	8.26	8.26	15.24	14.61	24.13	13.44
2011_F5_76_1	10.80	8.26	8.89	20.96	12.07	25.40	14.40

Table 4.6 Continued

Name	2016 CS	2016 MCG	2017 MCG	2017 COM	2017 BRD	2017 DIM	Average
2011_F5_76_4	8.26	7.62	10.16	22.23	14.61	25.40	14.71
2011_F5_83_1	10.16	10.16	13.97	20.96	15.24	26.67	16.19
2011_F5_88_3	12.07	10.16	11.43	22.23	14.61	25.40	15.98
2011_F5_9_2	12.70	10.80	11.43	20.32	17.15	33.02	17.57
2011_F5_90_5	10.16	10.80	11.43	21.59	14.61	22.86	15.24
2011_F5_91_1	11.43	8.89	9.53	18.42	15.88	19.05	13.87
2011_F5_91_2	8.89	10.16	10.16	16.51	13.34	27.94	14.50
2011_F5_95_1	9.53	10.16	10.80	19.05	15.88	22.86	14.71
2011_F5_96_2	13.97	11.43	15.24	20.96	18.42	26.67	17.78
2011_F5_96_4	15.24	10.80	17.15	22.23	18.42	29.21	18.84
2011_Short_11	13.34	10.16	11.43	19.05	19.69	24.13	16.30
2011_Short_12	10.16	8.89	11.43	15.24	21.59	29.21	16.09
2011_Short_13	10.16	8.89	12.70	13.34	21.59	22.86	14.92
2011_Short_16	10.80	9.53	11.43	17.15	17.78	25.40	15.35
2011_Short_8	12.07	10.16	10.80	19.05	13.97	19.05	14.18
Alba*	13.97	10.16	8.89	19.05	15.88	26.67	15.77
OKARS 216	8.26	8.26	10.16	14.61	13.34	34.29	14.82
OKARS_249	7.62	8.89	8.89	12.70	10.16	24.13	12.07
OKARS 248	8.26	8.26	8.89	14.61	11.43	25.40	12.81
OKARS_242	10.16	8.89	10.16	15.24	12.07	29.21	14.29
OKARS 452	8.26	8.26	10.16	11.43	12.70	25.40	12.70
OKARS 474	9.53	10.80	12.07	13.97	15.24	26.67	14.71
Maja*	10.80	7.62	10.16	20.96	14.61	21.59	14.29
MW09S4076_002	8.26	7.62	9.53	15.88	12.07	31.75	14.19
MW09S4080_001	19.05	11.43	21.59	22.23	24.13	41.91	23.39
MW10S4116_003	19.05	13.97	9.53	19.05	17.78	25.40	17.46
MW10S4116_004	27.94	23.50	8.26	24.13	15.88	38.10	22.97
MW10S4118_001	34.29	20.96	10.16	22.86	22.86	36.83	24.66
MW10S4118_003	18.42	17.78	17.78	17.15	26.67	38.10	22.65
MW10S4118_004	22.23	22.86	14.61	22.23	20.32	24.13	21.06
MW10S4120_008	20.32	22.86	21.59	24.77	26.67	35.56	25.30
MW10S4122_001	20.96	22.86	15.88	15.24	18.42	36.83	21.70
MW10S4122_005	25.40	21.59	13.34	23.50	21.59	39.37	24.13
OBADV11_13	12.07	12.70	15.88	13.97	18.42	25.40	16.41
OBADV11_29	8.26	8.26	12.07	15.88	16.51	26.67	14.61
OBADV11_31	7.62	8.26	10.80	15.88	13.34	26.67	13.76
OR101	11.43	10.16	12.07	22.86	15.88	30.48	17.15
OR103	15.24	16.51	12.07	20.96	19.05	24.13	17.99
OR104	12.70	9.53	12.07	22.23	13.97	25.40	15.98
OR106	10.16	9.53	10.16	20.32	13.34	22.86	14.40

Table 4.6 Continued

Name	2016 CS	2016 MCG	2017 MCG	2017 COM	2017 BRD	2017 DIM	Average
OR108	13.34	10.80	11.43	18.42	15.88	27.94	16.30
OR76	10.16	0.00	19.05	18.42	22.23	34.29	17.36
OR813	11.43	11.43	19.05	21.59	22.86	34.29	20.11
OR815	11.43	8.89	14.61	17.15	16.51	21.59	15.03
OR818	12.07	9.53	11.43	21.59	17.78	30.48	17.15
OR91	12.07	10.16	13.97	21.59	15.88	26.67	16.72
PO71DH_104	9.53	7.62	9.53	14.61	13.97	26.67	13.66
PO71DH_87	6.99	7.62	10.80	19.69	17.78	27.94	15.14
PYT211_6	12.07	9.53	15.88	15.24	19.69	27.94	16.73
TAM 304**	8.89	8.89	8.89	13.97	21.59	34.29	16.09
GRAND MEAN	12.26	11.06	12.34	18.98	16.57	27.32	16.42
CV (%)	18.05	11.99	11.78	15.18	11.76	13.74	-
LSD (0.05)	4.38	2.63	2.88	5.71	3.86	7.44	-
Repeatability	0.78	0.87	0.83	0.39	0.74	0.48	-
Heritability	-	-	-	-	-	-	0.51

CS= College Station, MCG= McGregor, COM= Comanche, BRD= Brady, DIM= Dimmitt, *= Barley check, **= Wheat check, C.V.= Coefficient of Variation, LSD= Least significant difference.

Table 4.7 Repeatability and heritability estimates for fall forage NDVI values taken at College Station, McGregor, Brady, Comanche, and Dimmitt from 2016-2017.

Name	2016 CS	2016 MCG	2017 MCG	2017 COM	2017 BRD	2017 DIM	Average
06OR_41	0.58	0.64	0.64	0.60	0.38	0.79	0.61
06OR_43	0.44	0.61	0.69	0.52	0.35	0.69	0.55
06OR_91	0.54	0.66	0.65	0.63	0.36	0.70	0.59
07OR_21	0.44	0.55	0.64	0.66	0.37	0.75	0.57
07OR_3	0.53	0.58	0.55	0.53	0.32	0.63	0.52
07OR_59	0.47	0.66	0.60	0.72	0.44	0.72	0.60
07OR_6	0.52	0.57	0.62	0.56	0.34	0.70	0.55
07OR_63	0.45	0.62	0.64	0.56	0.43	0.76	0.58
07OR_8	0.52	0.67	0.65	0.47	0.36	0.70	0.56
08OR_30	0.60	0.61	0.72	0.69	0.46	0.71	0.63
08OR_44	0.47	0.59	0.40	0.58	0.40	0.72	0.53
08OR_48	0.46	0.53	0.67	0.68	0.37	0.77	0.58
08OR_53	0.53	0.57	0.78	0.61	0.41	0.71	0.60
08OR_73	0.50	0.61	0.59	0.57	0.30	0.73	0.55
08OR_81	0.47	0.65	0.60	0.52	0.34	0.75	0.56
2011_F5_105_1	0.48	0.64	0.67	0.52	0.38	0.73	0.57
2011_F5_105_3	0.40	0.62	0.64	0.77	0.34	0.75	0.59

Table 4.7 Continued

Name	2016 CS	2016 MCG	2017 MCG	2017 COM	2017 BRD	2017 DIM	Average
2011_F5_106_1	0.44	0.67	0.61	0.77	0.39	0.72	0.60
2011_F5_108_1	0.45	0.57	0.66	0.74	0.40	0.72	0.59
2011_F5_109_1	0.60	.	0.63	0.73	0.34	0.74	0.61
2011_F5_112_1	0.50	0.61	0.62	0.68	0.34	0.75	0.58
2011_F5_112_3	0.46	0.63	0.60	0.75	0.40	0.75	0.60
2011_F5_113_2	0.54	0.57	0.65	0.60	0.35	0.74	0.58
2011_F5_119_1	0.58	0.60	0.63	0.75	0.38	0.73	0.61
2011_F5_120_3	0.55	0.62	0.63	0.67	0.41	0.77	0.61
2011_F5_121_1	0.56	0.60	0.65	0.77	0.34	0.75	0.61
2011_F5_121_2	0.48	0.63	0.74	0.69	0.46	0.75	0.63
2011_F5_121_3	0.47	0.65	0.67	0.72	0.38	0.75	0.61
2011_F5_121_4	0.50	0.62	0.69	0.70	0.37	0.77	0.61
2011_F5_121_5	0.41	0.70	0.70	0.68	0.41	0.75	0.61
2011_F5_124_1	0.46	0.61	0.67	0.57	0.37	0.75	0.57
2011_F5_126_1	0.50	0.64	0.68	0.59	0.36	0.72	0.58
2011_F5_126_2	0.48	0.59	0.72	0.80	0.37	0.76	0.62
2011_F5_129_1	0.39	0.58	0.65	0.56	0.38	0.76	0.55
2011_F5_131_1	0.48	0.62	0.61	0.62	0.35	0.78	0.58
2011_F5_132_1	0.59	0.54	0.63	0.62	0.40	0.75	0.59
2011_F5_134_3	0.52	0.59	0.62	0.55	0.36	0.74	0.56
2011_F5_136_1	0.56	0.60	0.71	0.66	0.37	0.77	0.61
2011_F5_22_3	0.52	0.54	0.61	0.47	0.28	0.65	0.51
2011_F5_23_1	0.47	0.61	0.72	0.41	0.36	0.76	0.56
2011_F5_27_1	0.45	0.60	0.70	0.64	0.39	0.72	0.58
2011_F5_32_1	0.56	0.59	0.69	0.65	0.35	0.72	0.59
2011_F5_35_2	0.50	0.53	0.69	0.60	0.41	0.72	0.58
2011_F5_36_2	0.38	0.56	0.70	0.71	0.42	0.78	0.59
2011_F5_37_1	0.40	0.52	0.65	0.59	0.40	0.74	0.55
2011_F5_37_3	0.53	0.54	0.65	0.63	0.44	0.75	0.59
2011_F5_4_2	0.46	0.54	0.51	0.50	0.28	0.66	0.49
2011_F5_47_1	0.50	0.63	0.64	0.71	0.30	0.70	0.58
2011_F5_47_3	0.38	0.58	0.60	0.47	0.32	0.67	0.50
2011_F5_48_1	0.55	0.52	0.61	0.68	0.38	0.66	0.57
2011_F5_5_1	0.55	0.58	0.58	0.57	0.36	0.75	0.57
2011_F5_50_1	0.48	0.61	0.61	0.65	0.35	0.76	0.58
2011_F5_52_2	0.54	0.53	0.63	0.72	0.35	0.71	0.58
2011_F5_55_1	0.38	0.65	0.69	0.57	0.36	0.78	0.57
2011_F5_56_1	0.44	0.71	0.68	0.70	0.42	0.74	0.62
2011_F5_56_3	0.47	0.55	0.70	0.54	0.30	0.75	0.55
2011_F5_57_2	0.48	0.64	0.64	0.69	0.33	0.77	0.59

Table 4.7 Continued

Name	2016 CS	2016 MCG	2017 MCG	2017 COM	2017 BRD	2017 DIM	Average
2011_F5_59_1	0.66	0.59	0.64	0.55	0.41	0.74	0.60
2011_F5_59_2	0.47	0.65	0.68	0.71	0.44	0.78	0.62
2011_F5_60_2	0.54	0.59	0.59	0.54	0.43	0.76	0.58
2011_F5_64_1	0.59	0.62	0.62	0.70	0.38	0.76	0.61
2011_F5_66_3	0.49	0.58	0.65	0.45	0.44	0.75	0.56
2011_F5_72_3	0.59	0.51	0.68	0.57	0.47	0.73	0.59
2011_F5_76_1	0.56	0.51	0.62	0.67	0.41	0.73	0.58
2011_F5_76_4	0.36	0.56	0.69	0.79	0.40	0.75	0.59
2011_F5_83_1	0.45	0.54	0.73	0.64	0.40	0.79	0.59
2011_F5_88_3	0.52	0.62	0.64	0.73	0.44	0.78	0.62
2011_F5_9_2	0.61	0.68	0.67	0.61	0.40	0.72	0.62
2011_F5_90_5	0.46	0.60	0.68	0.65	0.37	0.73	0.58
2011_F5_91_1	0.62	0.59	0.63	0.64	0.39	0.75	0.60
2011_F5_91_2	0.48	0.66	0.63	0.62	0.43	0.77	0.60
2011_F5_95_1	0.44	0.55	0.63	0.54	0.42	0.77	0.56
2011_F5_96_2	0.56	0.58	0.64	0.59	0.32	0.76	0.58
2011_F5_96_4	0.50	0.55	0.64	0.63	0.36	0.75	0.57
2011_Short_11	0.48	0.55	0.61	0.65	0.35	0.71	0.56
2011_Short_12	0.47	0.55	0.63	0.57	0.35	0.68	0.54
2011_Short_13	0.50	0.62	0.66	0.70	0.38	0.71	0.60
2011_Short_16	0.52	0.56	0.63	0.64	0.31	0.71	0.56
2011_Short_8	0.55	0.54	0.61	0.58	0.42	0.75	0.58
Alba*	0.57	0.65	0.58	0.57	0.42	0.76	0.59
OKARS 216	0.47	0.59	0.67	0.66	0.47	0.74	0.60
OKARS_249	0.39	0.62	0.69	0.47	0.46	0.76	0.57
OKARS 248	0.41	0.59	0.73	0.65	0.43	0.73	0.59
OKARS_242	0.48	0.69	0.73	0.66	0.38	0.71	0.61
OKARS 452	0.50	0.62	0.72	0.41	0.42	0.74	0.57
OKARS 474	0.52	0.71	0.70	0.66	0.34	0.74	0.61
Maja*	0.50	0.51	0.59	0.66	0.46	0.71	0.57
MW09S4076_002	0.55	0.59	0.78	0.72	0.41	0.74	0.63
MW09S4080_001	0.48	0.58	0.70	0.66	0.29	0.75	0.58
MW10S4116_003	0.55	0.63	0.37	0.54	0.27	0.70	0.51
MW10S4116_004	0.60	0.66	0.25	0.64	0.24	0.66	0.51
MW10S4118_001	0.60	0.61	0.49	0.59	0.32	0.66	0.55
MW10S4118_003	0.50	0.61	0.63	0.63	0.35	0.73	0.58
MW10S4118_004	0.45	0.67	0.64	0.68	0.34	0.72	0.58
MW10S4120_008	0.50	0.60	0.65	0.74	0.35	0.70	0.59
MW10S4122_001	0.46	0.61	0.59	0.46	0.33	0.68	0.52
MW10S4122_005	0.53	0.60	0.59	0.63	0.29	0.71	0.56

Table 4.7 Continued

Name	2016 CS	2016 MCG	2017 MCG	2017 COM	2017 BRD	2017 DIM	Average
OBADV11_13	0.40	0.60	0.63	0.41	0.35	0.69	0.51
OBADV11_29	0.41	0.59	0.68	0.62	0.44	0.77	0.59
OBADV11_31	0.41	0.51	0.69	0.55	0.44	0.70	0.55
OR101	0.51	0.57	0.63	0.68	0.35	0.75	0.58
OR103	0.48	0.65	0.44	0.66	0.29	0.70	0.54
OR104	0.53	0.56	0.63	0.64	0.39	0.69	0.57
OR106	0.39	0.60	0.62	0.54	0.39	0.67	0.54
OR108	0.59	0.62	0.58	0.62	0.40	0.75	0.59
OR76	0.49	0.00	0.66	0.60	0.37	0.74	0.48
OR813	0.47	0.55	0.75	0.66	0.36	0.73	0.59
OR815	0.51	0.59	0.67	0.56	0.29	0.72	0.56
OR818	0.45	0.55	0.64	0.61	0.44	0.66	0.56
OR91	0.54	0.53	0.69	0.63	0.35	0.66	0.57
PO71DH_104	0.36	0.51	0.65	0.49	0.44	0.71	0.53
PO71DH_87	0.47	0.51	0.69	0.72	0.42	0.72	0.59
PYT211_6	0.44	0.57	0.63	0.41	0.34	0.74	0.52
TAM 304**	0.51	0.55	0.69	0.52	0.31	0.61	0.53
GRAND MEAN	0.49	0.59	0.64	0.62	0.37	0.73	0.57
CV (%)	16.18	10.26	7.38	18.09	13.01	4.85	-
LSD (0.05)	0.16	0.12	0.09	0.22	0.10	0.07	-
Repeatability	0.09	0.09	0.65	0.10	0.33	0.32	-
Heritability	-	-	-	-	-	-	0.00

CS= College Station, MCG= McGregor, COM= Comanche, BRD= Brady, DIM= Dimmitt, *= Barley check, **= Wheat check, C.V.= Coefficient of Variation, LSD= Least significant difference.

Tables 4.8, 4.9, and 4.10 show repeatability estimates for spring silage height (cm), percent dry matter, and dry matter yield (t ha^{-1}), respectively. In these tables, mean values for each entry as well as the grand mean, coefficient of variation (C.V.), least significant differences (LSD), and repeatability estimates are shown for each environment. Additionally, the overall heritability estimate across environments is displayed as well. Repeatability estimates ranged from 0.49-0.75 for silage height, 0.36-0.57 for silage percent dry matter, and 0.00-0.45 for dry matter yield. Heritability estimates were 0.52 for spring silage height, 0.29 for percent dry matter, and 0.16 for dry matter yield. The heritability estimate for percent dry matter did not include the data obtained from Comanche.

Table 4.8 Repeatability and heritability estimates for spring silage height (cm) taken at College Station, Comanche, and Dimmitt from 2016-2017.

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
06OR_41	67.31	109.22	63.50	63.50	75.88
06OR_43	55.88	97.79	63.50	48.90	66.52
06OR_91	67.31	83.82	68.58	66.04	71.44
07OR_21	48.26	85.09	58.42	63.50	63.82
07OR_3	54.61	76.20	54.61	53.34	59.69
07OR_59	39.37	90.17	63.50	55.88	62.23
07OR_6	45.72	76.20	60.96	62.23	61.28
07OR_63	35.56	86.36	60.96	59.69	60.64
07OR_8	46.99	87.63	62.23	55.25	63.03
08OR_30	62.23	82.55	68.58	62.87	69.06
08OR_44	58.42	100.33	60.96	62.23	70.49
08OR_48	43.18	87.63	52.07	50.17	58.26
08OR_53	35.56	83.82	53.34	46.99	54.93
08OR_73	54.61	95.25	58.42	60.33	67.15
08OR_81	45.72	96.52	62.23	56.52	65.25
2011_F5_105_1	35.56	77.47	54.61	57.15	56.20
2011_F5_105_3	29.21	71.12	54.61	53.34	52.07
2011_F5_106_1	36.83	76.20	52.07	60.96	56.52
2011_F5_108_1	39.37	77.47	53.34	59.06	57.31
2011_F5_109_1	55.88	88.90	64.77	56.52	66.52
2011_F5_112_1	49.53	76.20	52.07	60.96	59.69
2011_F5_112_3	39.37	83.82	53.34	60.96	59.37
2011_F5_113_2	44.45	77.47	54.61	57.15	58.42
2011_F5_119_1	45.72	78.74	53.34	60.33	59.53
2011_F5_120_3	54.61	90.17	59.69	60.96	66.36
2011_F5_121_1	54.61	87.63	53.34	58.42	63.50
2011_F5_121_2	40.64	85.09	50.80	62.23	59.69
2011_F5_121_3	41.91	73.66	58.42	57.15	57.79
2011_F5_121_4	55.88	82.55	52.07	59.69	62.55
2011_F5_121_5	44.45	91.44	55.88	60.33	63.03
2011_F5_124_1	43.18	77.47	59.69	55.88	59.06
2011_F5_126_1	43.18	73.66	59.69	60.96	59.37
2011_F5_126_2	40.64	74.93	62.23	62.23	60.01
2011_F5_129_1	38.10	82.55	53.34	50.80	56.20

Table 4.8 Continued

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
2011_F5_131_1	64.77	88.90	57.15	62.23	68.26
2011_F5_132_1	55.88	80.01	58.42	59.06	63.34
2011_F5_134_3	41.91	82.55	59.69	59.06	60.80
2011_F5_136_1	46.99	76.20	58.42	59.69	60.33
2011_F5_22_3	64.77	77.47	55.88	52.07	62.55
2011_F5_23_1	54.61	85.09	55.88	58.42	63.50
2011_F5_27_1	38.10	76.20	54.61	54.61	55.88
2011_F5_32_1	67.31	81.28	59.69	60.33	67.15
2011_F5_35_2	35.56	78.74	46.99	55.88	54.29
2011_F5_36_2	33.02	68.58	49.53	52.71	50.96
2011_F5_37_1	36.83	78.74	44.45	49.53	52.39
2011_F5_37_3	43.18	73.66	50.80	58.42	56.52
2011_F5_4_2	66.04	85.09	54.61	59.06	66.20
2011_F5_47_1	66.04	74.93	52.07	57.15	62.55
2011_F5_47_3	55.88	86.36	57.15	59.69	64.77
2011_F5_48_1	50.80	74.93	49.53	54.61	57.47
2011_F5_5_1	68.58	82.55	60.96	60.96	68.26
2011_F5_50_1	44.45	81.28	55.88	57.15	59.69
2011_F5_52_2	36.83	71.12	50.80	54.61	53.34
2011_F5_55_1	31.75	69.85	44.45	53.34	49.85
2011_F5_56_1	34.29	69.85	57.15	63.50	56.20
2011_F5_56_3	38.10	82.55	55.88	59.69	59.06
2011_F5_57_2	39.37	74.93	55.88	55.25	56.36
2011_F5_59_1	59.69	81.28	54.61	58.42	63.50
2011_F5_59_2	44.45	86.36	52.07	56.52	59.85
2011_F5_60_2	50.80	73.66	55.88	58.42	59.69
2011_F5_64_1	59.69	81.28	54.61	58.42	63.50
2011_F5_66_3	36.83	74.93	54.61	57.15	55.88
2011_F5_72_3	39.37	58.42	55.88	55.88	52.39
2011_F5_76_1	55.88	82.55	52.07	62.23	63.18
2011_F5_76_4	34.29	82.55	54.61	58.42	57.47
2011_F5_83_1	38.10	73.66	58.42	58.42	57.15
2011_F5_88_3	43.18	67.31	55.88	57.15	55.88
2011_F5_9_2	55.88	88.90	59.69	60.96	66.36
2011_F5_90_5	40.64	91.44	55.88	58.42	61.60
2011_F5_91_1	60.96	83.82	55.88	57.15	64.45
2011_F5_91_2	45.72	90.17	59.69	62.87	64.61
2011_F5_95_1	38.10	90.17	55.88	59.69	60.96
2011_F5_96_2	66.04	99.06	60.96	62.87	72.23
2011_F5_96_4	64.77	93.98	64.77	64.77	72.07

Table 4.8 Continued

Name	**2016 CS**	**2017 COM**	**2016 DIM**	**2017 DIM**	**Average**
2011_Short_11	57.15	88.90	63.50	60.96	67.63
2011_Short_12	54.61	95.25	63.50	59.69	68.26
2011_Short_13	54.61	91.44	57.15	63.50	66.68
2011_Short_16	60.96	88.90	62.23	60.96	68.26
2011_Short_8	53.34	81.28	59.69	52.07	61.60
Alba*	59.69	80.01	53.34	62.23	63.82
OKARS 216	41.91	90.17	55.88	64.14	63.03
OKARS_249	26.67	86.36	48.26	57.15	54.61
OKARS 248	30.48	91.44	46.99	53.34	55.56
OKARS_242	50.80	83.82	60.96	57.15	63.18
OKARS 452	43.18	100.33	62.23	61.60	66.84
OKARS 474	55.88	93.98	58.42	63.50	67.95
Maja*	31.75	80.01	58.42	53.34	55.88
MW09S4076_002	64.77	115.57	76.20	67.95	81.12
MW09S4080_001	71.12	87.63	60.96	63.50	70.80
MW10S4116_003	74.93	91.44	67.31	60.96	73.66
MW10S4116_004	73.66	88.90	58.42	63.50	71.12
MW10S4118_001	73.66	87.63	62.23	64.14	71.92
MW10S4118_003	72.39	95.25	64.77	66.04	74.61
MW10S4118_004	68.58	83.82	57.15	58.42	66.99
MW10S4120_008	74.93	97.79	60.96	68.58	75.57
MW10S4122_001	64.77	86.36	60.96	62.23	68.58
MW10S4122_005	68.58	93.98	57.15	63.50	70.80
OBADV11_13	53.34	86.36	54.61	54.61	62.23
OBADV11_29	41.91	88.90	57.15	59.06	61.76
OBADV11_31	43.18	68.58	48.26	55.88	53.98
OR101	48.26	92.71	60.96	60.33	65.57
OR103	64.77	101.60	66.04	60.96	73.34
OR104	40.64	82.55	55.88	56.52	58.90
OR106	39.37	87.63	53.34	48.26	57.15
OR108	54.61	99.06	64.77	63.50	70.49
OR76	59.69	100.33	67.31	65.41	73.19
OR813	59.69	90.17	69.85	64.77	71.12
OR815	33.02	93.98	64.77	58.42	62.55
OR818	46.99	91.44	60.96	53.98	63.34
OR91	49.53	87.63	63.50	56.52	64.30
PO71DH_104	36.83	106.68	57.15	64.14	66.20
PO71DH_87	43.18	87.63	63.50	63.50	64.45
PYT211_6	50.80	91.44	53.34	58.42	63.50
TAM 304**	59.69	92.71	58.42	63.50	68.58

Table 4.8 Continued

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
GRAND MEAN	49.98	85.05	57.66	58.98	62.92
CV (%)	12.93	7.22	6.69	5.91	-
LSD (0.05)	12.80	12.17	7.65	6.90	-
Repeatability	0.75	0.64	0.60	0.49	-
Heritability	-	-	-	-	0.52

CS= College Station, COM= Comanche, DIM= Dimmitt, *= Barley check, **= Wheat check, C.V.= Coefficient of Variation, LSD= Least significant difference.

Table 4.9 Repeatability and heritability estimates for spring silage percent dry matter taken at College Station, Comanche, and Dimmitt from 2016-2017.

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
06OR_41	19.65	34.92	19.79	39.57	28.48
06OR_43	24.81	30.51	19.83	36.91	28.02
06OR_91	24.33	39.68	22.01	44.24	32.57
07OR_21	22.95	34.94	19.15	38.18	28.81
07OR_3	20.31	42.92	20.48	38.77	30.62
07OR_59	19.32	33.63	16.14	37.36	26.61
07OR_6	20.49	41.32	28.31	38.49	32.15
07OR_63	22.39	30.62	17.66	36.51	26.80
07OR_8	22.66	33.93	18.41	41.66	29.17
08OR_30	21.57	39.10	21.81	47.04	32.38
08OR_44	19.88	34.25	20.31	34.44	27.22
08OR_48	23.61	37.32	18.25	34.86	28.51
08OR_53	24.04	41.29	17.08	37.07	29.87
08OR_73	22.94	32.27	24.35	35.98	28.89
08OR_81	24.96	36.27	20.14	40.91	30.57
2011_F5_105_1	35.04	37.62	17.53	32.66	30.71
2011_F5_105_3	23.24	42.91	16.68	33.46	29.07
2011_F5_106_1	22.62	37.16	18.11	33.95	27.96
2011_F5_108_1	21.92	37.80	19.99	34.91	28.66
2011_F5_109_1	26.59	37.34	20.92	33.70	29.64
2011_F5_112_1	27.34	40.14	19.17	34.08	30.18
2011_F5_112_3	21.46	37.49	16.85	36.27	28.02
2011_F5_113_2	21.91	35.47	19.99	37.78	28.79
2011_F5_119_1	23.45	35.24	16.00	34.70	27.35
2011_F5_120_3	18.94	34.91	18.15	36.49	27.12
2011_F5_121_1	18.96	35.00	15.88	35.76	26.40
2011_F5_121_2	24.65	35.74	20.07	35.32	28.95

Table 4.9 Continued

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
2011_F5_121_3	22.05	37.87	16.46	32.33	27.18
2011_F5_121_4	20.99	36.98	19.75	33.69	27.85
2011_F5_121_5	19.42	35.63	18.71	37.27	27.76
2011_F5_124_1	23.96	34.86	22.18	32.33	28.33
2011_F5_126_1	19.94	35.88	18.40	38.55	28.19
2011_F5_126_2	19.36	59.25	24.66	37.14	35.10
2011_F5_129_1	23.54	39.03	16.83	33.63	28.26
2011_F5_131_1	20.12	37.94	17.78	36.73	28.14
2011_F5_132_1	21.00	36.66	17.46	36.18	27.83
2011_F5_134_3	20.83	36.07	17.73	33.92	27.14
2011_F5_136_1	21.16	39.47	17.88	38.40	29.23
2011_F5_22_3	22.49	42.04	17.86	39.63	30.51
2011_F5_23_1	24.27	43.89	18.43	38.95	31.39
2011_F5_27_1	22.96	34.46	17.66	37.63	28.18
2011_F5_32_1	19.32	37.35	21.91	47.05	31.41
2011_F5_35_2	22.70	34.04	18.14	40.38	28.82
2011_F5_36_2	25.03	39.59	16.60	41.94	30.79
2011_F5_37_1	21.07	41.61	20.68	37.41	30.19
2011_F5_37_3	22.56	43.74	17.11	38.22	30.41
2011_F5_4_2	22.35	41.54	18.05	36.70	29.66
2011_F5_47_1	22.71	46.12	19.70	41.22	32.44
2011_F5_47_3	21.67	39.91	18.20	43.05	30.71
2011_F5_48_1	25.19	39.18	17.99	41.30	30.92
2011_F5_5_1	23.47	39.48	18.06	42.68	30.92
2011_F5_50_1	22.71	32.13	18.27	40.03	28.29
2011_F5_52_2	22.68	40.63	18.64	46.26	32.05
2011_F5_55_1	22.86	39.92	21.68	38.35	30.70
2011_F5_56_1	26.09	36.07	17.07	35.30	28.63
2011_F5_56_3	22.92	38.13	17.30	36.17	28.63
2011_F5_57_2	20.63	44.05	17.84	36.78	29.83
2011_F5_59_1	18.46	34.49	17.22	35.56	26.43
2011_F5_59_2	21.24	37.62	16.84	36.27	27.99
2011_F5_60_2	21.18	44.60	18.62	36.15	30.14
2011_F5_64_1	21.60	36.64	17.99	41.87	29.53
2011_F5_66_3	24.54	40.20	17.33	39.69	30.44
2011_F5_72_3	21.00	41.42	20.49	40.91	30.96
2011_F5_76_1	19.56	39.15	17.97	33.97	27.66
2011_F5_76_4	21.90	40.02	17.79	38.39	29.53
2011_F5_83_1	21.69	39.38	18.14	37.71	29.23
2011_F5_88_3	21.40	41.33	16.15	34.51	28.35

Table 4.9 Continued

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
2011_F5_9_2	19.16	37.71	23.40	43.81	31.02
2011_F5_90_5	20.31	34.15	18.98	38.58	28.01
2011_F5_91_1	19.86	42.30	18.90	35.78	29.21
2011_F5_91_2	21.78	37.62	15.77	36.66	27.96
2011_F5_95_1	23.61	36.78	17.43	36.06	28.47
2011_F5_96_2	19.68	36.27	18.97	36.11	27.76
2011_F5_96_4	20.00	37.08	20.49	42.15	29.93
2011_Short_11	22.32	41.16	20.72	47.22	32.86
2011_Short_12	22.87	38.23	24.92	41.22	31.81
2011_Short_13	21.41	40.40	18.89	40.19	30.22
2011_Short_16	22.94	39.99	21.37	42.75	31.76
2011_Short_8	19.81	39.35	21.32	37.60	29.52
Alba*	20.22	44.52	16.58	39.27	30.15
OKARS 216	23.73	30.16	22.30	39.76	28.99
OKARS_249	25.79	27.53	15.85	42.04	27.80
OKARS 248	21.93	26.86	20.92	40.95	27.67
OKARS_242	19.71	31.25	22.02	41.99	28.74
OKARS 452	22.21	30.09	22.97	40.49	28.94
OKARS 474	22.50	34.52	23.00	41.43	30.36
Maja*	28.11	46.34	21.62	42.10	34.54
MW09S4076_002	21.29	28.24	22.71	40.19	28.11
MW09S4080_001	33.06	51.11	25.15	43.08	38.10
MW10S4116_003	22.79	35.18	19.99	34.50	28.12
MW10S4116_004	27.73	41.46	22.67	41.26	33.28
MW10S4118_001	32.67	44.43	23.86	41.37	35.58
MW10S4118_003	26.60	42.56	23.36	41.68	33.55
MW10S4118_004	24.48	41.28	20.00	40.34	31.53
MW10S4120_008	38.48	49.17	26.08	45.91	39.91
MW10S4122_001	30.15	45.60	24.69	42.87	35.83
MW10S4122_005	31.66	47.27	22.98	37.82	34.93
OBADV11_13	21.73	36.98	19.69	35.62	28.51
OBADV11_29	25.63	35.45	17.30	34.56	28.24
OBADV11_31	20.67	35.60	17.21	39.47	28.24
OR101	21.24	33.25	21.34	39.75	28.90
OR103	22.97	32.00	21.02	35.58	27.89
OR104	22.90	33.63	19.43	36.45	28.10
OR106	22.78	43.01	18.12	40.64	31.14
OR108	19.55	30.22	17.68	40.47	26.98
OR76	21.59	39.51	22.76	40.51	31.09
OR813	20.92	37.45	21.46	40.79	30.16

Table 4.9 Continued

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
OR815	22.30	35.42	18.08	34.69	27.62
OR818	22.40	36.34	19.60	43.71	30.51
OR91	23.57	35.67	19.39	36.60	28.81
PO71DH_104	24.61	31.31	18.26	38.98	28.29
PO71DH_87	22.27	33.61	21.98	35.76	28.41
PYT211_6	25.24	35.20	18.58	36.00	28.76
TAM 304**	23.26	37.99	22.57	46.46	32.57
GRAND MEAN	22.88	37.97	19.59	38.56	29.75
CV (%)	10.49	12.50	12.50	8.07	-
LSD (0.05)	4.76	9.40	4.85	6.16	-
Repeatability	0.57	0.36	0.36	0.43	-
Heritability	-	-	-	-	0.29

CS= College Station, COM= Comanche, DIM= Dimmitt, *= Barley check, **= Wheat check, C.V.= Coefficient of Variation, LSD= Least significant difference.

Table 4.10 Repeatability and heritability estimates for spring silage dry matter yield (t ha^{-1}) taken at College Station, Comanche, and Dimmitt from 2016-2017.

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
06OR_41	3.41	12.31	2.93	5.79	6.11
06OR_43	2.14	9.51	2.63	4.73	4.75
06OR_91	3.66	10.47	3.20	5.80	5.78
07OR_21	1.94	8.50	2.38	6.00	4.71
07OR_3	3.10	14.50	2.40	5.13	6.28
07OR_59	1.74	13.03	2.78	5.66	5.80
07OR_6	2.17	11.02	4.17	5.86	5.81
07OR_63	2.32	7.99	2.78	5.40	4.62
07OR_8	2.04	12.11	2.91	5.83	5.72
08OR_30	3.03	9.31	3.60	6.59	5.63
08OR_44	2.16	12.26	3.32	5.64	5.85
08OR_48	1.56	11.01	2.11	4.93	4.90
08OR_53	1.63	10.34	2.35	4.19	4.63
08OR_73	1.84	9.67	2.85	5.82	5.05
08OR_81	1.73	13.33	3.01	5.41	5.87
2011_F5_105_1	3.01	6.70	1.59	5.45	4.19
2011_F5_105_3	1.52	6.39	2.42	5.23	3.89
2011_F5_106_1	2.10	6.35	2.39	4.97	3.95
2011_F5_108_1	1.92	7.54	2.83	5.86	4.54
2011_F5_109_1	2.46	8.76	3.23	5.98	5.11

Table 4.10 Continued

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
2011_F5_112_1	2.33	7.53	2.53	4.98	4.34
2011_F5_112_3	1.74	8.44	2.34	5.45	4.49
2011_F5_113_2	2.22	6.59	2.81	5.25	4.22
2011_F5_119_1	3.33	9.23	2.23	5.08	4.97
2011_F5_120_3	3.26	9.37	2.82	4.96	5.10
2011_F5_121_1	2.71	9.11	2.37	5.44	4.91
2011_F5_121_2	2.12	7.81	2.75	5.33	4.50
2011_F5_121_3	2.26	6.90	2.64	5.15	4.24
2011_F5_121_4	3.21	7.16	2.86	5.31	4.64
2011_F5_121_5	2.17	10.51	2.25	6.23	5.29
2011_F5_124_1	2.45	6.56	3.70	5.19	4.48
2011_F5_126_1	2.07	6.07	3.37	6.04	4.39
2011_F5_126_2	2.00	11.91	4.57	6.31	6.20
2011_F5_129_1	1.36	8.60	2.15	5.41	4.38
2011_F5_131_1	3.17	11.57	2.44	5.79	5.74
2011_F5_132_1	2.80	6.63	2.19	6.68	4.58
2011_F5_134_3	1.68	7.96	2.91	5.59	4.54
2011_F5_136_1	2.71	6.65	3.09	5.78	4.56
2011_F5_22_3	3.57	11.85	2.74	5.37	5.88
2011_F5_23_1	1.43	13.70	3.13	5.97	6.06
2011_F5_27_1	1.64	11.06	2.84	4.85	5.10
2011_F5_32_1	3.65	10.62	3.61	6.19	6.02
2011_F5_35_2	2.18	9.40	2.20	5.96	4.94
2011_F5_36_2	1.27	5.22	2.55	5.89	3.73
2011_F5_37_1	1.97	9.63	2.52	5.21	4.83
2011_F5_37_3	2.46	5.28	2.06	5.91	3.93
2011_F5_4_2	3.63	13.98	2.37	6.11	6.52
2011_F5_47_1	3.75	11.43	2.63	6.32	6.03
2011_F5_47_3	2.39	13.41	2.80	6.46	6.27
2011_F5_48_1	3.27	12.09	2.61	5.37	5.84
2011_F5_5_1	3.67	8.16	2.55	6.71	5.27
2011_F5_50_1	2.13	10.45	3.08	5.90	5.39
2011_F5_52_2	1.68	10.85	2.98	5.76	5.32
2011_F5_55_1	1.52	6.74	2.63	5.20	4.02
2011_F5_56_1	2.05	5.69	2.40	5.65	3.95
2011_F5_56_3	2.16	8.02	2.77	5.50	4.61
2011_F5_57_2	1.49	7.46	2.29	5.29	4.13
2011_F5_59_1	3.65	6.83	2.54	6.23	4.81
2011_F5_59_2	1.98	9.81	2.15	5.69	4.91
2011_F5_60_2	2.37	8.62	2.74	5.69	4.86

Table 4.10 Continued

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
2011_F5_64_1	2.84	8.43	2.41	5.79	4.87
2011_F5_66_3	1.63	6.63	2.45	5.69	4.10
2011_F5_72_3	2.80	5.76	3.03	5.69	4.32
2011_F5_76_1	3.15	7.03	2.50	5.34	4.51
2011_F5_76_4	1.34	8.15	2.21	5.88	4.40
2011_F5_83_1	1.88	6.50	2.70	5.82	4.23
2011_F5_88_3	2.16	5.10	2.57	4.99	3.71
2011_F5_9_2	3.34	12.76	3.91	6.27	6.57
2011_F5_90_5	1.78	10.45	1.95	6.84	5.26
2011_F5_91_1	2.32	11.19	2.17	5.58	5.32
2011_F5_91_2	1.67	11.34	2.27	6.14	5.36
2011_F5_95_1	1.94	9.79	2.31	5.84	4.97
2011_F5_96_2	3.43	13.28	2.62	6.79	6.53
2011_F5_96_4	2.99	12.52	2.98	6.98	6.37
2011_Short_11	2.62	11.97	3.42	6.05	6.02
2011_Short_12	1.68	12.90	3.50	5.10	5.80
2011_Short_13	2.28	12.20	2.43	5.06	5.49
2011_Short_16	2.96	13.09	2.67	5.77	6.12
2011_Short_8	3.30	10.28	3.30	5.68	5.64
Alba*	3.31	8.98	2.27	5.83	5.10
OKARS 216	1.70	11.50	2.83	7.21	5.81
OKARS_249	0.90	10.57	2.29	6.51	5.07
OKARS 248	1.35	12.67	2.87	6.54	5.86
OKARS_242	3.34	12.65	3.11	3.50	5.65
OKARS 452	1.84	10.59	3.84	6.22	5.62
OKARS 474	3.06	14.87	3.22	7.05	7.05
Maja*	1.22	10.60	3.23	4.92	4.99
MW09S4076_002	3.45	14.51	3.06	6.51	6.88
MW09S4080_001	3.95	11.53	3.51	5.21	6.05
MW10S4116_003	3.61	9.54	3.14	5.01	5.33
MW10S4116_004	3.99	10.30	2.74	4.94	5.49
MW10S4118_001	4.64	12.66	2.56	5.36	6.31
MW10S4118_003	3.44	12.76	3.25	6.04	6.37
MW10S4118_004	2.79	10.67	2.72	5.55	5.43
MW10S4120_008	4.07	12.46	2.95	5.67	6.29
MW10S4122_001	3.22	10.36	3.72	5.63	5.73
MW10S4122_005	4.23	11.17	2.80	4.77	5.74
OBADV11_13	2.34	11.93	2.53	5.55	5.59
OBADV11_29	1.76	8.79	2.53	6.18	4.82
OBADV11_31	2.10	8.82	1.83	5.77	4.63

Table 4.10 Continued

Name	2016 CS	2017 COM	2016 DIM	2017 DIM	Average
OR101	1.93	10.44	3.48	6.28	5.53
OR103	2.09	12.18	3.18	6.50	5.99
OR104	1.70	9.47	2.74	5.70	4.90
OR106	1.02	12.06	2.63	4.75	5.12
OR108	2.68	10.94	3.08	6.08	5.70
OR76	2.41	12.50	3.34	6.07	6.08
OR813	2.51	10.55	3.46	6.08	5.65
OR815	1.53	11.39	3.06	5.62	5.40
OR818	2.24	11.76	2.71	5.55	5.57
OR91	2.32	12.05	3.24	5.14	5.69
PO71DH_104	1.50	12.09	1.99	6.53	5.53
PO71DH_87	1.94	10.59	3.24	6.60	5.59
PYT211_6	2.08	10.63	2.39	5.93	5.26
TAM 304**	3.72	12.26	3.02	5.70	6.18
GRAND MEAN	2.45	10.05	2.79	5.71	5.25
CV (%)	33.78	20.49	21.14	14.99	-
LSD (0.05)	1.64	4.08	1.17	1.70	-
Repeatability	0.30	0.45	0.18	0.00	-
Heritability	-	-	-	-	0.16

CS= College Station, COM= Comanche, DIM= Dimmitt, *= Barley check, **= Wheat check, C.V.= Coefficient of Variation, LSD= Least significant difference.

Discussion

Bi-plot analysis for fall forage revealed several lines with high NDVI values that were stable across environments. Entry 67, ‘2011_F5_88_3’, was found to have one of the highest mean NDVI values and was one of the best performing lines for the ‘DIM17’ environment. It was also very stable for NDVI values across all environments. Several of the entries that were not found to be suited for any environment such as 47, ‘2011_F5_4_2’, and 29, ‘2011_F5_121_4’, were also found to have the lowest mean NDVI values. Bi-plot analysis for NDVI values also showed that the McGregor location produced very different results from one year to the next (‘MCG16’ and ‘MCG17’) as these two environments are greatly separated in

Figure 4.2. This is most likely due to a hard freeze event that occurred during the ‘MCG17’ year that caused yellowing or tiller death of frost susceptible lines which greatly affects NDVI readings.

Using bi-plot analysis for spring silage yields (t ha^{-1}), several lines that were stable across environments could be identified. Entry 88, ‘MW09S4076_002’, was found to be one of the highest producing and most stable of all the lines and was best suited for the ‘DIM16’ and ‘COM17’ environments. Entries with low yield and poor stability such as 13, ‘08OR-53’, and 16, ‘2011_F5_105_1’, were not found to be well suited for any environment. Additionally, both irrigated locations, ‘COM17’ and ‘DIM16’, are close together in Figure 4.4 indicating they produced very similar results while the two non-irrigated environments, ‘DIM17’ and ‘CS16’, are separated indicating they produced very different results. The Eberhart-Russell stability analysis provided further information on barley line stability for each trait and offered a more precise estimation, especially for entries that could not be differentiated using the bi-plot analysis. While this analysis provides a more detailed report than bi-plots, it does not convey which lines had better yields or in which environments each line was best suited. Therefore, bi-plot analysis and the Eberhart-Russell stability analysis are best used in conjunction with one another.

Height, both for fall forage and spring silage, had the highest repeatability and heritability estimates all of traits. Heritability estimates were just over 0.5 indicating that the genetics of these lines accounted for about half of the variation in plant height. Conversely, NDVI had the lowest repeatability and heritability estimates. This is not surprising as NDVI readings can be influenced by a wide range of environmental effects such as disease and other abiotic stresses that cause yellowing in leaves (Knipling, 1970). Silage percent dry matter and dry matter yield also had fairly low repeatability and heritability estimates indicating that these traits were greatly influenced by environmental factors, and had high variation among environments. Percent dry matter can also be influenced by the timing of harvest at each location.

Conclusion

It is imperative that a thorough statistical analysis is conducted for any germplasm screening or breeding project. Environmental factors often have great effects on the performance of genotypes and without an in depth evaluation, these influences may not be fully understood or go completely unnoticed. Bi-plots offer a way to evaluate the performance and stability of entries visually as well as determine which genotypes are best suited for a particular environment. The Eberhart-Russell stability analysis can be used in combination with bi-plots and offer a more precise measurement of stability. Repeatability measurements are used to assess the ability of a genotype to repeat trait expression across years and locations while heritability estimates can be used to compare gains from selection. These analyses help to remove inferior genotypes while the best adapted lines are advanced for further testing.

CHAPTER V

SUMMARY

Despite the great demand for high quality forage crops as a feed source for the beef cattle and dairy industries, barley currently has a limited role in Texas. This is partially fueled by a lack of screening for new germplasm in both the public and private sectors. Wheat provides the majority of the 1.2 million hectares of small grains that are grazed in Texas each year while barley acreage has diminished to below 13,000 hectares. However, barley may have an expanded role moving forward due to its rapid growth in the fall, high silage production capabilities, and tolerance to several important stresses such as drought, saline soils, and Hessian fly, which is a prominent threat to wheat production in northeast, central and southern regions of Texas.

Screenings of barley lines identified several genotypes superior to commercial cultivars for fall forage and spring silage production. NDVI was able to estimate small plot biomass production in a quick and nondestructive method when utilized before canopy closure occurred. Several of the barley lines showed potential for producing both high fall forage and silage production such as ‘OKARS 248’ in Comanche or ‘MW10S4118_001’ in College Station. Barley appeared to be very well suited for the area near Comanche as some entries (‘OKARS 474’, ‘2011_F5_126_2’, and ‘MW09S4076_001’) exceeded 16 t ha^{-1} of silage production at that site. Although some lines performed well at many locations, yields are likely to be maximized by selecting specific lines for each environment. The results of this study gave an initial estimation of the silage production that can be expected from this barley germplasm.

Hessian fly infestations can greatly reduce biomass production of small grains that are planted early which is necessary for the establishment of a good fall pasture for grazing livestock. Field screenings of Hessian fly infestations revealed low insect pressure and high variability which prevented the identification of many susceptible lines. The growth chamber screening provided much better data for separating resistant lines from susceptible ones. In combination, these trials identified a select few barley lines that were resistant against all Hessian fly populations they were screened against. Overall, barley was found to have much lower Hessian fly infestation than winter wheat and may provide a more suitable source of forage production where this insect is most prevalent.

The analyses of stability, repeatability, and heritability were used to better understand the germplasm that was screened. Several lines were identified that had high fall forage NDVI values or spring silage yield and were stable across testing environments. Height measurements for both fall forage and spring silage were found to have high repeatability and heritability while NDVI values were found not to be repeatable nor heritable. Barley lines that were high yielding and stable may be advanced for further testing.

The barley germplasm screened in this study possesses the traits needed to compete with other small grains as a cool season forage source in Texas. This includes high fall forage and spring silage yields, resistance to a wide range of abiotic and biotic stresses, and stability in production across years and locations. In addition to this study, these barley lines were screened for malting quality, which puts Texas A&M AgriLife Extension at the forefront of reviving the barley industry in Texas.

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APPENDIX A

SAS Codes

A-1 SAS code for early season fall forage production

```
DATA forage;
Input bloc ibloc entry height ndvi;
cards;
;
proc glm data = forage;
class bloc ibloc entry;
model height ndvi =bloc ibloc(bloc) entry;
means entry/lsd;
run;
```

A-2 SAS Code for clipping data

```
DATA forage;
Input bloc ibloc entry weight;
cards;
;
proc glm data = forage;
class bloc ibloc entry;
model weight =bloc ibloc(bloc) entry;
means entry/lsd;
run;
```

A-3 SAS code for correlation

```
DATA forage;
Input ndvi weight;
cards;
;
proc corr data = forage;
var height;
with weight;
run;
```

A-4 SAS code for regression

```
DATA forage;
Input ndvi height weight;
cards;
;
proc reg;
model weight= height ndvi /slstay=0.05;
run;
```

A-5 SAS code for spring silage

```
DATA silage;
Input bloc ibloc entry height DM yield total;
cards;
;
proc glm data = silage;
class bloc ibloc entry;
model height DM yield total =bloc ibloc(bloc) entry;
means entry/lsd;
run;
```

A-6 SAS code for Hessian fly ANOVA

```
DATA HF;
Input bloc ibloc entry count;
cards;
;
proc glm data = HF;
class bloc ibloc entry;
model count = bloc ibloc(bloc) entry;
means entry;
run;
```

APPENDIX B

TABLES

B-1 Listing of early season forage barley lines and commercial cultivars ranked in order of their average performance across environments for height and NDVI measurements from 2016-2017.

Name	2016 CS	2016 MCG	2017 CMN	2017 MCG	2017 BRD	2017 DIM	AVG
MW09S4080_001	37	61	17	4	3	3	21
06OR_91	15	8	46	21	5	45	23
2011_F5_32_1	3	37	23	8	28	49	25
MW10S4120_008	27	25	2	19	38	52	27
2011_F5_9_2	6	11	64	55	15	35	31
08OR_30	23	40	35	12	33	47	32
2011_F5_121_2	80	21	43	13	4	39	33
2011_F5_47_1	22	10	5	25	81	58	34
06OR_41	11	34	99	31	29	6	35
2011_F5_136_1	19	54	38	9	89	5	36
2011_F5_64_1	13	18	8	68	108	4	37
2011_F5_96_2	12	59	63	39	51	32	43
2011_F5_88_3	40	43	9	70	60	36	43
MW10S4118_003	26	17	77	44	78	20	44
2011_F5_5_1	9	45	48	77	54	31	44
06OR_42	120	47	39	41	19	2	45
MW10S4116_004	2	4	16	132	58	61	46
OR813	69	71	25	1	80	28	46
OR108	5	30	72	112	27	33	47
2011_F5_96_4	29	76	37	29	90	25	48
2011_F5_56_1	105	5	21	69	26	66	49
2011_F5_23_1	47	24	121	2	91	8	49
2011_F5_27_1	97	53	44	11	25	63	49
06OR_59	117	2	1	86	11	79	49
2011_F5_124_1	70	49	75	33	39	30	49
MW10S4122_005	8	22	27	88	110	43	50
2011_F5_135_4	90	36	24	3	75	73	50
2011_F5_59_2	82	31	54	66	46	24	51
2011_F5_121_5	106	7	52	27	96	18	51
2011_F5_126_2	94	77	20	17	40	62	52
MW10S4118_004	48	1	13	40	92	116	52
2011_F5_36_2	102	109	42	38	12	9	52
OR76	68	130	80	18	2	16	52
MW09S4076_002	65	102	62	51	17	21	53
2011_F5_83_1	89	92	53	7	65	13	53

08OR_48	79	119	15	30	69	7	53
MW09S4076_001	118	3	6	20	121	59	55
2011_F5_131_1	56	19	100	81	53	19	55
2011_F5_50_1	58	44	19	83	100	26	55
2011_F5_120_3	35	58	59	121	21	40	56
Alba*	7	33	87	129	45	34	56
2011_F5_121_3	67	26	30	37	98	80	56
06OR_75	125	56	67	15	7	74	57
07OR_8	25	23	104	49	79	67	58
OR101	50	79	11	80	117	11	58
07OR_3	14	51	73	75	9	129	59
2011_F5_119_1	36	62	32	120	35	68	59
2011_F5_4_2	45	66	78	72	8	91	60
2011_F5_121_4	49	60	55	60	101	38	61
OR91	30	94	51	16	66	109	61
MW10S4122_001	46	15	124	74	48	60	61
OKARS 474	63	9	90	24	127	57	62
2011_F5_121_1	42	70	4	64	114	77	62
2011_F5_57_2	76	28	12	98	112	48	62
2011_F5_132_1	16	108	58	63	84	46	63
OKARS 242	72	52	81	45	68	64	64
MW10S4118_001	1	14	50	126	129	65	64
2011_F5_109_3	93	95	129	6	13	50	64
2011_F5_112_1	53	67	36	113	74	44	65
08OR_81	62	20	101	111	70	27	65
OR910	122	127	45	14	10	82	67
06OR_44	126	63	49	10	36	117	67
OKARS 216	95	100	92	85	23	14	68
2011_F5_48_1	21	101	26	78	86	102	69
2011_F5_91_2	84	29	88	115	88	12	69
2011_F5_108_1	100	93	28	79	32	84	69
2011_F5_37_3	31	112	86	89	1	100	70
06OR_52	131	48	115	28	57	41	70
2011_F5_55_1	116	32	102	22	97	51	70
2011_F5_52_2	18	98	14	97	72	122	70
OR103	41	6	33	105	116	121	70
2011_F5_76_4	115	118	7	54	63	69	71
OR818	75	106	57	84	22	85	72
Full Pint*	123	91	74	61	61	22	72
2011_F5_90_5	85	57	34	42	102	114	72
07OR_59	92	41	31	127	31	115	73
OBADV11_29	109	103	93	34	76	23	73
PO71DH_87	101	128	41	43	55	71	73

OBADV11_13	83	35	131	52	20	123	74
OKARS 452	81	80	132	53	24	75	74
2011_Short_8	24	90	84	110	30	107	74
2011_F5_22_3	17	65	82	47	111	127	75
PYT211_6	78	88	126	46	62	53	76
2011_F5_112_3	91	68	22	124	52	97	76
2011_F5_47_3	73	42	110	57	73	105	77
06OR_62	121	96	70	56	107	10	77
2011_F5_66_3	64	83	125	62	41	86	77
08OR_53	44	105	85	5	93	130	77
2011_F5_60_2	59	75	120	131	49	29	77
2011_F5_126_1	71	50	91	48	113	93	78
OR104	28	97	29	76	118	118	78
2011_Short_13	61	72	79	35	94	126	78
07OR_63	103	27	117	116	87	17	78
07OR_4	127	107	56	32	56	94	79
08OR_44	54	39	97	109	120	54	79
06OR_37	129	12	109	90	132	1	79
2011_F5_72_3	32	122	114	99	6	101	79
2011_F5_95_1	99	86	103	103	14	70	79
2011_F5_109_1	4	129	18	106	130	92	80
06OR_10	119	111	10	114	47	78	80
2011_Short_16	52	99	76	87	59	108	80
2011_F5_106_1	96	55	65	128	18	120	80
MW10S4116_003	10	13	94	130	126	113	81
08OR_73	38	64	71	95	128	90	81
2011_F5_35_2	57	120	89	91	44	87	81
2011_F5_105_3	112	69	3	104	106	104	83
Maja*	60	125	47	123	16	128	83
OKARS 248	110	104	95	65	37	88	83
2011_F5_56_3	88	117	106	58	115	15	83
2011_F5_91_1	20	87	68	117	109	98	83
2011_F5_105_1	87	38	119	59	77	124	84
07OR_6	34	78	69	118	124	83	84
06OR_78	128	132	66	23	123	37	85
2011_F5_129_1	114	110	111	67	67	42	85
2011_Short_11	43	84	61	101	104	119	85
2011_Short_12	77	113	112	92	43	81	86
06OR_43	86	46	116	71	71	131	87
2011_F5_134_3	66	82	108	107	64	96	87
OKARS 249	113	74	130	96	42	72	88
OR815	55	85	107	26	131	125	88
2011_F5_76_1	33	123	40	125	119	89	88

07OR_21	107	114	60	100	103	56	90
06OR_45	132	89	118	73	82	55	92
2011_F5_59_1	39	81	122	122	95	106	94
2011_F5_113_2	51	116	98	94	99	111	95
OBADV11_2	130	16	123	82	125	95	95
2011_F5_37_1	104	121	105	102	50	103	98
OR106	98	73	83	119	83	132	98
TAM 304**	74	115	127	93	105	76	98
TAM 304**	74	115	127	93	105	76	98
OBADV11_31	111	124	113	50	85	110	99
PO71DH_104	108	126	128	108	34	99	101
06OR_9	124	131	96	36	122	112	104

*= Barley commercial cultivar, **= Wheat commercial cultivar, CS= College Station, MCG= McGregor, CMN= Comanche, BRD= Brady, DIM= Dimmitt

B-2 Listing of spring silage barley lines and commercial cultivars ranked in order of their average performance across environments for spring silage production from 2016-2017.

Name	2016 CS	2016 DIM	2017 CMN	2017 DIM	AVG
06OR_9	NA	NA	16	11	14
OKARS 474	31	23	4	2	15
MW09S4076_002	15	32	1	15	16
MW09S4076_001	NA	NA	19	24	22
Full Pint*	NA	NA	26	26	26
2011_F5_47_3	8	52	34	17	28
2011_F5_9_2	56	3	29	23	28
MW10S4118_003	16	18	37	41	28
OR108	42	31	8	37	30
OR103	73	25	5	16	30
OR76	49	15	20	38	31
06OR_41	18	40	6	59	31
2011_F5_96_2	43	71	7	6	32
OKARS 452	86	4	11	28	32
2011_F5_23_1	10	27	49	45	33
06OR_37	NA	NA	48	18	33
TAM 304**	7	35	25	66	33
07OR_4	NA	NA	38	30	34
08OR_30	32	8	89	10	35
06OR_52	NA	NA	69	3	36
OR813	45	12	54	36	37
PO71DH_87	82	20	40	9	38
OKARS 216	93	48	13	1	39

OR101	92	11	32	22	39
06OR_45	NA	NA	60	19	40
2011_F5_96_4	98	38	21	4	40
2011_Short_11	57	13	51	40	40
06OR_91	9	24	72	58	41
08OR_44	66	16	9	76	42
OKARS 248	111	43	2	12	42
MW10S4120_008	3	39	61	73	44
2011_Short_12	35	10	18	114	44
06OR_78	NA	NA	62	29	46
07OR_8	76	41	22	55	49
OKARS 242	19	28	15	132	49
2011_F5_109_1	46	22	83	44	49
2011_F5_91_2	17	101	44	34	49
MW10S4122_001	26	5	90	77	50
07OR_6	62	2	86	51	50
MW09S4080_001	5	9	88	105	52
2011_F5_47_1	24	69	96	20	52
2011_Short_8	44	17	76	72	52
06OR_75	NA	NA	28	78	53
OR91	54	19	30	110	53
2011_F5_4_2	50	94	35	35	54
MW10S4116_003	13	26	59	117	54
2011_F5_32_1	113	7	65	31	54
2011_F5_135_4	14	108	66	33	55
2011_F5_121_5	48	102	45	27	56
08OR_73	87	45	36	57	56
MW10S4118_001	1	74	57	95	57
2011_F5_131_1	37	84	46	61	57
2011_F5_50_1	105	30	47	48	58
07OR_59	91	54	12	74	58
PO71DH_104	107	113	3	13	59
OR818	59	63	31	84	59
08OR_81	103	36	10	90	60
2011_F5_126_2	110	1	110	21	61
OR815	104	33	27	79	61
PYT211_6	72	90	43	39	61
OKARS 249	116	99	17	14	62
2011_F5_95_1	34	97	63	53	62
2011_Short_16	85	65	33	64	62
2011_F5_56_3	11	56	101	85	63
MW10S4122_005	2	53	73	126	64
OBADV11_13	52	78	42	82	64

OBADV11_2	NA	NA	14	113	64
2011_F5_90_5	97	114	39	5	64
2011_F5_126_1	77	14	123	42	64
2011_F5_59_1	51	77	107	25	65
2011_F5_134_3	40	42	99	80	65
MW10S4118_004	39	62	79	83	66
2011_F5_83_1	20	64	125	56	66
2011_Short_13	23	85	41	116	66
2011_F5_120_3	41	50	56	121	67
2011_F5_52_2	75	37	95	65	68
07OR_63	55	55	71	92	68
2011_F5_64_1	38	87	91	60	69
Alba*	22	100	106	54	71
OBADV11_29	89	81	80	32	71
07OR_3	30	89	52	112	71
2011_F5_5_1	96	76	104	7	71
2011_F5_59_2	36	109	67	71	71
OR104	94	59	64	67	71
06OR_43	67	68	23	128	72
2011_F5_113_2	21	51	113	102	72
2011_F5_27_1	61	46	55	125	72
06OR_42	NA	NA	53	91	72
2011_F5_108_1	83	49	108	52	73
2011_F5_37_1	12	80	97	104	73
2011_F5_37_3	6	112	130	47	74
07OR_21	80	92	81	43	74
2011_F5_124_1	74	6	111	107	75
2011_F5_36_2	47	75	129	49	75
2011_F5_48_1	68	72	68	93	75
2011_F5_121_2	58	57	93	97	76
06OR_59	NA	NA	24	130	77
2011_F5_121_4	63	44	102	99	77
2011_F5_35_2	79	105	78	46	77
2011_F5_66_3	29	83	126	70	77
MW10S4116_004	4	58	124	122	77
2011_F5_109_3	53	47	98	111	77
2011_F5_121_1	69	93	70	88	80
2011_F5_121_3	27	66	118	109	80
2011_F5_136_1	109	29	120	62	80
2011_F5_132_1	95	106	112	8	80
2011_F5_76_4	64	104	105	50	81
2011_F5_129_1	28	110	100	89	82
2011_F5_119_1	25	103	85	115	82

2011_F5_22_3	99	60	77	94	83
2011_F5_112_3	60	96	94	86	84
2011_F5_91_1	81	107	75	81	86
2011_F5_60_2	101	61	115	69	87
2011_F5_72_3	112	34	132	68	87
06OR_10	NA	NA	74	100	87
Maja*	114	21	92	124	88
OBADV11_31	70	115	103	63	88
2011_F5_105_1	33	116	117	87	88
2011_F5_55_1	65	67	127	106	91
OR106	115	70	58	127	93
2011_F5_76_1	84	82	109	96	93
08OR_48	102	111	50	123	97
OR910	NA	NA	87	108	98
2011_F5_56_1	108	88	128	75	100
2011_F5_57_2	78	98	122	101	100
2011_F5_112_1	90	79	114	119	101
2011_F5_106_1	71	91	121	120	101
08OR_53	100	95	82	131	102
2011_F5_88_3	88	73	131	118	103
2011_F5_105_3	106	86	116	103	103
06OR_44	NA	NA	84	129	107
06OR_62	NA	NA	119	98	109

*= Barley commercial cultivar, **= Wheat commercial cultivar, CS= College Station, CMN= Comanche, DIM= Dimmitt, NA= Entry not tested

B-3 Listing of TCAP barley lines, average number of Hessian fly pupae per tiller, and resistant/susceptible rating at each screening environment from 2016-2017.

Name	MCG 2016	R/S	MCG 2017	R/S	BRD 2017	R/S	Growth Chamber	R/S	Grand Mean
2011_F5_4_2	0.00	R	0.00	NR	0.00	R	0.00	R	0.00
MW09S4076_002	0.05	R	0.05	NR	0.00	R	0.00	R	0.03
OR76	0.00	R	0.00	NR	0.00	R	0.50	R	0.13
OKARS 474	0.00	R	0.05	NR	0.15	R	0.33	R	0.13
2011_F5_64_1	0.00	R	0.00	NR	0.05	R	0.50	R	0.14
2011_F5_56_3	0.05	R	0.15	NR	0.05	R	0.33	R	0.15
OKARS 248	0.00	R	0.10	NR	0.00	R	0.50	R	0.15
2011_Short_13	0.20	R	0.10	NR	0.30	R	0.00	R	0.15
2011_F5_121_5	0.00	R	0.05	NR	0.15	R	0.50	R	0.18
2011_F5_119_1	0.50	S	0.15	NR	0.05	R	0.00	R	0.18
06OR_9	ND	NR	0.05	NR	0.00	R	0.50	R	0.18

OBVAD11_13	0.00	R	0.10	NR	0.00	R	0.67	S	0.19
OBADV11_31	0.00	R	0.00	NR	0.60	S	0.17	R	0.19
06OR_91	0.00	R	0.00	NR	0.00	R	0.83	S	0.21
MW09S4076_001	0.00	R	0.00	NR	0.00	R	0.83	S	0.21
MW10S4120_008	0.00	R	0.00	NR	0.00	R	0.83	S	0.21
2011_F5_132_1	0.00	R	0.20	NR	0.00	R	0.67	S	0.22
06OR_42	0.00	R	0.05	NR	0.00	R	0.83	S	0.22
2011_F5_35_2	0.05	R	0.20	NR	0.00	R	0.67	S	0.23
08OR_53	0.05	R	0.20	NR	0.05	R	0.67	S	0.24
2011_F5_88_3	0.00	R	0.15	NR	0.35	R	0.50	R	0.25
08OR_44	0.00	R	0.25	NR	0.15	R	0.67	S	0.27
2011_F5_59_2	0.05	R	0.05	NR	0.15	R	0.83	S	0.27
08OR_48	0.00	R	1.00	NR	0.10	R	0.00	R	0.28
OKARS 242	0.50	S	0.45	NR	0.20	R	0.00	R	0.29
2011-F5-135-4	ND	NR	0.30	NR	0.40	R	0.17	R	0.29
2011_F5_5_1	0.00	R	0.00	NR	0.00	R	1.17	S	0.29
OR108	0.10	R	0.20	NR	0.05	R	0.83	S	0.30
Full Pint-2	0.00	R	0.25	NR	0.00	R	1.00	S	0.31
OBADV11_13	0.00	R	0.00	NR	0.25	R	1.00	S	0.31
2011_F5_131_1	0.00	R	0.20	NR	0.15	R	1.00	S	0.34
2011_F5_66_3	0.25	R	0.20	NR	0.10	R	0.83	S	0.35
2011_F5_91_1	0.00	R	0.65	NR	0.25	R	0.50	R	0.35
2011_F5_136_1	0.25	R	0.20	NR	0.20	R	0.83	S	0.37
2011_F5_76_4	0.00	R	0.45	NR	0.05	R	1.00	S	0.38
OKARS 452	0.20	R	0.40	NR	0.45	R	0.50	R	0.39
Alba-2	0.05	R	0.30	NR	0.15	R	1.17	S	0.42
2011_F5_96_2	0.00	R	0.00	NR	0.00	R	1.67	S	0.42
MW10S4118_004	0.00	R	0.00	NR	0.70	S	1.00	S	0.43
2011_F5_52_2	0.00	R	0.50	NR	0.05	R	1.17	S	0.43
OBADV11_29	0.00	R	0.30	NR	0.25	R	1.17	S	0.43
07OR_59	0.00	R	0.05	NR	0.00	R	1.67	S	0.43
OKARS 216	0.00	R	0.60	NR	0.20	R	1.00	S	0.45
OR103	0.00	R	0.00	NR	0.00	R	1.83	S	0.46
06OR_44	ND	NR	0.00	NR	0.00	R	1.50	S	0.50
06OR_75	ND	NR	0.00	NR	0.00	R	1.50	S	0.50
2011_F5_109_1	0.10	R	0.10	NR	0.15	R	1.67	S	0.50
2011_F5_105_1	0.05	R	0.40	NR	0.15	R	1.50	S	0.53
OR815	0.20	R	1.00	NR	0.25	R	0.67	S	0.53
OR106	0.10	R	0.15	NR	0.05	R	1.83	S	0.53
MW10S4122_001	0.00	R	0.00	NR	0.30	R	1.83	S	0.53

Alba-1	0.05	R	0.25	NR	0.35	R	1.50	S	0.54
2011_F5_90_5	0.05	R	0.20	NR	0.30	R	1.67	S	0.55
Full Pint-1	0.00	R	0.15	NR	0.00	R	2.17	S	0.58
OR101	0.05	R	0.55	NR	0.40	R	1.33	S	0.58
2011_F5_112_3	0.15	R	0.40	NR	0.15	R	1.67	S	0.59
2011_F5_121_3	0.35	R	0.10	NR	0.45	R	1.50	S	0.60
PO71DH_104	0.25	R	0.15	NR	0.35	R	1.67	S	0.60
OR910	ND	NR	0.00	NR	0.00	R	1.83	S	0.61
MW10S4122_005	0.45	S	0.30	NR	0.45	R	1.33	S	0.63
Maja-2	0.00	R	0.70	NR	0.50	R	1.33	S	0.63
PYT211_6	0.15	R	0.25	NR	0.15	R	2.00	S	0.64
Maja-1	0.00	R	0.30	NR	0.60	S	1.67	S	0.64
2011_F5_121_2	0.00	R	0.45	NR	0.30	R	1.83	S	0.65
06OR_43	0.20	R	0.00	NR	0.05	R	2.33	S	0.65
2011_F5_91_2	0.00	R	0.15	NR	0.10	R	2.33	S	0.65
2011_F5_60_2	0.20	R	0.45	NR	0.30	R	1.67	S	0.65
2011-F5-109-3	0.15	R	0.15	NR	1.00	S	1.33	S	0.66
2011_F5_36_2	0.05	R	0.10	NR	0.00	R	2.50	S	0.66
2011_F5_109_3	ND	NR	0.00	NR	0.00	R	2.00	S	0.67
06OR_62	0.00	R	0.60	NR	0.10	R	2.00	S	0.68
06OR_37	0.10	R	0.20	NR	0.10	R	2.33	S	0.68
07OR_63	0.15	R	0.45	NR	0.20	R	2.00	S	0.70
06OR_52	0.00	R	0.00	NR	0.00	R	2.83	S	0.71
2011_F5_96_4	0.00	R	0.00	NR	0.00	R	2.83	S	0.71
2011_F5_32_1	0.00	R	0.05	NR	0.15	R	2.67	S	0.72
07OR_21	0.00	R	0.25	NR	0.15	R	2.50	S	0.73
08OR_30	0.00	R	0.00	NR	0.15	R	2.83	S	0.75
PO71DH_87	0.05	R	0.10	NR	0.40	R	2.50	S	0.76
06OR_45	0.05	R	0.65	NR	0.20	R	2.17	S	0.77
2011_F5_121_1	0.10	R	0.35	NR	0.45	R	2.17	S	0.77
MW10S4116_004	0.00	R	0.50	NR	0.10	R	2.50	S	0.78
2011_F5_129_1	0.25	R	0.65	NR	0.10	R	2.17	S	0.79
2011_F5_126_2	0.10	R	0.50	NR	0.40	R	2.17	S	0.79
2011_Short_16	0.00	R	0.00	NR	0.00	R	3.17	S	0.79
2011_F5_48_1	0.05	R	0.00	NR	0.00	R	3.17	S	0.80
08OR_73	0.00	R	0.10	NR	0.00	R	3.17	S	0.82
MW10S4118_001	0.00	R	0.10	NR	0.00	R	3.17	S	0.82
OBADV11_2	ND	NR	0.25	NR	0.05	R	2.17	S	0.82
2011_F5_23_1	0.00	R	0.00	NR	0.00	R	3.33	S	0.83
MW09S4080_001	0.00	R	0.10	NR	0.00	R	3.25	S	0.84

2011-F5-124-1	0.30	R	0.10	NR	0.00	R	3.00	S	0.85
07OR_6	0.15	R	0.00	NR	0.10	R	3.17	S	0.85
2011_F5_83_1	0.20	R	0.50	NR	0.25	R	2.67	S	0.90
2011_F5_95_1	0.15	R	0.45	NR	1.35	S	1.67	S	0.90
2011_F5_55_1	0.25	R	0.35	NR	0.40	R	2.67	S	0.92
07OR_3	0.00	R	0.00	NR	0.00	R	3.67	S	0.92
2011_F5_27_1	0.00	R	0.35	NR	0.35	R	3.00	S	0.93
2011_F5_105_3	0.50	S	0.05	NR	0.35	R	2.83	S	0.93
2011_Short_12	0.00	R	0.25	NR	0.50	R	3.00	S	0.94
2011_F5_47_3	0.00	R	0.00	NR	0.25	R	3.50	S	0.94
2011_F5_124_1	ND	NR	0.45	NR	0.20	R	2.17	S	0.94
OR104	0.10	R	0.40	NR	0.10	R	3.17	S	0.94
2011_F5_22_3	0.00	R	0.10	NR	0.00	R	3.67	S	0.94
2011_F5_121_4	0.00	R	0.40	NR	1.05	S	2.33	S	0.95
06OR_10	0.70	S	0.45	NR	0.20	R	2.50	S	0.96
OR818	0.05	R	0.30	NR	0.00	R	3.50	S	0.96
2011_Short_11	0.00	R	0.15	NR	0.05	R	3.67	S	0.97
2011_F5_126_1	0.05	R	0.10	NR	0.05	R	3.67	S	0.97
2011_F5_113_2	0.55	S	0.10	NR	0.10	R	3.17	S	0.98
2011_F5_56_1	0.25	R	0.05	NR	0.45	R	3.17	S	0.98
OR813	0.00	R	0.10	NR	0.00	R	3.83	S	0.98
2011_F5_72_3	0.60	S	1.00	NR	0.15	R	2.33	S	1.02
2011_F5_112_1	0.35	R	0.45	NR	0.00	R	3.33	S	1.03
2011_F5_37_3	0.05	R	0.15	NR	0.10	R	3.83	S	1.03
2011_F5_50_1	0.15	R	0.50	NR	0.20	R	3.33	S	1.05
2011_F5_37_1	0.20	R	0.30	NR	0.00	R	3.75	S	1.06
07OR_8	0.00	R	0.40	NR	0.05	R	3.83	S	1.07
2011_F5_57_2	0.25	R	0.10	NR	0.10	R	3.83	S	1.07
06OR_59	0.00	R	0.75	NR	0.00	R	3.67	S	1.10
06OR_78	ND	NR	0.15	NR	0.00	R	3.17	S	1.11
2011_F5_135_4	0.50	S	0.00	NR	0.00	R	4.00	S	1.13
2011_F5_59_1	0.00	R	0.55	NR	0.25	R	3.83	S	1.16
2011_F5_76_1	0.15	R	0.05	NR	0.30	R	4.17	S	1.17
2011_F5_9_2	0.25	R	0.45	NR	0.15	R	3.83	S	1.17
08OR_81	0.70	S	0.35	NR	0.05	R	3.67	S	1.19
2011_F5_108_1	0.00	R	0.30	NR	0.50	R	4.00	S	1.20
MW10S4116_003	0.00	R	0.20	NR	0.10	R	4.50	S	1.20
MW10S4118_003	0.00	R	0.00	NR	0.00	R	4.83	S	1.21
06OR_41	0.10	R	0.10	NR	0.05	R	4.83	S	1.27
2011_Short_8	0.00	R	0.90	NR	0.25	R	4.00	S	1.29

07OR_4	0.45	S	0.60	NR	0.45	R	3.83	S	1.33
2011_F5_106_1	0.30	R	0.45	NR	0.20	R	4.67	S	1.40
2011_F5_47_1	0.00	R	0.00	NR	0.10	R	5.83	S	1.48
2011_F5_134_3	0.25	R	0.25	NR	0.50	R	5.33	S	1.58
2011_F5_120_3	0.30	R	0.50	NR	0.10	R	5.67	S	1.64
OR91	0.25	R	0.20	NR	0.00	R	6.50	S	1.74
OKARS 249	0.35	R	0.90	NR	1.75	S	4.00	S	1.75
06OR-59	ND	NR	0.00	NR	0.00	R	6.83	S	2.28
TAM 304	0.20	R	0.45	NR	0.00	R	10.67	S	2.83
Mean	0.11		0.24		0.18		2.26		0.72
CV (%)	162.5		108.3		157.4		101.3		-
LSD (0.05)	0.36		-		0.57		0.53		-

MCG=McGregor, BRD= Brady, R= Resistant, S= Susceptible, NR= Not Rated, ND= No Data, Grand Mean= Average number of Hessian fly pupae per tiller in all four environments

B-4 Listing of winter wheat lines, average number of Hessian fly pupae per tiller, and resistant/susceptible rating for both screening environments in 2017.

Name	MCG 2017	R/S	Growth Chamber	R/S	Grand Mean
WB 4303	0.02	R	ND	NR	0.02
Doans	0.93	R	ND	NR	0.93
LSC Chrome	ND	NR	1.00	R	1.00
SY Flint	0.17	R	4.33	S	2.25
Duster	0.19	R	4.83	S	2.51
Bentley	0.24	R	5.17	S	2.70
SY Southwind	1.05	R	4.83	S	2.94
WB Grainfield	2.37	S	3.83	S	3.10
Jackpot	ND	NR	3.17	S	3.17
TAM 401	0.02	R	6.33	S	3.18
TAM 204	0.22	R	6.67	S	3.44
Greer	0.67	R	6.50	S	3.59
TAM 114	1.06	R	6.33	S	3.70
SY Lllano	0.18	R	8.17	S	4.17
TAM 305	0.73	R	8.33	S	4.53
SY Rugged	0.41	R	8.83	S	4.62
Gallagher	0.12	R	9.17	S	4.64
SY Grit	0.13	R	9.17	S	4.65
TAM 113	ND	NR	4.67	S	4.67
TAM W 101	1.06	R	9.50	S	5.28

WB 4721	ND	NR	5.33	S	5.33
Fannin	0.28	R	10.50	S	5.39
WB 4515	1.72	S	9.17	S	5.44
T158	ND	NR	5.50	S	5.50
Zenda	0.15	R	11.00	S	5.58
WB 4269	0.71	R	10.50	S	5.61
Iba	3.25	S	8.00	S	5.63
SY Drifter	1.94	S	9.33	S	5.64
SY Razor	ND	NR	5.67	S	5.67
LCS Pistol	ND	NR	6.17	S	6.17
WB 4458	0.01	R	12.33	S	6.17
AG Robust	ND	NR	6.50	S	6.50
TAM 304	0.19	R	13.00	S	6.60
CPLN 69-16	ND	NR	6.67	S	6.67
KanMark	ND	NR	6.67	S	6.67
WB Cedar	1.39	R	12.33	S	6.86
Long Branch	ND	NR	7.50	S	7.50
LCS Mint	ND	NR	7.83	S	7.83
TX11A001295	ND	NR	8.25	S	8.25
Winterhawk	ND	NR	9.33	S	9.33
TX12M4068	ND	NR	11.50	S	11.50
Weathermaster 135	ND	NR	11.50	S	11.50

MCG=McGregor, R= Resistant, S= Susceptible, NR= Not Rated, ND= No Data, Grand Mean= Average number of Hessian fly pupae per tiller in all four environments