GENOTYPE-BY-ENVIRONMENT INTERACTION IN SUNFLOWERS FOR THE NORTHERN PLAINS

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Genotype by environment interaction (GxE) is the tendency of the phenotypic performance of two or more plant genotypes in one environment to not be predictive of their relative performance in another environment. To discover the importance of GxE in this region, a large set of USDA and commercial hybrids were tested in the regions of practical significance to sunflower production in order to produce recommendations regarding mega-environments for yield and oil. Rank changes for oil content occurred among hybrids and two common factors accounted for 68.6% of the total GxE variation. Breeding programs testing pre-commercial hybrids in multiple environments for oil content could be beneficial. Yield covariates for lodging, bird damage, and disease were significant but occurred in different locations with variable severity each year making it difficult to divide the growing region into mega-environments for yield.

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DEDICATION

This project is dedicated to the 6 most influential people in my life. My Mom, Dad and all 4 of my Grandparents. You have each touched my heart and mind in so many different ways, helping to shape the person I am today. To my Mom. Thank you for letting me find my own way but never giving up on me. I will never forget my first taste of travel and how that changed me forever. Thank you for always telling me you are proud of me and being there no matter what the cause. I am so grateful that you made me "pick beans" and re-assured me that it creates character. From you, I have learned that without character, there is no determination or fun to life. Dad, you have instilled wisdom, faith and practicality in me. Your words of wisdom and advice through the years have helped me more than you will ever know. Seeing you as a man of faith has allowed me to follow the same path. I am not sure where I would be without God in my life, he has answered my prayers in ways I didn't even know were possible. In 2002, you mailed me a handwritten letter and at the bottom you quoted Proverbs 16:9 "The mind of man plans his way, but the Lord direct his steps". Those words have helped me through many a-times.

To my Robinson Grandparents. Your happiness in life with each other, your friends and family, and the farm is what brought me to agriculture. Without all those hours spent at the farm growing up and knowing you, my life would have gone down a different path. To my Stone Grandparents. Without your love and determination for every grandchild to get an advanced degree, I would not be completing my Master's degree. Thank you for never giving up on me, teaching me to be strong, practical, well-mannered and caring for others.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

LIST OF APPENDIX FIGURES

1. LITERATURE REVIEW

1.1. Background on Sunflower Breeding

Sunflower (*Helianthus annuus* L.) is one of the few crops which originated in North America. As early as 3000 B.C., sunflowers were widely used as a source of oil and pigments for ceremonies and pottery (Heiser, 1978). When Europeans arrived in North America, explorers brought back cultivated sunflowers. Russians discovered the nutritional value of sunflower seeds during the middle 1800s (Rogers et al., 1982). Starting in 1912, a well-known Russian breeder by the name of V.S. Pustovoit worked for four decades to increase the oil percentage in sunflowers, resulting in increases from about 300 g kg^{-1} to more than 500 g kg^{-1} in seed oil content (Virupakshappa and Rangganantha, 1999).

Sunflowers were then brought back to the United States and Canada when Russian-born Mennonites began to immigrate to North America. Through the mid-1900s sunflowers were grown in large scale production, but only for confection and birdseed. During the 1970s, sunflowers started to be produced on a large scale for the oilseed market, as it is today (Rogers et al., 1982). Sunflowers are now grown across a broad area of the northern and central plains of the US (Fig. 1).

Scientific breeding in North America began in Canada in the 1920s (Miller, 1987). Eric Putt developed open-pollinated sunflower varieties that were earlier maturing, shorter and rust (caused by *Puccinia helianthi* Schw.) resistant (Miller, 1987). The first hybrids were made using nuclear male sterility in the late 1940s, but this was not very effective as female line male sterility was incomplete (Vear, 2010). The discovery of cytoplasmic male sterility (CMS) in 1969 (Leclercq, 1969) and a nuclear gene for restoration of fertility in 1970 (Kinman, 1970) were genetic landmarks in the sunflower industry (Virupakshappa and Ranganatha, 1999). With the use of those two traits, breeders were able to produce F_1 hybrids to be used as cultivars in an efficient manner.

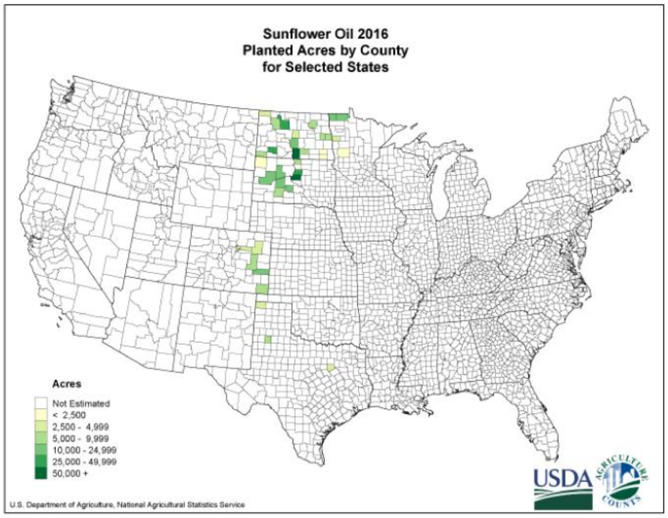

Figure 1. Oilseed sunflower planted acres for the United States in 2016 (U.S. Department of Agriculture, National Agricultural Statistics Service, 2016)

The oil produced from sunflower seeds supplies more vitamin E than any other vegetable oil on the market, with the exception of hazelnut oil (U.S. Department of Agriculture, Agricultural Research Service, 2013). Within oilseed sunflower are three different oil classes: high linoleic (traditional), NuSun® or mid-oleic (NS), and high oleic (HO). Each class differs by fatty acid composition, which affects oxidative stability and human health. Traditional oil is a predominantly polyunsaturated, omega-6 oil due to linoleic acid concentration of 680-720 g kg^{-1}. HO oil is mostly omega-9, monounsaturated fat because of an oleic concentration of $\geq$750 g kg^{-1} (Codex Alimentarius Commission, 2001). NS oil is predominantly a combination of monounsaturated and polyunsaturated fatty acids with moderate oleic concentration of 550-700 g kg^{-1}. Since 2007, 85 to 90% of all the oilseed sunflower hectares in the United States had been transitioned to NS from high linoleic hybrids (National Sunflower Association, 2014). Parts of the world have already transitioned to growing HO sunflower exclusively and the U.S. market is considering converting from NS to HO (Lilleboe, 2012).

Because of its composition, HO sunflower oil has excellent oxidative stability when compared to other frying oils including traditional soybean, palm, and peanut oil (Edem, 2002). Oil with high oxidative stability does not require hydrogenation which is a source of unhealthy trans fats. The Food and Drug Administration (FDA) has recently determined that partially hydrogenated oils (PHOs) are food additives that are not generally recognized as safe (FDA, 2013). The FDA is currently in the process of removing PHOs from the food supply, which has added demand for NS and HO sunflower oil. While traditional oil with high linoleic and low oleic composition is not as desirable for commercial frying applications, omega-6 fats are considered an essential fatty acid which humans cannot make but must supplement in their diet. Omega-9 fats are only conditionally essential meaning that humans may only need to obtain them from food under certain disease and developmental conditions (Asif, 2011). NS benefits from oxidative stability while keeping human health aspects through balancing both monounsaturated and polyunsaturated fatty acids and decreasing the amount of saturated fatty acid.

In breeding programs, experimental parent lines are assessed for many traits in addition to oil quality. Examples include relative maturity, disease, and root strength, but the end goal is still high seed oil content and seed yield because these determine crop value (Vear, 2010). In some countries, growers are paid based on oil yield (kg oil ha^{-1}), and not necessarily seed yield (kg seed ha^{-1}; Vear, 2010). In the United States, producers are paid primarily based on grain yield, but there is an attractive premium for seed oil content over 400 g kg^{-1}. For every 10 g kg^{-1} oil over 400 g kg^{-1}, a grower gets an additional 2% price premium on top of their contracted price. For example, a 440 g kg^{-1} oil content will receive an additional \$1.28 cwt^{-1} if the price is \$16 cwt^{-1} (\$0.32 x 40 g kg^{-1} over 400 g kg^{-1}) (N. Westphal, personal communication, 2012). Now instead of receiving \$16 cwt^{-1}, a producer will earn \$17.28 cwt^{-1}. Every sunflower growing country has a different system: France for example, determines value by grain yield, but also has a discount/premium system for oil with a base of 440 g kg^{-1} (Vear, 2010).

A hybrid breeding program for sunflower requires production of new inbred lines both for male (restorer) and female (cytoplasmic male sterile) heterotic groups (Miller, 1987). Typically, new experimental lines are crossed with a released "tester" line of the opposite heterotic group to produce hybrids for evaluation in multi-location field trials. From this, yield and other agronomically important phenotypes are analyzed across the environments. This information will help determine what inbred lines and hybrids can move forward for seed sales and for future breeding.

1.2. Importance of GxE to Sunflower Breeding

Industry and breeding programs should analyze GxE to understand which hybrids are optimal for end users across the range of potential environments. For example, if certain hybrids generally do better in north central South Dakota than in the soils of eastern North Dakota because of environmental factors, then separate recommendations and testing could be justified if the GxE interaction explains a large proportion of the total genetic variance.

Maize seed companies have been adapting germplasm to specific environments for decades, but only recently have begun using it as their sales pitch. Dupont Pioneer has "FIT ® Services", for field-by-field planning. They suggest they can help a grower to put the "correct" hybrid in their fields to optimize yield. Croplan by Winfield has a similar program called genetics-by-environment interaction. This program aims to help a producer make hybrid placement choices based on the hybrid’s genetic background. One tool they use is called the R7™ Placement Strategy, which determines a proper variety for their field depending on seven areas of agronomic management.

1.3. Techniques Used to Analyze GxE Interactions

There have been a number of statistical techniques used to analyze GxE interaction. Commonly used analyses include: analysis of variance (ANOVA), principal components analysis (PCA), linear regression (LR), additive main effects and multiplicative interaction (AMMI), genotype main effect plus genotype-by-environment interaction (GGE, a specific form of shifted multiplicative model [SHMM]) and factor analytic mixed models (FAMM; otherwise known as multiplicative mixed models or MMM). Some of these models are able to build on each other. For example, ANOVA and PCA can be combined to form AMMI. Both the AMMI and GGE Biplots combine G and GE when conducting mega-environment analysis and genotype evaluation. One of the purposes of PCA, AMMI, GGE, and FAMM is to graphically condense the relationship among the genotypes, environments and/or the interaction into something more intuitive. However, just because the output is displayed in a similar manner does not mean that the procedure to get there is identical or that the interpretation is the same.

ANOVA is the traditional analysis but it lacks power to understand the basis of a significant interaction effect (Crossa, 1990). One of ANOVA’s risks in the context of this study is the large number of degrees of freedom (df) present for the interaction [(G-1) x (E-1)]. This could increase the risk for Type I error in calling significance in multiple comparisons (Zobel et al., 1988; Crossa, 1990).

Linear Regression can be used to dissect the stability of genotypes for specific traits. In this type of analysis, genotype and GxE are not separated into distinct terms (Zobel et al., 1988).

For instance, to determine yield stability, yields for each genotype in each environment are regressed against the mean yields in the same environments and the slope and magnitude of the intercept are used to determine stability and performance across environments. Environments can also be grouped by their characteristics, such as precipitation, and plant traits regressed against these measures. Other characteristics can also be analyzed using LR to understand stability (Finlay and Wilkinson, 1963). With this approach the nature of any interaction could be oversimplified because only one variable can be regressed against the trait of interest at a time. Second, because the model is constrained to linear parameters, the covariates only account for a small amount of the total GxE sum of squares (Zobel et al., 1988).

Principal Components Analysis (PCA) is a generic multiplicative model which converts complex data into simpler linear combinations (Crossa, 1990). Each linear combination is known as a principal component (PC), and while it provides a way to visually examine GxE, the PCs may or may not have an intuitive interpretation to real variables. This procedure works well for GxE if there are only a few PCs involved in the interaction, which ideally are orthogonal and uncorrelated, as multiple PCs with similar importance in the model are difficult to visualize and logically interpret (Crossa, 1990). The first PC is the variable construct with the largest effect; the second PC has the second largest, etc. PCA itself does not include an additive model for main effects, analyzing only the interaction (Zobel et al., 1988).

AMMI is one of the more frequently used methods and is common among genetics, plant breeding and agronomy. It essentially combines ANOVA with PCA analysis by treating main effects, such as genotype, as additive and the GxE interaction as multiplicative (Crossa, 1990; Bernardo, 2010). In AMMI, all effects are considered fixed and the GxE model is typically shown on a biplot or triplot, similar to PCA analysis.

Another type of analysis is the GGE Biplot, which is a special form of the SHMM model (Smith et al., 2005). SHMM and GGE combine genotypic main effects into the GxE interaction, in order to simplify interpretation of the best performing genotypes on the biplot (Smith et al., 2005). This makes it a great tool for answering the practical question of "which genotype wins in what environments." However, the limitations of GGE Biplot have not been completely understood from the standpoint of what happens in this type of analysis if the G and/or E are random effects and how well it can actually detect significant interactions because of the confounded main effect (Yang et al., 2009).

The last type of model often used for GxE studies is FAMM or MMM (multiplicative mixed model), which is the mixed model counterpart to AMMI. In FAMM, the GxE effects are random, and G and E may be considered random effects as well (Resende and Thompson, 2004). As a mixed model procedure, it can work with unbalanced data sets and adequately model heterogeneity of variance between trials, both of which AMMI does not handle well (Resende and Thompson, 2004).

The multiplicative component of FAMM is called Exploratory Factor Analysis (EFA) and is the random effect counterpart to PCA, as they are both variable reduction techniques. PCA describes the percentage of total interaction variation due to unknown, orthogonal variables, but lacks the predictive capacity to determine the true number of unknown variables (known as common factors) like EFA (Suhr, 2005). EFA first resolves common factors, which suggest a trend over multiple environments because of a putative real, but unidentified cause, and the remaining GxE falls into unique factors, which could be error due to unreliability in measurement or GxE effects unique to a single environment. Ideally, common factors could be used to describe mega-environments (Suhr, 2005). Comparing the common factor loadings for each environment to known conditions (such as weather) at each environment may help identify the real basis of common factors. Once common factor loadings are identified, Pearson correlations can be calculated for each hypothetical environmental variable, such as rainfall, temperature, latitude/longitude, soil type and tillage. Very high correlations would indicate a strong linear relationship between an environmental characteristic and common factor loadings, which may demonstrate the basis of the common factor.

1.4. Previous GxE Research in Sunflower and Other Crops

Ahmed and Abdella (2009) conducted a GxE study in Sudan because there was a lack of information about the stability of sunflower hybrids under Sudanese growing conditions. Their knowledge of the landscape suggested there may be mega-environments related to variability in pH, fertility of soils, temperature, altitude and rainfall. This study was carried out at two locations, one in eastern Sudan (semi-arid) and the other in the central plains in both the summer and winter seasons. A randomized complete block field design with four replicates per location was combined with conventional Analysis of Variance (ANOVA) to estimate the GxE variance. Their results showed a significant GxE interaction for yield, and means comparisons showed that most of the twenty hybrids evaluated had a change in rank across environments. The authors concluded the hybrid which showed stability and adaptation across all environments also did the best under adverse environmental conditions.

In Argentina, ten sunflower hybrids were observed in 21 environments with a goal to characterize environments, find possible mega-environments, interpret changes in yield and find environmental causes for GxE (de la Vega et al., 2001). The environments fell into three categories: northern, central and managed (irrigated) areas. Their research suggested that the central and northern environments are different mega-environments with the underlying causes being photoperiod and minimum temperature. The authors concluded that selecting hybrids separately for northern and central environments would be beneficial for efficient genetic gain over selecting for a broad adaptation. Most breeding centers are in the central region, however late planting in the central areas correlated with results from the northern plots, most likely due to photoperiod. These findings suggest that preliminary or early generation testing for the northern environment can be conducted efficiently by late planting near the breeding centers.

Later work by de la Vega and Chapman (2006) built on this research to test this hypothesis of breeding for adaptation to specific regions in Argentina. The authors used 10 sunflower hybrids in 46 environments to predict how a breeding program might benefit from having separate germplasm and evaluation for each mega-environment. The predicted ratio of correlated response, which factors in heritability in each environment and correlation between environments for the trait of interest, showed that selecting for specific adaptation to the two Argentine mega-environments was 3 times more effective than selecting for broad adaptation. Sub-regions within the regions were further analyzed for the possibility of exploiting more repeatable GxE and further dividing the regions. However, the G: GxE ratios were high, suggesting that there was little additional GxE that could be converted to G variation by this approach.

GxE for fatty acid composition was also studied in Argentina, where temperature is a major environmental variable across the growing region (Izquierdo et al., 2002). Overall, higher night temperatures produced higher oleic acid levels regardless of the daytime temperature. HO hybrids were less affected by environmental conditions as compared to traditional or NS hybrids. Yield was not affected by these differences in daytime or nighttime temperatures (Izquierdo et al., 2002). Flagella et al. (2002) repeated this finding in Italy with HO, but also found irrigation to be a factor. While high temperature and irrigation increased yield, they decreased oleic composition.

In 1978, Harris and colleagues studied how temperature can influence oil content of sunflower seeds in Australia. They began the study after observing large variation of oil content in the country, ranging from 30-50%. Similar oil content differences are found in the United States among different environments as well. They concluded high temperatures during seed development were associated with lower oil content. In addition to temperature, moisture stress and diseases also contributed to variation in oil content. Over all of the seed development stages, no single stage was more susceptible to these stresses over others, instead it was a cumulative process.

There are many causes for root lodging, including genotype, soil type, sunflower growth stage at the severe weather event, and plant density in the field. Sposaro et al. (2007) attempted to dissect these factors with two different hybrids grown at two locations, each providing different root lodging susceptibility or stress. The experimental plots were evaluated with a mechanical lodging instrument which applies force on plants with a pulley system. In coarser soils, the root plate diameter of the plants was shown to be significantly greater, thus showing a better tolerance to root lodging. A significant difference was shown in lodging between the R2 and R5.9 stages, with the earlier stage displaying better resistance. Lodging susceptibility increased with higher plant density in both hybrids. However, higher yields are also correlated with higher plant densities. The authors make note of the importance for breeders to not only select for high yields, but also for greater root anchorage strength.

In 2001, Leon et al. made note of GxE interaction for days to flowering (DTF) in sunflowers. DTF is complex and mainly determined through genotype, photoperiod and temperature. Since DTF is related to maturity, it is important for environmental adaptation and maximizing yield potential. The authors found that selecting a hybrid in its correct maturity range can also help with overall oil yield, as sunflowers are particularly sensitive to the environment during grain-fill (stages R7 and R8). So if a genotype is not adapted to its area in terms of maturity and flowering, then grain fill could be reduced, thus resulting in lower than expected yield.

In France, Foucteau et al. (2001) researched underlying causes of GxE in 30 sunflower yield trial sites. They divided hybrids into two categories: early to mid-early (E/ME) and mid-early to mid-late (ME/ML). The environments were separated into short season and long season regions based on growing degree days and north/south geography. The authors created two covariate models (E/ME and ME/ML) to determine environmental and genotypic covariates that influenced adaptation to the short and long season regions, respectively. The models had poor fit when used in opposite regions. The genotypic covariates for the ME/ML model included: Sclerotinia resistance, moisture content at harvest, and Phomopsis resistance. Environmental covariates included: water deficiency from sowing to emergence, radiation days from sowing to flowering, moisture content at harvest, water deficit from emergence to B9, and fungicide treatment. The genotypic covariates for the E/ME model included: degree days based on 6ºC from sowing to flowering, Phomopsis resistance, and oil content. Environmental covariates included: degree days based on 6ºC from sowing to flowering, oil content, water deficit during flowering, water deficit from B9 to beginning of flowering, and moisture content at harvest. Two common covariates (Phomopsis and moisture content at harvest) were found between the models, suggesting that selection for adaptation will require different targets in each region.

Kang and Gorman (1989) found that maize yields in Louisiana were influenced more by cultural practices and fertility than weather factors. They determined this on the basis of a covariate analysis including weather variables, such as maximum/minimum temperatures, rainfall prior to the season, rainfall and relative humidity during the season, and GxE environmental indexes (mean yield of all cultivars in a location minus overall mean yield for all cultivars and all locations). The environmental index GxE contributed to the largest percent (9.61%) of GxE variation of all the covariates. The weather covariates were found to be minor and statistically insignificant.

1.5. Environmental and Geological Background on our Study Region

Four geological regions of agricultural importance are found in North Dakota and the surrounding region: Missouri Slope, Missouri Coteau, Glaciated Plains and Red River Valley (Enz, 2003; Fig. 2). The regions to the west tend to have lower organic matter and the soil is often loam or sand-based. The effects of soil types on germination have been studied for sunflowers and Idu et al. (2003) found light sandy soil to promote significantly better germination than clay. Potential reasons included poor aeration, water logging, and crusting due to the structure of clay soil. The geological regions may also show geographical differences with regards to daylength and day and night temperatures, which may affect DTF (Leon et al., 2001). In addition, the tillage system changes from east to west. No-till is the system of choice in the western part of the region, while conventional tillage is more typical of the eastern portion. This too could have an effect on germination rates and seedling emergence. It takes no-till soils longer to warm up in the spring and dry out than a freshly tilled field, which can delay emergence or planting dates (Fortin, 1993). No-till does, on the other hand, have many benefits to producers in the western region of the state where moisture can be a limiting factor. No-till is known to capture snowmelt, control moisture evaporation, reduce erosion loss and minimize soil disturbance (Lal, 2007). Nonetheless, if no-till was practiced in the Red River Valley, yield could potentially be reduced in the poorly drained clay-type soils, especially in the spring when cold and wet weather is common (Lal, 2007).

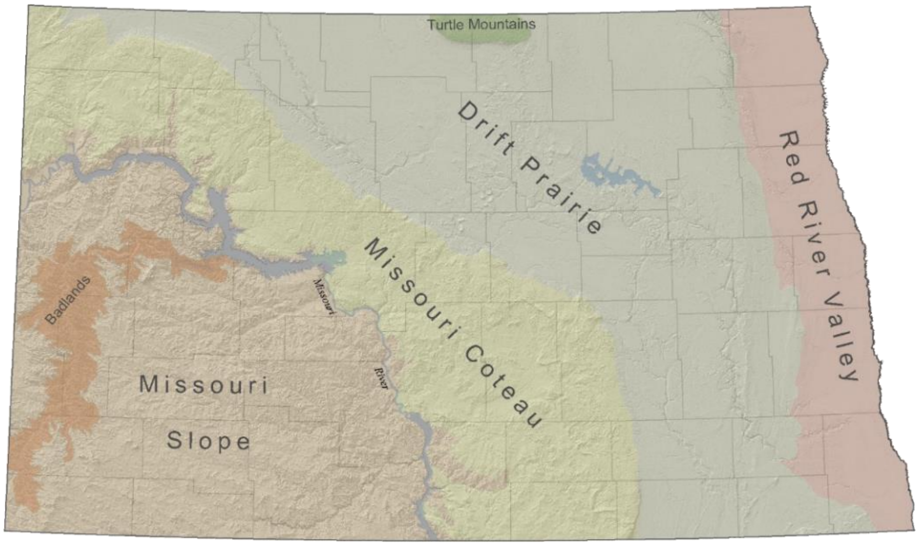

Figure 2: Geographic regions of North Dakota (ND Game and Fish Dept., 2018).

The Missouri Slope is comprised of sandstone and shale layers, differentiating it from the eastern part of the region. This is mainly due to this area not being affected by the glaciers during the last ice age (ND Game and Fish Dept., 2018). The topography is hilly to gently rolling with an occasional butte. Soil types have a higher percentage of silt and loam, the average amount of rainfall is less and the temperatures are typically warmer. The Temvik-Wilton silt loam in Mandan is an example of one of the soils found in the Missouri Slope. These soils are typically well-drained with moderate permeability. The main issues for this region are controlling erosion during severe weather events, conserving moisture (no-till) and maintaining fertility. Most of the land area is cultivated in small grains, but many other crops are suitable. Growing sunflowers in this region is popular due to their ability to root down to water 1.2 meters below the soil surface (Berglund, 2007)

Bordering the Missouri River to the east is the Missouri Coteau. This 48 to 113 kilometer wide area of steeply rolling topography has many wetlands (Enz, 2003). During the last ice age, the glaciers in North Dakota extended along the Missouri Coteau and east. The majority of this area is under no-till cultivation and is suitable for many row crops, but moisture availability is a concern. However, during wet periods, the water table can be as high as 1.2-1.8m below the soil surface. With a soil type that has a moderate shrink-swell capacity and is well-drained, both the Missouri Slope and the Missouri Coteau regions grow a large amount of small grains and sunflowers, with the more undesirable land used for livestock pasture (ND Game and Fish Dept., 2018).

To the east of the Missouri Coteau is the Glaciated Plains or Drift Prairie region. This region covers the majority of the rest of the state extending from the northwest to the southeast. This land was recently glaciated so it is much flatter than the regions to the west. There are gently rolling hills with many prairie potholes across the landscape (ND Game and Fish Dept., 2018). These soils are typically well-drained with moderate permeability due to a combination of clay, sand and gravel. The western region, where more sunflowers are grown, is a fine-loamy soil, versus the eastern region, which has a higher percentage of coarse particles.

Lastly, the Red River Valley (RRV) area is much different geologically than any other part of the region. This area is extremely flat and, from north to south, it only changes 55.5 meters in elevation (Enz, 2003). From its start in Wahpeton, ND, to Lake Winnipeg in Canada, it runs 515 kilometers south to north and extends 48-64 kilometers on either side of the river east and west. The flatness of the valley is due to it being the bottom of ancient Lake Agassiz, which left behind very fertile lake-laid material with high organic matter. Covered with silt and clay deposits, it is regarded as some of the most fertile soil in the world (ND Game and Fish Dept., 2018). The soils are deep, poorly drained, with moderate-slow permeability. In wet years, the water table can reach 0.5-1 m. There is very little pasture and most land is farmed. The increased moisture can lead to disease problems in sunflower. On the edges of the old lake bed are remnants of beach ridges. Fine-sandy loam soil soils are common on these interbeach/lake plains areas. Although these beach ridges are still in the RRV and as such are somewhat poorly drained with a high water table, the soil is moderate-rapid in permeability because of the increase in sand and loam. This can be better for sunflower with regards to limiting disease development and improving oxygen status of the soil.

2. GENOTYPE-BY-ENVIRONMENT INTERACTION IN SUNFLOWER HYBRID VARIETY TRIALS IN THE NORTHERN PLAINS

2.1. Introduction

Hybrid sunflower (*Helianthus annuus* L.) is grown on 26.9 million ha (NSA, 2017) across 60 countries, with the United States growing 567,774 ha (NASS, 2017). The Northern Plains region (Minnesota, North Dakota, and South Dakota) combined produces 444,628 ha (NASS, 2017). The region is divided into four geographical regions: Missouri Slope, Missouri Coteau, Glaciated Plains, and the Red River Valley (Enz, 2003). Each geographical region has distinct climate, soil, landscape, and agronomic practices. These distinctions have been observed to affect sunflower hybrid performance, and some hybrids may be more sensitive to environmental differences than others. Ahmed and Abdella (2009) noted that efficient breeding should emphasize yield stability, where a hybrid performs well under adverse environmental conditions and is adapted to multiple environments or mega-environments. A mega-environment is formed when a group of evaluation environments differentiate hybrids in a similar manner (Yan and Rajcan, 2002). The concept of mega-environments and their role in interpreting evaluation data has been recognized as an important step to understanding multi-environment trials (METs) for over half a century. By grouping like environments in analysis and interpretation, a breeder can be assured that they have enough statistical power to thoroughly vet a new hybrid product for specific mega-environments, or for compatibility in multiple mega-environments. Conversely, they can also determine where a new hybrid is likely to fail to meet producer’s standards. METs are simple in theory; however, budget limitations and lack of resources can sometimes make it difficult, in practice, to obtain this large amount of phenotypic data, especially when the breeding centers are not located within the main production region.

These observations have led researchers to study Genotype-by-Environment (GxE) effects. Miller et al. (1958) studied the effects of the GxE interaction in cotton (*Gossypium herbaceum*) for selection of varieties, and many other crops have also been analyzed, the most noteworthy being maize (*Zea mays*) (Falconer and Mackay, 1996). Many of the sunflower growing countries of the world also studied GxE including: South Africa (Schoeman, 2004), India (Amahla et al., 2007), Sudan (Ahmed and Abdella., 2009), Pakistan (Ullah et al., 2007), France (Foucteau et al., 2001) and Argentina (Leon et al., 2001). Yet in the United States, a thorough analysis of GxE for oil and yield in the main production region has not yet been published for sunflowers. Zaffaroni and Schneiter (1991) and Gross and Hanzel (1991) researched some components of GxE in North Dakota, but neither specifically analyzed both grain yield and oil content. Zaffaroni focused on the effects of a standard height sunflower versus a semi-dwarf pertaining to plant populations and row arrangements in two environments. Gross and Hanzel's objective was to determine if the physical traits found to protect sunflowers from bird damage were stable throughout multiple environments.

Our objectives are to (i) study GxE so that we may begin to understand how many mega-environments require evaluation in a breeding program for sunflower in the Northern Plains and where they are located, and to (ii) determine the underlying variables which contribute to GxE in the Northern Plains using model fitting with multiplicative mixed models.

2.2. Materials and Methods

2.2.1. Germplasm

This study will be using every available oilseed A-line that was developed by the USDA since 1970, for a total of 81. The A-lines show a wide range of diversity and many have been included in the SAM association mapping panel (Mandel et al., 2013). These A-lines were crossed to two R-line testers (RHA 373 and RHA 377) that were released in 1990 and have vastly different pedigrees, which make them ideal testers for estimating general combining ability for yield, disease resistance, and agronomic traits. The crosses were made in 2012 at a winter nursery site in Rancagua, Chile. In 2012, 157 A-line/R-line hybrids were evaluated, along with eight industry hybrids and four modern check hybrids from the USDA, totaling 169 hybrids (Table D2). Not enough seed was produced for 30 of the hybrids at the 2012 winter nursery site, so an additional increase of these hybrids took place in winter nursery the next year, before the 2013 summer field season. Unfortunately, not all of the plants produced enough seed for the 2013 season. These eight hybrids were substituted with industry hybrids that were not already in the trial but are widely grown in the region (Table D1).

2.2.2. Environments

This experiment consists of six environments in the USA: Velva/Minot (Velv), Mandan (Mand), Wyndmere (Wyn) and Carrington (Carr), ND; Crookston (Crk), MN; and Eureka (Eurk), SD (Fig. 3). Velv, Wynd, Mand and Eurk were planted, maintained and harvested by the USDA. The Crk location was planted and harvested by Croplan Genetics and the Carrington Research and Extension Center planted and harvested their onsite location. These locations were chosen based on the regions where sunflowers are grown and where assistance could be provided in a way that would be conducive to small plot research. The environments varied for rainfall amounts, latitude, soil type, populations, tillage practices, geology, and geography. Cultural practices are described in Table 1 and environmental characteristics in Table 2.

Table 1: Cultural differences among evaluation environments

Loc†	Planted	Fertilizer Form‡	Fertilizer Rate	Herbicide Active Ingredient	Rate	Insecticide Active Ingredient	Rate
			--kg/ha--		--ml/ha--		-ml/ha-
Crk	22-May-12	N/A	N/A	sulfentrazone+carfentrazone‡‡	118	chlorpyrifos	473
						lambda-cyhalothrin	113
Carr	12-Jun-12	46-0-0	56	ethalfluralin, quizalofop§§	946	chlorpyrifos + gamma cyhalothrin, esfenvalerate	1124
Mand	21-May-12	46-0-0	112	Glyphosate	828	esfenvalerate#	251
				sulfentrazone+carfentrazone	118		
Velv	31-May-12	N/A	N/A	sulfentrazone+carfentrazone	118	esfenvalerate	284
				Clethodim	237		
Eurk	5-Jun-12	98-20-0§	280	glyphosate, sulfentrazone	651, 118	esfenvalerate#	284
Wyn	1-Jun-12	14-31-36	151	None	0	lambda-cyhalothrin#	59
Crk	8-Jun-13	29-14-7§	393	sulfentrazone+carfentrazone	118	lambda-cyhalothrin	113
				Imazamethabenz	237		
Carr	11-Jun-13	0¶	0	ethalfluralin, quizalofop	946, 296	none	0
Mand	11-Jun-13	46-0-0	112	sulfentrazone+carfentrazone	118	esfenvalerate	266
				glyphosate, clethodim	946, 237		
Velv	17-Jun-13	46-0-0	112	pendimethalin, sulfentrazone	1420, 118	esfenvalerate	284

† Crookston (Crk) Carrington (Carr) Mandan (Mand) Velva (Velv) Eureka (Eurk) Wyndmere (Wyn)

‡ Fertilizer formulation corresponding to the level of N-P-K in the blend; N/A = not known

§ Minor amounts of S and Zn were included in the fertilizer blend

¶ No fertilizer was added because the soil test showed 101 kg N/ha

\# 147-177 mL/ha of pyraclostrobin fungicide was in the tank-mix with insecticide

‡‡ sulfentrazone + carfentrazone, ethalfluralin, glyphosate, sulfentrazone, and pendimethalin were all applied preemergence

§§ quizalofop, clethodim, and imazamethabenz were applied postemergence

Table 2. Environmental characteristics of sunflower trial sites, 2012-2013.

Location†	**Region**	**Soil Type**	**Lat‡**	**Long§**	**Elev¶**
			---- degrees ----		-- meters --
Eurk12	West/South	Bryant-Grassna Silt Loam	45.8	99.6	564.9
Carr12	Central	Silt Loam	47.4	99.1	447.6
Crk12	North/East	Bearden Silty Clay Loam	47.7	96.6	268.8
Mand12	West	Temvik-Wilton Silt Loam	46.8	100.9	504.9
Wyn12	South/East	Borup Silt loam and Mantador-Delamere-Wyndmere fine sandy loam	46.3	97.1	290.4
Velv12	West/North	Barnes-Svea Loam	48.1	100.9	449.7
Carr13	Central	Silt Loam	47.4	99.1	447.6
Crk13	North/East	Bearden Silty Clay Loam	47.7	96.6	268.8
Man13	West	Temvik-Wilton Silt Loam	46.8	100.9	504.9
Velv13	West/North	Williams Loam	48.2	101.3	483.3

† Crookston (Crk) Carrington (Carr) Mandan (Mand) Velva (Velv) Eureka (Eurk) Wyndmere (Wyn), followed by the year

‡ Latitude in degrees North

§ Longitude in degrees West

¶ Elevation above sea level

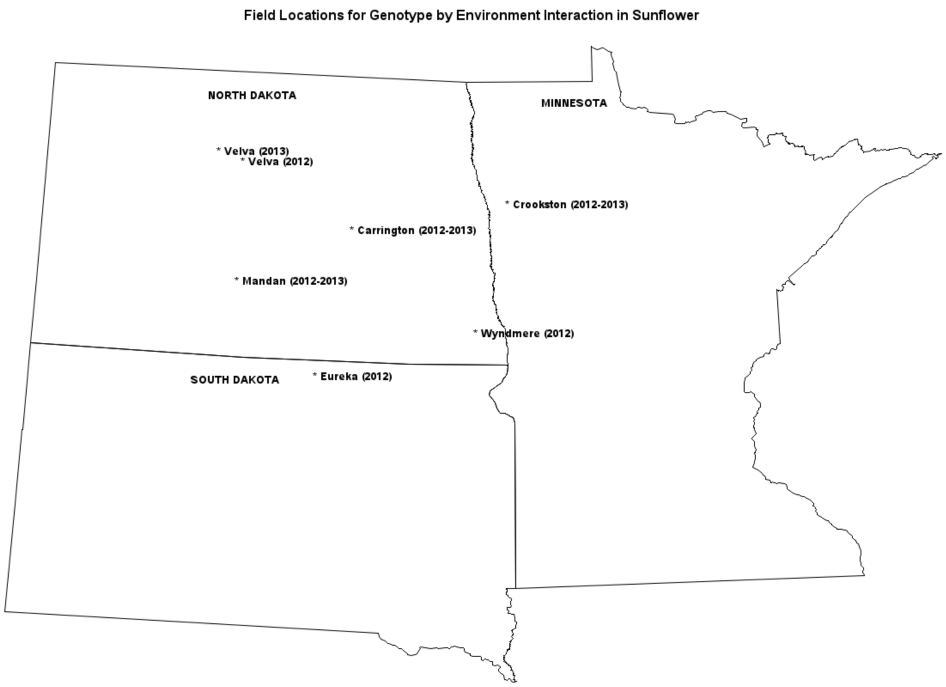

Figure 3. Ten location trials for genotype by environment sunflower regions.

All geographical regions of interest in the Northern Plains are represented. Crk is located in the Red River Valley (RRV) and Wyn is situated between the RRV and the Drift Prairie on the beach ridges of Lake Agassiz. Both Velv and Carr are situated in the Drift Prairie region. Eurk is in the Missouri Coteau region and Mand is on the edge of the Missouri Slope. Over all environments, the elevation variability ranges by almost 300 meters with Crk being the closest to sea level and Eurk as the highest point.

2.2.3. Experimental Design

The field design for each environment is a randomized complete block design (RCBD) with a nested simple lattice design (Cochran and Cox, 1957). There were 169 treatments with 13 incomplete blocks and 2 replications at each environment. The actual plot length varied based on the layout of the land available and the planting system used by each cooperator, but in general all locations had two row micro-plots between 6 and 7 meters in length. Each genotype was planted at a higher population and then thinned to 49,400 to 56,810 plants ha^{-1}, depending on local recommendations. The Crk site used a Precision Planter (Precision Planter, Tremont, IL) which plants slightly above recommended population, and therefore, only required thinning out of doubles (two plants placed close together because of technical reasons). Other locations were planted with a belt cone or standard cone planters (Almaco, Nevada, IA).

Agronomic notes were taken based on the methods of Hulke and Gulya (2015). Notes on lodging was assessed on a 1-9 scale, with 1 showing no lodging. Bird damage (BD) was taken as a visual assessment of individual heads aided by damage pictographs and averaged across assessments within a plot, and height was measured by taking a three-plant median per plot. Flowering and maturity dates were taken at the Wyn location only as days after planting to 50% blooming plants and 50% mature plants, respectively. Disease notes were to be taken only at locations showing stalk disease symptoms. Disease was quantified through an overall health score of the stalks called a disease incidence score (DI) from 1-9 with 1 showing no disease and 9 being complete infection. Predominant diseases present were also noted for each environment.

All plots were maintained in accordance with common practices for the area and given knowledge of weed and insect pests in the area. Ideally, the sunflower plots were placed in a field surrounded by other sunflowers so it would get treated the same as a producer's field for fertilizer, chemical, fungicide and insecticide treatments. Unfortunately, at some locations this was not feasible, but plots were still treated according to locally recommended practice. Carr12, Carr13, and Velv13 were at NDSU Research Extension Centers. Crk12 and Crk13 were planted in the same area as other Croplan sunflower trials but was not itself surrounded by a sunflower field. Wynd13 was in a joint location with Nuseed next to their sunflower breeding nursery.

2.2.4. Statistical Design

Statistical analysis was conducted using multiplicative mixed models with covariate terms and exploratory factor analysis (EFA) of the GxE term. Since the field design is both an RCBD and a simple lattice with repetition (Gomez and Gomez, 1984), statistical models appropriate for both types of field designs were analyzed and compared for relative efficiency.

The basic RCBD model is:

$$Y_{ijk} = \mu + E_i + r[E]_{ij} + g_k + gE_{ik} + e_{ijk}$$

Where Y_{ijk} is the ijk^{th} observation; μ is the experimental mean; E_i is the effect of environment i; $r[E]_{ij}$ is the effect of j^{th} rep within the i^{th} environment; g_k is the effect of genotype k; gE_{ik} is the pooled genotype by environment effect; and e_{ijk} is the random error.

By extension, the simple lattice model becomes:

$$Y_{ijkl} = \mu + E_i + r[E]_{ij} + b[rE]_{ijl} + g_k + gE_{ik} + e_{ijkl}$$

The main difference between the lattice and the RCBD model is an additional term to control in-field variation and decrease error variability. The $b[rE]_{ijl}$ is the l^{th} incomplete block within the j^{th} rep and the i^{th} environment.

Within these basic models, there could be unidentified, common factors that can be exposed within gE. These can be added by substituting the gE_{ik} term for $\Sigma^z \beta_{iz} x_{kz} + v_{ik}$, an EFA submodel, where z is the number of common factors determined by the best fitting model. The first EFA term contains all z common factors, and the second term encompasses all unique factors (residual gE; Piepho, 1998). The common environmental basis of GxE can potentially be exposed by correlating the common factor loadings to known location characteristics, such as those in Table 3. For example, if Factor 1 has a significant negative correlation with seasonal precipitation at each environment, Factor 1 could be abiotic stress related to soil moisture.

Table 3. Environmental variables used for possible correlations.†

Temp‡	**Moisture**	**Flowering Characteristics§**	**Planting Conditions**	**Land Characteristics**
Minimum & Maximum	Nov-March	Pre-Flwr Max Temp	Planting Date¶	Regional Dir#
May-Sept	April-Oct	Pre-Flwr Min Temp	Soil Temp	Soil Type
May	monthly	Flower Max Temp		Elevation
June		Flower Min Temp		Tillage
July				Population
August				
Sept				

† Correlations were ran with factors determined from Exploratory Factor Analysis with ASReml software

‡ Temperature (Temp), September (Sept), November (Nov), October (Oct), Pre-Flower Maximum/Minimum Temperature (Pre-Flwr Max Temp, Pre-Flwr Min Temp),

§ A fifteen day period of temperature was recorded starting 10 days before the plot reached mid-flower

¶ Analyzed using days after January 1st

Regional direction (Regional Dir) is a numbering scale 1-5 given to all locations based where they are at geographically

Of the data collected, there are some traits that are known to negatively correlate with yield, but their importance to total GxE in our target region is unknown. These include lodging, bird damage, disease, maturity and flowering date. Linear regression (or covariate) terms for these were included in some models before the EFA terms were fit to determine if they are important within pooled GxE (i.e. are statistically significant, improve model fit, and/or replace a common factor).

In multiplicative mixed models, in particular, the best model can be difficult to determine without objective criteria. To select the best model, Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used for model selection (Posada and Buckley, 2004).

Where l is the log likelihood; K is the number of estimable parameters; n is the number of genotypes:

$$\text{AIC} = -2l + 2K$$

$\text{BIC} = -2l + K \log n$. These criteria have a goodness of fit term and include a penalty for overfitting (Dziak et al., 2012). BIC criteria generally leads to the most parsimonious model and risks underfitting. AIC on the other hand, risks being too liberal (Dziak et al., 2012).

2.2.5. Software

Models were fit using ASReml 3 software (VSN International Ltd, Hemel Hempstead, United Kingdom). This software was produced specifically for fitting linear mixed models and has the ability to work with large datasets and complex models. It uses the average information algorithm, which provides a solution to the computational efficiency issues surrounding large sample mixed models. It also has the ability to interactively fit additional terms to models, making it possible to conduct stepwise model fitting and comparison. Subsets of data, such as individual locations and groups of contrasting hybrids, were analyzed with an ANOVA using Proc GLM or Proc Mixed of SAS 9.4. Correlations were calculated using Proc Corr of SAS 9.4 and pairwise linear regressions were calculated with the lm function in R.

2.3. Results

2.3.1. Weather and Environmental Observations

Our experiment captured environmental differences in terms of locations and years. High/low temperatures and rainfall for the main growing months can be found in Table 4, along with the average for each location and year. 2012 was much drier overall and average temperatures during flowering were higher. A breakdown of all the temperature variables and rainfall amounts for the growing months are found in the appendix (Table A2 & A3). Planting dates also varied from year to year (Table 1) as a wet spring in 2013 delayed planting for most of the region and brought more rain and cooler temperatures. Velv13 received almost twice as much rain as the average (586 mm versus 298 mm) (Table 4) during the growing season and experienced slightly below average temperatures. Planting was the latest of all locations, on June 17, due to excess moisture. Late planting, plus cooler temperatures led to a delay in flowering and a wet harvest. Yields were second lowest at 1458 kg ha^{-1}.

Table 4. Average (avg) high and low temperatures, June-August high and low temperatures and rain compared to genotype by environment sunflower plots in 2012 and 2013.†

		High Temp	Low Temp	June High	June Low	July High	July Low	Aug High	Aug Low	Rain
		------------------------------------Celsius							--	mm
Carrington	Avg	25.3	10.2	23.8	11.4	26.6	14.0	26.3	12.3	315.0
	2012	24.3	9.9	25.0	12.2	29.0	15.7	25.7	10.8	272.0
	2013	23.5	10.4	24.0	11.9	26.1	13.1	26.8	12.4	237.8
Crookston	Avg	23.6	10.6	24.2	12.1	27.0	14.2	26.5	12.9	393.0
	2012	25.6	8.6	25.4	12.7	31.0	16.8	27.5	11.5	205.2
	2013	24.6	11.1	25.1	12.9	27.5	14.3	27.9	12.5	310.6
Eureka	Avg	25.2	11.2	25.3	12.1	29.2	15.1	28.5	14.1	345.0
	2012	26.2	10.2	27.2	12.4	31.5	16.9	27.4	11.0	218.8
Mandan	Avg	24.4	10.5	24.4	11.4	28.4	14.4	27.8	13.2	337.0
	2012	26.0	10.2	26.4	11.8	31.0	16.1	27.6	11.8	275.9
	2013	24.8	11.0	23.9	11.7	27.7	13.6	29.1	13.9	366.9
Velva	Avg	24.4	9.3	25.1	10.8	27.9	13.2	27.4	11.4	298.0
	2012	24.3	10.8	23.9	12.2	28.9	16.4	27.5	12.5	174.6
	2013	22.9	11.4	22.9	12.5	24.9	14.2	26.3	14.3	585.6
Wyndmere	Avg	24.8	12.1	25.3	13.3	28.3	15.9	27.6	14.9	387.0
	2012	26.7	11.7	27.7	14.4	31.1	17.9	28.0	11.8	256.8

† Average high and low temperatures and rainfall was taken May-September at the nearest North Dakota Agricultural Weather Station and South Dakota State Weather Station

In 2013, two environments were destroyed due to severe weather. On August 6, 2013, the Wyn plot was destroyed by hail. No relative maturity notes were available in 2013 due to the hail damage at Wyn. In September, the Eurk plot was subjected to high winds, completely lodging over 90% of the sunflowers in the trial. Another noteworthy event occurred on October 4, 2013, when a snowstorm left 15 cm of wet snow, causing damage to the plot, but still allowing for harvest. Lodging notes were taken before and after the storm on all hybrids in that environment for yield analysis purposes.

Table 5 shows the average yield and oil at each environment along with the traits measured. The average lodging scores were the second highest at Velv12 out of all environments and years. This was not seen in the DI scores, as disease pressure was very low but excessive winds that came through the area before harvest. Disease notes were only taken at Wyn12, Crk13, and Velv13 due to a lack of disease in all other areas. Only Phomopsis stem canker disease (caused by *Diaporthe* sp.) was observed in biologically noteworthy amounts.

Table 5. Location means for measured traits at sunflower trial sites 2012-2013.

Environment	Oil	Yield	Bird Damage	Height	Disease score‡	Lodging	Late Lodging‡
	-g/kg-	-kg/ha-	---%---	--cm--			
Carr12†	382.4	2153	1.3	186.5	--	2.4	--
Carr13	436.9	1457	0.5	164.8	--	2.6	--
Crk12	436.4	3691	9.5	154.6	--	2.2	--
Crk13	458.3	2972	--¶	178.5	3.3	3.2	--
Eureka12	398.7	2757	0.8	161.7	--	2.2	--
Mandan12	427.6	2500	14.1	170.4	--	2.2	--
Mandan13	434.4	1162	16.9	183.3	--	2.8	5.5
Velva 12	421.1	2384	--	195.7	--	4.7	--
Velva 13	427.3	1458	5.1	188.5	4.0	2.9	--
Wyn12	437.6	2745	6.0	188.8	3.1	4.3	--

† Crookston (Crk) Carrington (Carr) Mandan (Mand) Velva (Velv) Eureka (Eurk) Wyndmere (Wyn), followed by the year.

‡ Disease scores measured the amount of disease present on a scale from 1-9

§ Lodging scores were taken at all locations, but a second set of scores at Mand13 were taken due to an early season snowstorm causing additional damage (late lodging) to account for the yield loss

¶ Denotes that no information was taken for that location and trait due to lack of presence

Notes were only taken at 8 locations for BD due to low pressure at the other environments. The largest percentage of average bird damage (16.88%) was in Mand13, despite the use of a propane cannon to scare away the birds, although some of this may have been due to wind and snow shattering.

A pre-emergent application of sulfentrazone (trade name Spartan®) was not able to be put on before the plants emerged in Wyn12. Weeds were controlled by hand until the plants shaded the rows. The shallow water table and high residual nitrogen at the site allowed for vigorous plant growth and development. Due to the resulting excessive height (189cm on average), some lodging occurred, making the location 2nd highest in lodging scores (mean=4.34 out of 9). Carr13 had the lowest yield of all environments at 1153.52 kg ha^{-1}, but the oil remained average (Table 4). This is the only location that received no fertilizer in the field, but soil tests showed 101 kg N/ha^{-1} (90 lb A^{-1}) (Table 1).

2.3.2. Multiplicative Mixed Model Results

We compared 247 models for yield and 218 for oil using various combinations of the following covariates: DI, maturity, flowering, BD, height and lodging, and attempting as many as 3 common factors. Terms were also fit to accommodate either a simple lattice or RCBD field design. The AIC and BIC scores were identified for each model (Table D1). Overall, inclusion of incomplete block effects for the lattice design led to the best model solutions for both traits.

For yield, the best model according to the BIC included terms for lodging, BD and DI, but with no common factors in the factor analytic decomposition of GE effects (Table 6). For the AIC, one common factor that explained a practically insignificant proportion of variance was identified, in addition to lodging, BD, DI, and height as linear covariates. In both yield models, lodging and bird damage contributed most of the GxE variation, with the BIC model including a substantial amount of variation in unique factors. All three of these covariates and factors are unpredictable from year to year and site to site. The oil analysis produced much different optimal models than yield. The best oil model according to BIC included two common factors and the AIC led to selection of two common factors with lodging, BD and height as statistically significant, but minor, linear covariates. The oil AIC and BIC models were very similar in that most of the GxE variation was due to common factor 1. The relative importance of each of the covariates and factors on yield and oil content at each location are shown in Tables 7-10.

Table 6. Pooled variances for random effects across all locations and years.

Effect	Yield AIC Variance		Yield BIC Variance		Oil AIC Variance		Oil BIC Variance	
Block (rep x env) †	16935.40	***	18609.41	***	0.3250	***	0.3517	***
Rep (env) ‡	8923.03	ns	9488.81	ns	0.3663	*	0.3617	*
Entrynumber	13550.30	***	26212.60	***	1.4582	**	1.1157	*
Total GxE	1498644.33		1908689.96		20.8845		19.5694	
Covariate Lodging	1023173.92	***	967449.85	***	1.0698	**	--	
Covariate Height	48863.99	***	--		2.1172	***	2.2403	ns
Covariate Bird Damage	407787.26	***	396977.83	***	0.8312	***	--	
Covariate Disease Incidence	18812.20	***	18877.48	**	--		0.1386	ns
Unique Factors §	2.96		525384.80		3.8187		3.7564	
Common Factor 1	4.00	***	--		11.8476	***	12.2491	***
Common Factor 2	--		--		1.2000	***	1.1850	***
Residual Error	122729.00		126936.00		2.5064		2.5525	
Total Variance	1660782.06		2089936.77		24.1689		22.6196	

† Block, entry number, covariate height, bird damage, and green stalk, common factor 1 and 2 variance significance was determined using log-likelihood ratio statistic

‡ Rep and entrynum variance significance was determined using the Wald test

§ Pooled unique factors were not able to have the log-likelihood ratio test ran due to missing parameters need for the test

Lodging notes were taken at all locations regardless of disease or wind pressure. Lodging, which accounts for over 50% of the total GxE variation for yield, is unpredictable in nature and is due to a combination of susceptible plant stage, severe weather events, and lodging resistance due to genetics. Height may also be related to lodging, so it is no surprise to see a significant correlation between height and lodging in seven of the ten linear regression graphs across a range of environments (Figures C1-32) (Kiani and Sarrafi, 2010).

Disease and height are not significantly correlated at any location, along with height and BD where seven of the eight locations were found to have no significant correlations either. Velv13 and Wyn12 were the only locations with disease and bird damage notes both taken. Wyn12 had a highly negative correlation between the two factors ($P \leq 0.001$), the higher the DI score, the lower the percentage of BD (Figure 4). This is also the same location that had a negative correlation between lodging and BD ($P \leq 0.001$) (Figure 5). The higher the lodging score, the less BD that occurred. Of the three locations where disease notes were taken, the lodging and disease positively correlated at only one location, Wyn12 (Figure 6). The other two were non-significant. With a higher DI level and lodging at this location, the BD was much less among hybrids that were affected by both. The excess fertilizer applied in Wyn12 with a shallow water table made for abnormally tall and leafy sunflower plants. This could have had an impact on the lodging since plant rooting dynamics may not be able to support the increased top growth. The extra vegetativeness of the plants also created a humid microenvironment within the canopy, leading to a higher probability for disease. These lodged plants likely decreased attractiveness for birds to pick those hybrids. Generally, the correlations between lodging and BD showed a lot of inconsistency with three of the eight locations showing significant positive correlation and another two with significant negative correlations.

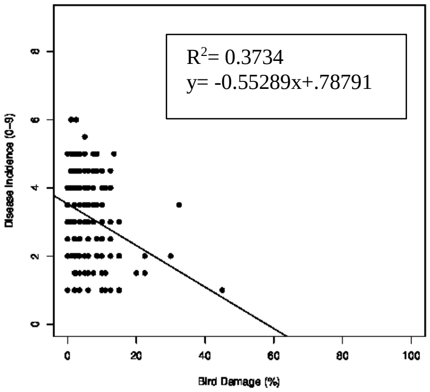

Figure 4. Relationship between disease incidence and bird damage at Wyndmere 2012. Slope is significant at $P \leq 0.001$.

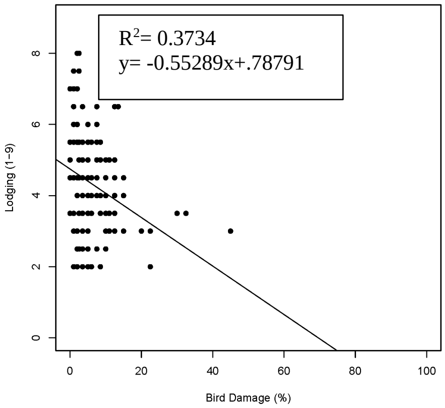

Figure 5. Relationship between lodging and bird damage at Wyndmere 2012. Slope is significant at $P \leq 0.001$.

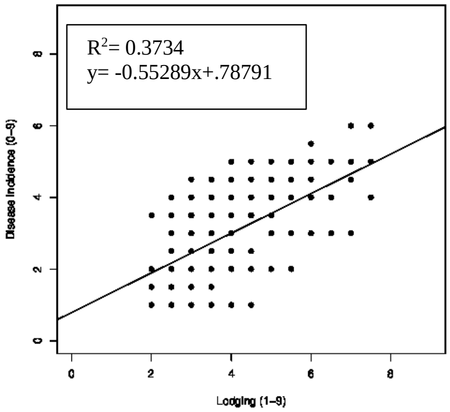

Figure 6. Relationship between disease incidence and lodging at Wyndmere 2012. Slope is significant at $P \leq 0.001$.

Table 7. Yield AIC component variances for pooled effects using the Wald test.

Env	Location	Height		Bird Damage		Lodging		Disease Incidence		Unique		FA1	
1	Carrington 2012	5695.090	ns	62901.800	ns	0.004	ns	--		0.372	***	0.160	ns
2	Carrington 2013	0.002	ns	82756.600	ns	0.001	ns	--		0.000	ns	0.217	**
3	Crookston 2012	1260.970	ns	145287.000	*	0.003	ns	--		0.716	***	1.055	***
4	Crookston 2013	22963.800	*	--		360152.000	*	0.000	ns	0.222	**	0.347	***
5	Eureka 2012	305.216	ns	1796.420	ns	2552.920	ns	--		0.000	ns	0.287	***
6	Mandan 2012	7178.420	ns	105705.000	*	6716.320	ns	--		0.720	***	0.132	ns
7	Mandan 2013	0.000	ns	7797.080	ns	188961.000	*	--		0.000	ns	0.167	*
8	Velva 2012	1628.530	ns	--		190449.000	*	--		0.128	ns	0.328	***
9	Velva 2013	9831.960	ns	0.000	ns	7057.670	ns	18812.200	ns	0.800	***	0.261	*
10	Wyndmere 2012	0.000	ns	1543.360	ns	267285.000	*	0.001	ns	0.000	ns	1.049	***

*,**,*** significant cofactors at $P \leq 0.05$, 0.01, 0.001, respectively

^{ns} non-significant

Table 8. Yield BIC component variances for pooled effects using the Wald test.

Env	Location	Bird Damage		Lodging		Disease Incidence		Unique	
1	Carrington 2012	64077.500	ns	0.009	ns	--		43939.600	***
2	Carrington 2013	78709.700	ns	0.013	ns	--		0.000	ns
3	Crookston 2012	152146.000	*	0.027	ns	--		164383.000	***
4	Crookston 2013	--		355151.000	*	0.0295	ns	34061.400	**
5	Eureka 2012	2435.800	ns	2140.040	ns	--		0.000	ns
6	Mandan 2012	94100.800	*	8398.700	ns	--		83310.500	***
7	Mandan 2013	3749.940	ns	176164.000	*	--		0.000	ns
8	Velva 2012	--		193995.000	*	--		15435.700	ns
9	Velva 2013	0.005	ns	0.061	ns	18877.4000	ns	104480.000	***
10	Wyndmere 2012	1758.080	ns	231601.000	*	0.0456	ns	79774.600	***

*,**,*** significant cofactors at $P \leq 0.05$, 0.01, 0.001, respectively

^{ns} non-significant

Table 9. Oil BIC component variances for pooled effects using the Wald test.

Env	Location	Disease Incidence	Height	Unique	FA1	FA2
1	Carrington 2012	--	0.018 ^{ns}	0.000 ^{ns}	1.222 ^{ns}	0.347 ^{ns}
2	Carrington 2013	--	0.038 ^{ns}	0.000 ^{ns}	0.897 ***	0.000 ^{ns}
3	Crookston 2012	--	0.164 ^{ns}	0.000 ^{ns}	1.371 ***	0.000 ^{ns}
4	Crookston 2013	0.000 ^{ns}	0.730 **	0.004 ^{ns}	1.174 ***	0.048 ^{ns}
5	Eureka 2012	--	0.078 ^{ns}	0.000 ^{ns}	1.508 ***	0.559 ^{ns}
6	Mandan 2012	--	0.000 ^{ns}	0.055 ^{ns}	1.260 ***	0.126 ^{ns}
7	Mandan 2013	--	1.212 **	3.698 ***	1.436 ***	0.105 ^{ns}
8	Velva 2012	--	0.000 ^{ns}	0.000 ^{ns}	1.364 ***	0.000 ^{ns}
9	Velva 2013	0.063 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	0.897 ***	0.000 ^{ns}
10	Wyndmere 2012	0.075 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	1.120 ***	0.000 ^{ns}

*,**,*** significant cofactors at $P \leq 0.05$, 0.01, 0.001, respectively

^{ns} non-significant

Table 10. Oil AIC component variances for pooled effects using the Wald test.

Env	Location	Bird Damage	Lodging	Height	Unique	FA1	FA2
1	Carr2012	0.000 ^{ns}	0.015 ^{ns}	0.013 ^{ns}	0.005 ^{ns}	1.187 ^{ns}	0.351 ^{ns}
2	Carr 2013	0.072 ^{ns}	0.569 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	0.855 ***	0.008 ^{ns}
3	Crookston 2012	0.000 ^{ns}	0.234 ^{ns}	0.151 ^{ns}	0.000 ^{ns}	1.323 ***	0.502 ^{ns}
4	Crookston 2013	--	0.055 ^{ns}	0.696 **	0.006 ^{ns}	1.130 ***	0.048 ^{ns}
5	Eureka 2012	0.106 ^{ns}	0.000 ^{ns}	0.082 ^{ns}	0.000 ^{ns}	1.490 ***	0.558 ^{ns}
6	Mandan 2012	0.224 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	0.019 ^{ns}	1.234 ***	0.147 ^{ns}
7	Mandan 2013	0.429 ^{ns}	0.000 ^{ns}	1.175 **	3.788 ***	1.382 ***	0.097 ^{ns}
8	Velva 2012	--	0.000 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	1.326 ***	0.163 ^{ns}
9	Velva 2013	0.000 ^{ns}	0.010 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	0.823 ***	0.215 ^{ns}
10	Wyn 2012	0.000 ^{ns}	0.187 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	1.097 ***	0.485 ^{ns}

*,**,*** significant cofactors at $P \leq 0.05$, 0.01, 0.001, respectively

^{ns} non-significant

2.3.3. Correlations with Common Factors

A total of 37 environmental characteristics were examined for correlations with the common factor loadings corresponding to the best fitting GE models (Tables C1-3). Environmental characters which correlated with FA1 for yield in the best AIC model include elevation, minimum average temperature in May and June and maximum average temperature in May (Table 11). Elevation was negatively correlated with FA1, whereas all the temperature covariates were positively correlated. Elevation correlated negatively to the average minimum temperature for May and June, implying average temperature decrease as elevation increases from east to west.

Table 11. Correlation coefficients of selected environmental variables with common factor 1 (FA1) loadings from the yield model selected by minimizing the Akaike information criterion (AIC).

	Elevation	Min Temp May†	Min Temp June	Max Temp May‡
FA1	-0.76*	0.85**	0.77**	0.75*
Elevation		-0.66*	-0.67*	-0.48
Min Temp May			0.92*	0.71*
Min Temp June				0.59

*,**,*** significant cofactors at $P \leq 0.05, 0.01, 0.001$, respectively

† Minimum average temperature for May & June (Min Temp May, Min Temp June),

‡ Maximum average temperature for May (Max Temp May)

The best oil model as determined by BIC had two common factors, the first and most important significantly ($P \leq 0.05$) correlated with four environmental variables (Table 12). Three of the four variables are related to temperature: pre-flowering maximum temperature, average temperature, and maximum temperature in July. The fourth correlation is November through March rainfall. The second factor correlated negatively with March rain and positively with elevation ($P \leq 0.05$).

Table 12. Correlation coefficients of the common factor 1 (FA1) and factor 2 (FA2) as chosen by the Bayesian information criterion (BIC) oil model with several selected environmental variables†

	FA2	Pre-Fwr Max Temp‡	Nov-Mar Rain§	Average Temp¶	Elevation	March Rain	Max Temp July
FA1	0.34	0.72*	-0.73*	0.79*	0.17	-0.52	0.67*
FA2		0.28	-0.55	0.08	0.68*	-0.74*	0.06
Pre-Fwr Max Temp			-0.67*	0.93***	0.04	-0.47	0.92***
Nov-Mar Rain				-0.57	-0.30	0.81**	-0.70*
Average Temp					0.05	-0.29	0.89***
Elevation						-0.42	-0.12
March Rain							-0.37

*,**,*** significant cofactors at $P \leq 0.05, 0.01, 0.001$, respectively

† Significant correlations derived from the top BIC by Exploratory factor analysis with ASReml software

‡ Pre-flowering maximum temperature: a fifteen day period of temperature was recorded starting 10 days before the plot reached mid-flower

§ November through March rainfall

¶ Temperature

2.4. Discussion

Foucteau et al. (2001) found that earlier maturing genotypes were more sensitive to environmental conditions in early development (sowing to flowering), while later maturing genotypes were more sensitive to environmental conditions from flowering to harvest. Although a large number of hybrids were tested for our study, most were adapted for the Northern Plains region and thus were in the early to medium maturity range. We are not able to simplify our results quite so elegantly because of the influences of disease, lodging, and bird damage on our experiment. Perhaps if lodging or disease pressure, as unpredictable sources of GxE, were reduced by improved genetics or cultural practices, additional, predictable GxE factors could be exposed. Since lodging and Phomopsis disease resistance are highly heritable, they are attainable goals in breeding (Talukder et al., 2014). Reducing the influence of these stresses in hybrids through genetics should reduce the relative importance of these sources of GxE in selection programs.

Since there was no common factor under the conservative BIC model for yield, we turn to look at the AIC model for possible insight into a predictable GxE factor. The common factor that was discovered in the liberal yield model negatively correlated with elevation and positively correlated with minimum and maximum average temperatures in May and minimum temperatures in June. This suggests temperature variation at these time points, which were also associated with elevation, influenced yield in a repeatable manner across environments. Although these factors were found to be significant, it only accounted for less than one percent of the total GxE variation.

To test the hypothesis that genetic improvement could change the relative importance of some sources of GxE, as well as the overall importance of GxE in the model, we compare the variance components of groups of 19 hybrids from three eras based on their year of release (Table 13). Between the 1990-1995 hybrid group and 2010-2015, the relative percentage of GxE contributing to lodging goes up over 22%, but the percent of unique factors (unpredictable GxE variation unique to specific environments with unknown cause) goes down 25% as well as the importance of total GxE in the model. Overall, the GxE:G ratio drops to 2.28, implying that variation among the most recent hybrids was more consistent across all environments.

It is clear that lodging, disease, and bird damage caused significant differences in yield performance of genotypes, relative to each other, among the environments. The lack of certainty on when these stresses will occur or how severe they will be in any location makes it difficult to plan ideal test environments or delineate mega-environments. Mega-environments for yield cannot be defined in this case because the most important components of GxE are not tied to geography. Ideally, breeders would want to provide sufficient application of these stresses to discover resistant breeding materials, and the inverse (minimal stress) to understand the yield trade-offs of having resistance traits in favorable environments. Generally, this is accomplished by sampling more environments and expecting some percentage of them to be affected by stresses like disease or lodging, and still others to be unaffected.

Table 13. Comparison of variance components among three groups of 19 sunflower hybrids grown at 10 field environments, 2012-2013.

	1975-1983†		1990-1995		2010-2015	
Source	Estimate	% GE	Estimate	% GE	Estimate	% GE
Rep(loc)	21048.00		10972.00		2648.84	
Block(loc*rep)	21657.00		23101.00		84012.00	
Genotype	12565.00		9992.83		38179.00	
Total GxE	70571.00	100.00	109817.00	100.00	86897.00	100.00
Lodging	26133.00	37.03	29285.00	26.67	42681.00	49.12
Bird damage	112.97	0.16	139.21	0.13	325.33	0.37
Disease Incidence	3318.20	4.70	324.85	0.30	2260.14	2.60
Unique factors	41007.00	58.11	80068.00	72.91	41631.00	47.91
Residual	150415.00		161030.00		115025.00	
Total	276256.17		314912.89		326762.31	
GxE:G ratio	5.62		10.99		2.28	

† Date of hybrid release

A different approach for producing stressful environments is to intentionally impose these abiotic and biotic stresses on specially designed yield trials. Viguie et al. (2000) conducted a ten-year study that tested sunflower hybrids for both semi-natural Phomopsis inoculation in the field and artificial infection in the laboratory. The artificial infection methods were more repeatable, providing consistent results in both the leaf and petiole tests. Their semi-natural tests produced significant variability, concluding a large number of tests would need to be conducted in different environments and with varying levels of disease pressure. Some hybrids showing susceptibility to Phomopsis with the leaf and petiole tests showed good Phomopsis tolerance in natural settings. This shows that some laboratory tests circumvent natural modes of resistance, such as resistance to spore germination and colonization on the leaf. Thus, a balance between repeatability in artificial tests and practicality in semi-natural tests needs to be found in cases where field testing shows low repeatability (heritability). In contrast, Talukder et al. (2014) showed that field studies with naturally occurring Phomopsis inoculum can produce trait phenotypes with high heritability across sites and years. Likewise, Gulya et al. (2004) developed a Sclerotinia evaluation method for field settings that is also highly repeatable. These types of tests are important for breeding companies to conduct as Phomopsis and Sclerotinia resistance are both quantitative traits that currently have under described physiology and, at this time, lack useful genomics-assisted methods for selection.

To improve disease resistance, breeding companies should utilize natural field infestations, and public sector disease screening programs alongside genomics assisted breeding methods, as they become available. Phomopsis resistance has quantitative inheritance, making it difficult for breeding companies to develop marker-assisted methods. It would be costly for every breeding program to have their own artificial disease testing program in a field setting due to costs in manpower and equipment, and the lack of available field sites where growers approve of dumping inoculum of a long-lasting soil disease such as Phomopsis and Sclerotinia. However, resources must be spent on this because high levels of Phomopsis incidence can occur even under natural conditions with most currently marketed commercial hybrids (Kandel, 2016).

The options for managing birds in sunflowers are limited since avian species' populations cannot be eliminated without public outcry and one of the market options for sunflowers is for bird food, eliminating the market acceptability of long-lasting bird-deterring chemical options.

Growers right now have multiple agronomic practices to consider, such as early maturity, desiccation, repellents, noise machines/propane cannons, and ethical hazing practices to manage bird predation. Unfortunately, none of these agronomic practices are good solutions, but rather an additional tool to help with management (Werner et al., 2005; Dolbeer and Linz, 2016). Breeders have been unable to identify effective plant genetic solutions to this problem, but should continue to produce hybrids with declining head angles and shorter stature to provide some discouragement to migratory birds (Seiler & Rogers, 1987).

Lodging resistance has not been considered important enough to warrant specialized screening nurseries, and it is often thought by breeders that lodging susceptible hybrids can be eliminated through the yield trial process. However, disease-dependent and independent lodging may be better studied using specialized trials on stalk strength and wind resistance. Dupont Pioneer has a wind machine they use to test brittle snap in corn (L. Streit, personal communications, 2018). Sposaro and colleagues research in 2008 used a mechanical tool to induce lodging in sunflowers. Either method could be used by a private breeding company to determine the stalk and root strength of new hybrids.

Oil is a much different story than yield. Covariates for lodging and disease incidence, which are environment-dependent stresses, were not significant, but two common factors are apparent and contribute 68.6 % of the total GxE variation. Common factor 1 accounts for 62.6% of the total variation, which correlates with pre-flowering maximum temperature, average temperature, maximum temperature in July and November-March rainfall. Common factor 2 accounts for 6% of the total GxE variation and correlates with elevation and March rain. Elevation did not correlate with any of the temperatures from common factor 1. A study done by Harris et al. (1978) in Australia showed similar results with temperature, moisture and diseases playing a role in overall oil content when placed in different environments. They found that higher temperatures combined with moisture stresses could influence oil content, but there was not a particular time in seed development that was most susceptible. Instead the effect of these stresses is cumulative. Their research took into account seed development from pollination to maturity, but did not consider pre-flowering temperature. Our results indicate that pre-flowering temperatures may also have an impact on oil content, since our plots bloomed in late July to August and we saw the greatest association to pre-bloom minimum temperatures.

We found that the ranks in oil content among hybrids can change from location to location because of GxE (Tables D4-5). Given these results, we recommend that breeders, both public and private, analyze oil content at contrasting environments throughout the sunflower region. This has added importance in sunflower because farm-gate values of oilseed sunflower is dependent on both yield and oil content of the grain product. Since the addition of oil content analysis drives up costs in breeding operations, mega-environments with contrasting elevation and long-term average minimum temperatures could be delineated and a subset of environments evaluated to better understand oil content variability across the target region for a hybrid.

In general, breeders looking to cut back on the number of yield trial locations should consider doing so carefully due to the lack of certainty on when and how severe some of these stresses can be in individual environments. Some breeders conducting yield tests in multiple locations have decided to forgo taking seed samples for oil content determination at off-site locations to cut back on manpower or because their equipment doesn’t allow the operator to take a seed sample. Doing so may cause a breeder to select hybrids for commercialization that fail in one or more of the target environments for seed oil content.

Precipitation at any point in the year can be accessed by the crop because sunflower rooting depth is known to be deeper than many of the major crops in the region, allowing for mining of stored water in the soil. In semi-arid regions, snowmelt can be a very important source of moisture for the crop. Knowing the temperature and precipitation effects on oil content allows us to look at historical weather trends in and near the study area to determine optimal study environments. Datasets encompassing multiple environments will allow us to find hybrids that are sensitive to environmental differences and consider eliminating unstable hybrids for commercialization. Analyzing stability can help determine how a genotype performs in reference to other genotypes and how consistent it is across environments (Bernardo, 2010). Conversely, such data could also allow producers to select hybrids that are ideally suited for weather conditions that are most commonly found at their location.

Based on these trends, evaluation of hybrids in central SD, which was outside of our study area, but is a strong area of production currently, would be advised because temperatures in the middle to late summer are warmer and precipitation is also more limiting than our northern and eastern environments. We did not directly measure the amount of moisture available to the plant within the soil at the beginning of each season but our results suggest this influenced its overall potential during the growing season.

The current level of yield GxE found in this study does not make it an attractive crop to grow. The instability and unpredictability is one of the points that can sometimes drive growers away from planting sunflowers. While there are many reasons why a grower may choose not to continue sunflowers in his rotation, such as unattractive market price, on many occasions disasters with lodging, disease or bird damage are the “final straw” when a grower decides to quit sunflowers. By directing some of our breeding efforts towards these pain points, we can help to restore the confidence in growers to maintain sunflower acres on their farms. There are many benefits to a grower by keeping sunflowers in the rotation, such as good water utilization, deep tap roots for nutrients, and market diversity (Blamey et al., 1997). As our climate changes, along with options for other crops in the Northern Plains, we may start to look at other areas for growing sunflowers that have had minimal acres in the past (Debaeke et al., 2017). Conversely, growers that have abandoned sunflower may find they need to reconsider it to increase economic stability in uncertain future climates.

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APPENDIX A. INDIVIDUAL LOCATION ANOVAS

Table A1. Carrington 2012 individual location ANOVA.

	----------------------------Variance---------------------------------				
Sources of Variation	Height	Lodging	Bird Damage	Yield	Oil
Rep	32.97	0.013	0.000	31078	1.351
Block (Rep)	15.44***	0.003	2.092*	34830**	0.662**
Entry	19.50***	0.101***	3.923**	28881*	5.639***
Residual Variance	10.33***	0.188***	14.19***	182742***	1.790***
CV (%)	4.4	17.9	289.8	17.6	3.5

*,**,*** significant cofactors at $P \leq 0.05, 0.01, 0.001$, respectively

Table A2. Carrington 2013 individual location ANOVA.

	----------------------------Variance----------------------------				
Sources of Variation	Height	Lodging	Bird Damage	Yield	Oil
Rep	0.000	0.002	0.000	12952	0.000
Block (Rep)	7.634***	0.013	0.417	9188*	0.508**
Entry	15.572***	0.209***	0.000	28903***	3.648***
Residual Variance	7.915***	0.194***	31.361***	73351***	0.619***
CV (%)	4.3	16.8	1056.6	21.0	1.8

*,**,*** significant cofactors at $P \leq 0.05, 0.01, 0.001$, respectively

Table A3. Crookston 2012 individual location ANOVA.

	------------------------------Variance------------------------------				
Sources of Variation	Height	Lodging	Bird Damage	Yield	Oil
Rep	7.695	0.001	15.930	17513	0.099
Block (Rep)	0.000	0.006	2.895	28575*	0.000
Entry	13.250***	0.056**	82.281***	251805***	7.151***
Residual Variance	27.412***	0.221***	76.866***	161759***	1.033***
CV (%)	8.6	21.9	92.6	12.0	2.3

*,**,*** significant cofactors at *P* ≤ 0.05, 0.01, 0.001, respectively

Table A4. Crookston 2013 individual location ANOVA.

	-------------------------------Variance------------------------------				
Sources of Variation	Height	Lodging	Green Stalk	Yield	Oil
Rep	0.262	0.000	0.000	14521	0.266
Block (Rep)	0.000	0.004	0.017	18925	0.000
Entry	21.007***	0.884***	3.058***	108707***	4.794***
Residual Variance	23.244***	0.919***	2.432***	212453***	2.864***
CV (%)	6.9	29.6	46.8	17.0	3.7

*,**,*** significant cofactors at *P* ≤ 0.05, 0.01, 0.001, respectively

Table A5. Eureka 2012 individual location ANOVA.

	------------------------------------Variance----------------------------------				
Sources of Variation	Height	Lodging	Bird Damage	Yield	Oil
Rep	0.928	0.012	0.000	0.0	0.000
Block (Rep)	1.413*	0.005	0.617*	22544**	0.281**
Entry	20.136***	0.046**	0.740	24738***	7.662***
Residual Variance	5.361***	0.148***	7.659***	57206***	0.960***
CV (%)	3.6	17.82	345.9	10.0	2.5

*,**,*** significant cofactors at *P* ≤ 0.05, 0.01, 0.001, respectively

Table A6. Mandan 2012 individual location ANOVA.

	------------------------------Variance------------------------------				
Sources of Variation	Height	Lodging	Bird Damage	Yield	Oil
Rep	22.675	0.024	0.000	0.0	0.043
Block (Rep)	2.816**	0.000	20.097*	19427	0.064
Entry	15.318***	0.105***	82.139***	81340**	5.942***
Residual Variance	4.467***	0.218***	188.950***	282392***	1.615***
CV (%)	3.2	20.9	97.8	24.0	3.0

*,**,*** significant cofactors at *P* ≤ 0.05, 0.01, 0.001, respectively

Table A7. Mandan 2013 individual location ANOVA.

	-----------------------------Variance--------------------------------				
Sources of Variation	Flower	Lodging	Bird Damage	Yield	Oil
Rep	56.267	0.087	21.71	6018	0.889
Block (Rep)	7.728**	0.049*	21.49*	3945	0.000
Entry	16.201***	0.409***	122.21***	137614***	7.986***
Residual Variance	8.257***	0.456***	109.39***	88712***	15.575***
CV (%)	4.0	12.2	62.0	29.0	9.1

*,**,*** significant cofactors at *P* ≤ 0.05, 0.01, 0.001, respectively

Table A8. Velva 2012 individual location ANOVA.

	---------------------Variance---------------------			
Sources of Variation	Height	Lodging	Yield	Oil
Rep	2.102	0.517	12468	0.000
Block (Rep)	6.390**	0.412**	10516	0.645**
Entry	16.372***	1.726***	146576***	6.515***
Residual Variance	6.858***	0.978***	165544***	0.957***
CV (%)	3.4	21.2	19.0	2.3

*,**,*** significant cofactors at *P* ≤ 0.05, 0.01, 0.001, respectively

Table A9. Velva 2013 individual location ANOVA.

	----------Variance----------					
Sources of Variation	Height	Lodging	Bird Damage	Green Stalk	Yield	Oil
Rep	11.972	0.000	7.539	0.584	30667	1.093
Block (Rep)	3.615**	0.171*	4.582*	0.110	54815**	0.205*
Entry	22.463***	0.380***	40.801***	2.473***	117987***	3.500***
Residual Variance	12.287***	0.888***	42.468***	3.297***	156440***	1.273***
CV (%)	4.7	33.0	127.5	45.9	30.0	2.6

*,**,*** significant cofactors at $P \leq 0.05, 0.01, 0.001$, respectively

Table A10. Wyndmere 2012 individual location ANOVA.

	----------Variance----------							
Sources of Variation	Flower	Maturity	Height	Lodging	Bird Damage	Green Stalk	Yield	Oil
Rep	0.000	0.000	0.000	0.362	2.313	0.197	103785	0.138
Block (Rep)	0.805***	0.345*	12.978***	1.028**	3.926*	0.174*	171529**	1.011***
Entry	2.936***	3.256***	28.057***	1.002***	25.960***	1.361***	195421***	5.244***
Residual Variance	0.642***	1.448***	11.318***	1.237***	21.984***	0.604***	186272***	0.853***
CV (%)	2.8	15.9	4.5	25.6	78.4	25.0	18.0	2.1

*,**,*** significant cofactors at $P \leq 0.05, 0.01, 0.001$, respectively

APPENDIX B. WEATHER

Table B1. Precipitation amounts for the 2012-2013 sunflower trial sites.

Location	Nov‡-March	April-Oct	Total Precip	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct
	---centimeters---														
Carr12†	3.4	38.4	41.8	0.10	0.71	3.02	1.07	0.69	4.72	5.44	8.48	4.01	8.66	0.61	7.11
Carr13	10.3	37.1	47.4	2.74	1.93	2.17	1.32	3.43	3.89	10.01	2.29	4.11	2.39	4.98	10.06
Crk12	7.9	34.6	42.5	0.28	1.04	3.36	0.97	5.00	3.33	2.41	6.50	5.82	5.49	0.30	7.44
Crk13	8.8	24.9	33.7	1.60	0.89	3.31	2.92	1.80	1.65	10.74	8.10	2.34	3.25	6.63	6.15
Eurk12	4.3	28.3	32.6	0.08	0.53	0.94	2.49	0.33	5.89	7.37	4.65	7.44	2.29	0.13	1.02
Man12	3.2	34.5	37.8	0.00	0.48	3.13	0.71	1.07	4.80	4.42	7.80	8.36	6.73	0.28	2.69
Man13	4.7	50.6	55.2	2.06	1.42	3.51	0.28	0.69	3.12	18.64	6.32	2.51	1.22	8.00	11.53
Velv12	7.0	30.3	37.3	1.30	1.52	3.37	1.57	2.16	7.11	4.83	7.57	2.24	2.69	0.13	6.22
Velv13	13.2	64.4	77.6	2.95	1.68	2.09	2.57	4.62	3.76	16.38	10.77	14.78	10.46	6.17	6.81
Wyn12	7.0	39.9	47.0	0.28	0.51	2.79	3.35	1.88	8.84	4.47	10.52	3.25	6.96	0.48	6.05

† Crookston (Crk) Carrington (Carr) Mandan (Mand) Velva (Velv) Eureka (Eurk) Wyndmere (Wyn), followed by the year

‡ November (Nov), October (Oct), November (Nov), December (Dec), January (Jan), February (Feb), August (Aug), September (Sept)

Table B2. Soil, pre-flowering, flowering and minimum (min) and maximum (max) temperatures (temp) for 2012-2013 sunflower trial sites during the growing season (May – September).

Location	Soil Temp	Avg Flw Min‡	Avg Flw Max	Pre Flw Min Temp§	Pre Flw Max Temp	Min Temp May	Max Temp May	Min Temp June	Max Temp June	Min Temp July	Max Temp July	Min Temp Aug	Max Temp Aug	Min Temp Sept	Max Temp Sept
	--Celsius--														
Carr12†	17.2	11.1	24.8	16.1	28.9	6.5	19.7	12.2	25.0	15.7	29.0	10.8	25.7	4.3	22.2
Carr13	23.3	13.7	28.5	9.4	22.8	5.5	18.0	11.9	24.0	13.1	26.1	12.4	26.8	9.2	22.8
Crk12	18.9	14.9	30.0	17.4	30.4	7.2	21.7	12.7	25.4	16.8	31.0	11.5	27.5	4.8	22.5
Crk13	15.6	9.0	24.1	15.2	27.7	6.3	19.2	12.9	25.1	14.3	27.5	12.5	27.9	9.3	23.2
Eurk12	16.7	11.9	26.8	18.3	35.5	6.0	20.1	12.4	27.2	16.9	31.5	11.0	27.4	4.6	25.0
Man12	17.8	14.2	28.6	16.7	31.7	5.4	20.1	11.8	26.4	16.1	31.0	11.8	27.6	6.1	24.7
Man13	22.2	15.3	30.9	11.7	25.6	5.5	19.6	11.7	23.9	13.6	27.7	13.9	29.1	10.3	24.0
Velv12	13.9	13.2	26.8	17.8	29.4	6.5	18.1	12.2	23.9	16.4	28.9	12.5	27.5	6.6	23.2
Velv13	17.2	15.8	29.2	12.2	23.3	5.7	17.6	12.5	22.9	14.1	24.9	14.3	26.3	10.5	22.9
Wyn12	15.6	17.3	31.6	17.2	30.6	9.5	22.3	14.4	27.7	17.9	31.1	11.8	28.0	4.8	24.4

† Crookston (Crk) Carrington (Carr) Mandan (Mand) Velva (Velv) Eureka (Eurk) Wyndmere (Wyn), followed by the year

‡ The average temperature during the flowering period was calculated 10 days before and after the plot was in mid-flower

§ A fifteen day period of temperature was recorded starting 10 days before the plot reached mid-flower

APPENDIX C. CORRELATIONS

Table C1. Yield Akaike Information Criterion (AIC) Correlations.

	Height	Disease	Lodging	FA1†	PF Max Temp‡	PF Min Temp	Nov-Mar§	Apr-Oct	Total Rain	Avg Temp¶	Region	Soil Type	Elevation	Plant Date	Soil Temp
Bird Damage	-0.12	-0.06	0.26	0.06	-0.01	-0.13	-0.31	0.39	0.27	0.07	0.57	0.17	0.12	-0.36	0.41
Height		0.46	0.66*	-0.19	-0.28	-0.03	0.08	0.35	0.33	-0.25	-0.04	0.21	0.04	0.41	-0.44
Disease			0.36	0.20	-0.38	-0.24	0.61	0.50	0.57	-0.42	-0.31	-0.12	-0.38	0.42	-0.32
Lodging				0.03	-0.26	-0.17	-0.03	0.22	0.19	-0.09	0.19	0.20	-0.04	0.18	-0.02
FA1					0.27	0.40	0.17	-0.12	-0.06	0.40	-0.35	-0.11	-0.76*	-0.47	-0.22
PF MaxTemp						0.91***	-0.67*	-0.61	-0.69*	0.93***	0.28	0.13	0.04	-0.61	-0.52
PF MinTemp							-0.51	-0.56	-0.61	0.88***	-0.04	-0.07	-0.19	-0.62	-0.77**
Nov-Mar								0.42	0.61	-0.57	-0.64*	-0.41	-0.30	0.38	0.08
Apr-Oct									0.98***	-0.47	0.12	0.18	0.27	0.51	0.32
Total Rain										-0.55	-0.05	0.05	0.16	0.53	0.29
Avg Temp											0.22	0.07	0.05	-0.64*	-0.47
Region												0.76*	0.64*	-0.09	0.31
Soil Type													0.42	0.13	0.18
Elevation														0.28	0.23
Plant Date															0.21

Table C1. Yield Akaike Information Criterion (AIC) Correlations (continued).

	AF Min#	AF Max	Nov Rain	Dec Rain	Jan Rain	Feb Rain	Mar Rain	Apr Rain	May Rain	June Rain	July Rain	Aug Rain	Sept Rain	Oct Rain	MinTemp May‡‡
Bird Damage	0.56	0.67*	-0.09	-0.11	0.41	-0.56	-0.06	-0.16	0.23	0.12	0.12	0.03	0.17	0.22	-0.12
Height	0.11	-0.07	0.24	0.15	0.31	0.23	-0.21	0.35	0.26	0.66*	-0.12	0.27	0.17	0.20	0.21
Disease	0.18	0.14	0.44	0.06	0.00	0.80*	0.26	-0.10	0.63	0.68*	0.29	0.42	0.64	0.12	0.30
Lodging	0.32	0.34	0.30	0.27	0.45	-0.02	-0.23	0.24	0.41	0.21	-0.49	-0.37	0.36	0.50	0.20
FA1	0.44	0.47	-0.34	-0.25	0.16	0.35	0.44	0.34	-0.48	0.25	-0.15	0.14	-0.36	0.00	0.85**
PF Max Temp	-0.17	-0.14	-0.90***	-0.83**	-0.19	0.13	-0.47	0.45	-0.66*	0.02	-0.10	-0.09	-0.77**	-0.80**	0.32
PF MinTemp	-0.16	-0.21	-0.86**	-0.75*	0.03	0.23	-0.28	0.50	-0.75*	0.30	-0.12	0.10	-0.81**	-0.73*	0.48
Nov-Mar	0.20	0.13	0.76*	0.67*	-0.16	0.43	0.81**	-0.25	0.37	0.12	0.39	0.21	0.48	0.33	0.00
Apr-Oct	0.62	0.53	0.55	0.44	-0.06	-0.08	0.35	-0.10	0.65*	0.39	0.59	0.50	0.47	0.43	-0.13
Total Rain	0.59	0.49	0.66*	0.55	-0.09	0.03	0.50	-0.15	0.66*	0.37	0.61	0.49	0.53	0.46	-0.12
Avg Temp	0.05	0.08	-0.80**	-0.62	-0.14	0.04	-0.29	0.53	-0.62	-0.01	-0.09	-0.16	-0.77**	-0.65*	0.36
Region	0.28	0.36	-0.25	-0.33	-0.18	-0.33	-0.68*	0.26	0.17	-0.17	0.01	-0.19	-0.05	-0.17	-0.21
Soil Type	0.40	0.37	-0.20	-0.26	-0.31	0.01	-0.53	0.63	-0.01	-0.02	-0.08	0.05	-0.21	-0.06	0.22
Elevation	0.02	-0.03	0.12	0.14	-0.48	-0.35	-0.42	0.08	0.34	-0.29	0.37	-0.11	0.02	-0.20	-0.66*
Plant Date	-0.17	-0.23	0.64*	0.46	-0.33	0.22	-0.06	-0.24	0.73*	0.04	0.14	0.09	0.64*	0.41	-0.26

Table C1. Yield Akaike Information Criterion (AIC) Correlations (continued).

	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
Bird Damage	-0.23	-0.05	0.32	0.14	0.36	0.04	0.19	0.55	0.32
Height	0.20	-0.03	0.40	0.23	-0.31	-0.31	-0.33	-0.06	-0.10
Disease	0.61	-0.18	0.63	0.54	-0.06	-0.12	-0.44	0.12	0.02
Lodging	0.12	-0.11	0.53	0.36	-0.06	-0.23	-0.18	0.62	0.14
FA1	0.77**	0.61	-0.25	-0.44	0.75*	0.44	0.47	0.22	-0.04
PF MaxTemp	0.24	0.84**	-0.73*	-0.82**	0.62	0.82**	0.92***	0.17	0.56
PF MinTemp	0.38	0.91***	-0.66*	-0.82**	0.57	0.67*	0.84**	0.05	0.30
Nov-Mar	0.21	-0.42	0.58	0.59	-0.45	-0.54	-0.70*	-0.23	-0.43
Apr-Oct	-0.08	-0.38	0.71*	0.51	-0.27	-0.51	-0.56	-0.16	-0.17
Total Rain	-0.02	-0.44	0.76*	0.58	-0.35	-0.58	-0.66*	-0.20	-0.25
Avg Temp	0.21	0.86**	-0.58	-0.78**	0.60	0.66*	0.89***	0.25	0.49
Region	-0.27	0.06	-0.03	-0.08	0.20	0.37	0.33	0.38	0.75*
Soil Type	0.13	0.19	-0.18	-0.24	0.22	0.42	0.24	0.02	0.50
Elevation	-0.67*	-0.22	0.15	0.13	-0.48	-0.18	-0.12	-0.16	0.36
Plant Date	-0.09	-0.62	0.43	0.55	-0.59	-0.52	-0.76*	-0.35	-0.31

Table C1. Yield Akaike Information Criterion (AIC) Correlations (continued).

	AF Min	AF Max	Nov Rain	Dec Rain	Jan Rain	Feb Rain	Mar Rain	Apr Rain	May Rain	June Rain	July Rain	Aug Rain	Sept Rain	Oct Rain	MinTemp May
Soil Temp	0.24	0.39	0.43	0.47	-0.03	-0.59	0.15	-0.46	0.44	-0.63	-0.02	-0.29	0.48	0.63*	-0.45
AF Min		0.96***	0.12	0.18	0.03	-0.06	0.37	0.42	0.09	0.25	0.29	0.26	-0.04	0.25	0.35
AF Max			0.10	0.14	0.06	-0.13	0.31	0.29	0.14	0.09	0.17	0.07	0.05	0.30	0.31
Nov Rain				0.89***	-0.05	0.03	0.44	-0.43	0.78**	-0.13	0.19	-0.12	0.83**	0.62	-0.43
Dec Rain					0.04	-0.22	0.55	-0.32	0.54	-0.30	0.08	-0.20	0.57	0.69*	-0.42
Jan Rain						-0.42	0.05	-0.20	-0.09	0.29	-0.49	-0.02	0.11	0.47	0.13
Feb Rain							0.09	0.33	-0.04	0.41	0.14	0.20	-0.02	-0.39	0.53
Mar Rain								-0.23	0.01	0.07	0.41	0.32	0.13	0.31	0.09
Apr Rain									-0.49	0.25	-0.11	0.12	-0.67*	-0.36	0.63
May Rain										0.00	0.23	-0.14	0.92***	0.50	-0.50
June Rain											0.29	0.73*	-0.06	-0.15	0.47
July Rain												0.63	0.04	-0.34	-0.29
Aug Rain													-0.20	-0.18	0.25
Sept Rain														0.63	-0.44
Oct Rain															-0.08

Table C1. Yield Akaike Information Criterion (AIC) Correlations (continued).

	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
Soil Temp	-0.50	-0.64*	0.27	0.42	-0.14	-0.32	-0.34	0.12	-0.14
AF Min	0.25	0.19	0.37	0.04	0.28	0.02	0.06	0.22	0.20
AF Max	0.21	0.13	0.35	0.08	0.39	0.08	0.12	0.43	0.28
Nov Rain	-0.27	-0.84**	0.84**	0.92***	-0.75*	-0.82**	-0.94***	-0.03	-0.34
Dec Rain	-0.41	-0.71*	0.70*	0.72*	-0.73*	-0.89***	-0.81**	-0.12	-0.51
Jan Rain	-0.05	-0.06	0.17	0.10	0.16	-0.23	0.00	0.35	-0.34
Feb Rain	0.79**	0.29	-0.04	-0.04	0.09	0.33	-0.02	-0.08	0.21
Mar Rain	0.13	-0.16	0.34	0.25	-0.14	-0.44	-0.37	-0.26	-0.56
Apr Rain	0.48	0.73*	-0.34	-0.58	0.33	0.50	0.51	-0.02	0.40
May Rain	-0.31	-0.78**	0.83**	0.88***	-0.54	-0.61	-0.75*	0.21	-0.01
June Rain	0.53	0.33	0.20	-0.05	0.19	0.06	0.00	-0.10	-0.02
July Rain	-0.12	-0.07	0.29	0.17	-0.24	-0.17	-0.23	-0.43	0.07
Aug Rain	0.29	0.21	-0.02	-0.17	0.09	0.00	-0.08	-0.63	-0.27
Sept Rain	-0.23	-0.88***	0.79**	0.94***	-0.49	-0.62	-0.81**	0.25	-0.17
Oct Rain	-0.18	-0.63*	0.53	0.56	-0.23	-0.65*	-0.59	0.14	-0.57

Table C1. Yield Akaike Information Criterion (AIC) Correlations (continued).

	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
MinTemp May	0.92***	0.70*	-0.35	-0.54	0.71*	0.56	0.47	0.10	0.05
MinTemp June		0.57	-0.22	-0.34	0.59	0.54	0.30	0.09	0.13
MinTemp July			-0.65*	-0.88***	0.72*	0.76*	0.87***	0.04	0.35
MinTemp Aug				0.90***	-0.55	-0.72*	-0.75*	0.27	-0.08
MinTemp Sept					-0.67*	-0.74*	-0.87***	0.20	-0.15
MaxTemp May						0.80**	0.82**	0.36	0.32
MaxTemp June							0.86**	0.22	0.64*
MaxTemp July								0.26	0.50
MaxTemp Aug									0.56

† FA1: Common factor

‡ Pre-flowering: a fifteen day period of temperature was recorded starting ten days before the plot reached mid-flower

§ Total rainfall between November-March (Nov-Mar) and April-October (Apr-Oct)

¶ Average temperature from May through September

Average Flower Minimum/Maximum: temperature during the flowering period was calculated 10 days before and after the plot was in mid-flower

‡‡ Minimum/maximum average temperatures recorded for the month

Table C2. Oil Akaike Information Criterion (AIC) Correlations.

	Height	Disease	Lodging	FA1†	FA2	PF Max Temp‡	PF Min Temp	Avg Yield	Avg Oil	Nov-Mar§	Apr-Oct	Total Rain	Avg Temp¶	Region
Bird Damage	0.07	-0.13	-0.02	0.35	-0.23	-0.01	-0.03	0.06	0.50	-0.28	0.22	0.11	0.07	0.45
Height		0.41	0.73*	-0.21	-0.13	-0.28	-0.03	-0.38	-0.08	0.08	0.35	0.33	-0.25	-0.04
Disease			0.37	-0.58	-0.40	-0.30	-0.12	0.06	0.45	0.63*	0.37	0.48	-0.37	-0.37
Lodging				-0.11	-0.47	-0.08	0.18	0.05	0.27	0.21	-0.07	-0.01	0.03	-0.23
FA1					0.34	0.75*	0.64*	0.44	-0.31	-0.76*	-0.48	-0.61	0.81**	0.36
FA2						0.27	0.01	-0.29	-0.59	-0.54	-0.25	-0.35	0.07	0.47
PF MaxTemp							0.91***	0.71*	-0.38	-0.67*	-0.61	-0.69*	0.93***	0.28
PF MinTemp								0.80**	-0.32	-0.51	-0.56	-0.61	0.88***	-0.04
Avg Yield									0.19	-0.15	-0.61	-0.57	0.69*	-0.32
Avg Oil										0.51	-0.01	0.11	-0.35	-0.26
Nov-Mar											0.42	0.61	-0.57	-0.64*
Apr-Oct												0.98***	-0.47	0.12
Total-Rain													-0.55	-0.05
Avg Temp														0.22

Table C2. Oil Akaike Information Criterion (AIC) Correlations (continued).

	Soil Type	Elevation	Plant Date	Soil Temp	AFr Min#	AF Max	Nov Rain	Dec Rain	Jan Rain	Feb Rain	Mar Rain	Apr Rain	May Rain	June Rain
Bird Damage	-0.12	-0.03	-0.43	0.21	0.47	0.59	-0.03	-0.06	0.7	-0.54	-0.1	-0.28	0.23	0.19
Height	0.21	0.04	0.41	-0.44	0.11	-0.07	0.24	0.15	0.31	0.23	-0.21	0.35	0.26	0.66*
Disease	-0.16	-0.42	0.35	-0.38	0.12	0.04	0.35	0.01	-0.07	0.78**	0.31	-0.03	0.32	0.68
Lodging	0.10	-0.32	0.02	-0.54	0.19	0.08	0.13	0.14	0.29	0.45	-0.01	0.58	-0.09	0.41
FA1	-0.02	0.17	-0.46	-0.20	-0.19	-0.07	-0.64*	-0.49	0.12	-0.3	-0.55	0.15	-0.28	-0.2
FA2	0.24	0.69*	0.31	0.08	-0.62	-0.58	-0.17	-0.25	-0.42	-0.19	-0.73*	-0.17	0.16	-0.38
PFMaxTemp	0.13	0.04	-0.61	-0.52	-0.17	-0.14	-0.9***	-0.83**	-0.19	0.13	-0.47	0.45	-0.66*	0.02
PF MinTemp	-0.07	-0.19	-0.62	-0.77**	-0.16	-0.21	-0.86	-0.75	0.03	0.23	-0.28	0.50	-0.75	0.30
Avg Yield	-0.43	-0.58	-0.73*	-0.55	-0.15	-0.09	-0.66*	-0.59	0.12	0.30	0.12	0.13	-0.69*	0.15
Avg Oil	-0.37	-0.58	-0.19	0.15	0.18	0.30	0.43	0.27	0.38	0.21	0.41	-0.33	0.24	0.03
Nov-Mar	-0.41	-0.3	0.38	0.08	0.20	0.13	0.76*	0.67*	-0.16	0.43	0.81**	-0.25	0.37	0.12
Apr-Oct	0.18	0.27	0.51	0.32	0.62	0.53	0.55	0.44	-0.06	-0.08	0.35	-0.10	0.65*	0.39
Total-Rain	0.05	0.16	0.53	0.29	0.59	0.49	0.66*	0.55	-0.09	0.03	0.50	-0.15	0.66	0.37
Avg Temp	0.07	0.05	-0.64*	-0.47	0.05	0.08	-0.8**	-0.62	-0.14	0.04	-0.29	0.53	-0.62	-0.01

Table C2. Oil Akaike Information Criterion (AIC) Correlations (continued).

	July Rain	Aug Rain	Sept Rain	Oct Rain	MinTemp May‡‡	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
Bird Damage	-0.10	-0.16	0.27	0.22	-0.14	-0.24	-0.08	0.42	0.27	0.25	-0.07	0.13	0.73*	0.28
Height	-0.12	0.27	0.17	0.2	0.21	0.2	-0.03	0.4	0.23	-0.31	-0.31	-0.33	-0.06	-0.1
Disease	0.33	0.47	0.39	-0.03	0.34	0.63*	-0.07	0.42	0.37	-0.05	-0.05	-0.39	-0.04	-0.01
Lodging	-0.40	-0.08	-0.06	0.11	0.54	0.50	0.25	0.21	0.04	-0.06	-0.04	-0.06	0.22	0.03
FA1	-0.37	-0.48	-0.41	-0.33	0.02	-0.15	0.48	-0.4	-0.49	0.43	0.41	0.71*	0.48	0.41
FA2	0.00	-0.25	0.01	-0.35	-0.59	-0.53	-0.19	-0.29	-0.06	-0.28	0.11	0.05	-0.17	0.29
PF MaxTemp	-0.1	-0.09	-0.77**	-0.8**	0.32	0.24	0.84**	-0.73*	-0.82**	0.62	0.82**	0.92***	0.17	0.56
PF MinTemp	-0.12	0.10	-0.81**	-0.73*	0.48	0.38	0.91***	-0.66	-0.82**	0.57	0.67*	0.84**	0.05	0.30
Avg Yield	-0.12	-0.01	-0.56	-0.55	0.49	0.48	0.71*	-0.53	-0.59	0.65*	0.60	0.70*	0.22	0.17
Avg Oil	-0.16	-0.25	0.51	0.33	0.1	0.25	-0.30	0.49	0.55	0.04	-0.13	-0.26	0.58	0.04
Nov-Mar	0.39	0.21	0.48	0.33	0.00	0.21	-0.42	0.58	0.59	-0.45	-0.54	-0.7*	-0.23	-0.43
Apr-Oct	0.59	0.50	0.47	0.43	-0.13	-0.08	-0.38	0.71*	0.51	-0.27	-0.51	-0.56	-0.16	-0.17
Total-Rain	0.61	0.49	0.53	0.46	-0.12	-0.02	-0.44	0.76*	0.58	-0.35	-0.58	-0.66*	-0.2	-0.25
Avg Temp	-0.09	-0.16	-0.77**	-0.65*	0.36	0.21	0.86***	-0.58	-0.78**	0.60	0.66*	0.89***	0.25	0.49

Table C2. Oil Akaike Information Criterion (AIC) Correlations (continued).

	Soil Type	Elevation	Plant Date	Soil Temp	AF Min	AF Max	Nov Rain	Dec Rain	Jan Rain	Feb Rain	Mar Rain	Apr Rain	May Rain	June Rain
Region	0.76*	0.64*	-0.09	0.31	0.28	0.36	-0.25	-0.33	-0.18	-0.33	-0.68*	0.26	0.17	-0.17
Soil Type		0.42	0.13	0.18	0.4	0.37	-0.2	-0.26	-0.31	0.01	-0.53	0.63	-0.01	-0.02
Elevation			0.28	0.23	0.02	-0.03	0.12	0.14	-0.48	-0.35	-0.42	0.08	0.34	-0.29
Plant Date				0.21	-0.17	-0.23	0.64*	0.46	-0.33	0.22	-0.06	-0.24	0.73*	0.04
Soil Temp					0.24	0.39	0.43	0.47	-0.03	-0.59	0.15	-0.46	0.44	-0.63
AF Min						0.96***	0.12	0.18	0.03	-0.06	0.37	0.42	0.09	0.25
AF Max							0.1	0.14	0.06	-0.13	0.31	0.29	0.14	0.09
Nov Rain								0.89***	-0.05	0.03	0.44	-0.43	0.78**	-0.13
Dec Rain									0.04	-0.22	0.55	-0.32	0.54	-0.30
Jan Rain										-0.42	0.05	-0.2	-0.09	0.29
Feb Rain											0.09	0.33	-0.04	0.41
Mar Rain												-0.23	0.01	0.07
April Rain													-0.49	0.25
May Rain														0.00

Table C2. Oil Akaike Information Criterion (AIC) Correlations (continued).

	July Rain	Aug Rain	Sept Rain	Oct Rain	MinTemp May	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
Region	0.01	-0.19	-0.05	-0.17	-0.21	-0.27	0.06	-0.03	-0.08	0.20	0.37	0.33	0.38	0.75*
Soil Type	-0.08	0.05	-0.21	-0.06	0.22	0.13	0.19	-0.18	-0.24	0.22	0.42	0.24	0.02	0.50
Elevation	0.37	-0.11	0.02	-0.2	-0.66*	-0.67*	-0.22	0.15	0.13	-0.48	-0.18	-0.12	-0.16	0.36
Plant Date	0.14	0.09	0.64*	0.41	-0.26	-0.09	-0.62	0.43	0.55	-0.59	-0.52	-0.76*	-0.35	-0.31
Soil Temp	-0.02	-0.29	0.48	0.63*	-0.45	-0.5	-0.64*	0.27	0.42	-0.14	-0.32	-0.34	0.12	-0.14
AF Min	0.29	0.26	-0.04	0.25	0.35	0.25	0.19	0.37	0.04	0.28	0.02	0.06	0.22	0.20
AF Max	0.17	0.07	0.05	0.30	0.31	0.21	0.13	0.35	0.08	0.39	0.08	0.12	0.43	0.28
Nov Rain	0.19	-0.12	0.83**	0.62	-0.43	-0.27	-0.84**	0.84**	0.92***	-0.75*	-0.82**	-0.94***	-0.03	-0.34
Dec Rain	0.08	-0.2	0.57	0.69*	-0.42	-0.41	-0.71*	0.7*	0.72*	-0.73*	-0.89***	-0.81**	-0.12	-0.51
Jan Rain	-0.49	-0.02	0.11	0.47	0.13	-0.05	-0.06	0.17	0.10	0.16	-0.23	0.00	0.35	-0.34
Feb Rain	0.14	0.20	-0.02	-0.39	0.53	0.79**	0.29	-0.04	-0.04	0.09	0.33	-0.02	-0.08	0.21
Mar Rain	0.41	0.32	0.13	0.31	0.09	0.13	-0.16	0.34	0.25	-0.14	-0.44	-0.37	-0.26	-0.56
April Rain	-0.11	0.12	-0.67*	-0.36	0.63	0.48	0.73*	-0.34	-0.58	0.33	0.50	0.51	-0.02	0.40
May Rain	0.23	-0.14	0.92***	0.50	-0.5	-0.31	-0.78**	0.83**	0.88***	-0.54	-0.61	-0.75*	0.21	-0.01

Table C2. Oil Akaike Information Criterion (AIC) Correlations (continued).

	July Rain	Aug Rain	Sept Rain	Oct Rain	MinTemp May	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
June Rain	0.29	0.73*	-0.06	-0.15	0.47	0.53	0.33	0.20	-0.05	0.19	0.06	0.00	-0.10	-0.02
July Rain		0.63	0.04	-0.34	-0.29	-0.12	-0.07	0.29	0.17	-0.24	-0.17	-0.23	-0.43	0.07
Aug Rain			-0.2	-0.18	0.25	0.29	0.21	-0.02	-0.17	0.09	0.00	-0.08	-0.63	-0.27
Sept Rain				0.63	-0.44	-0.23	-0.88**	0.79**	0.94***	-0.49	-0.62	-0.81**	0.25	-0.17
Oct Rain					-0.08	-0.18	-0.63	0.53	0.56	-0.23	-0.65*	-0.59	0.14	-0.57
MinTemp May						0.92***	0.7*	-0.35	-0.54	0.71*	0.56	0.47	0.10	0.05
MinTemp June							0.57	-0.22	-0.34	0.59	0.54	0.30	0.09	0.13
MinTemp July								-0.65*	-0.88***	0.72*	0.76*	0.87***	0.04	0.35
MinTemp Aug									0.9***	-0.55	-0.72*	-0.75*	0.27	-0.08
MinTemp Sept										-0.67*	-0.74*	-0.87***	0.20	-0.15
MaxTemp May											0.8**	0.82**	0.36	0.32
MaxTemp June												0.86**	0.22	0.64*
MaxTemp July													0.26	0.50
MaxTemp Aug														0.56

† FA1/FA2: Common factor 1 or 2

‡ Pre-flowering: a fifteen day period of temperature was recorded starting ten days before the plot reached mid-flower

§ Total rainfall between November-March (Nov-Mar) and April-October (Apr-Oct)

¶ Average temperature from May through September

Average Flower Minimum/Maximum: temperature during the flowering period was calculated 10 days before and after the plot was in mid-flower

‡‡ Minimum/maximum average temperatures recorded for the month

Table C3. Oil Bayesian Information Criterion (BIC) Correlations.

	Height	Disease	Lodging	FA1†	FA2	PFMax Temp‡	PFMin Temp	Avg Yield	Avg Oil	Nov-Mar§	Apr-Oct	Total Rain	Avg Temp¶	Region
Bird Damage	0.07	-0.13	-0.02	0.38	-0.24	-0.01	-0.03	0.06	0.50	-0.28	0.22	0.11	0.07	0.45
Height		0.41	0.73*	-0.20	-0.13	-0.28	-0.03	-0.38	-0.08	0.08	0.35	0.33	-0.25	-0.04
Disease			0.37	-0.57	-0.40	-0.30	-0.12	0.06	0.45	0.63*	0.37	0.48	-0.37	-0.37
Lodging				-0.12	-0.46	-0.08	0.18	0.05	0.27	0.21	-0.07	-0.01	0.03	-0.23
FA1					0.34	0.72*	0.62	0.43	-0.29	-0.73*	-0.44	-0.57	0.79**	0.34
FA2						0.28	0.02	-0.29	-0.59	-0.55	-0.26	-0.36	0.08	0.47
PF MaxTemp							0.91***	0.71*	-0.38	-0.67*	-0.61	-0.69*	0.93***	0.28
PF MinTemp								0.8**	-0.32	-0.51	-0.56	-0.61	0.88***	-0.04
Avg Yield									0.19	-0.15	-0.61	-0.57	0.69*	-0.32
Avg Oil										0.51	-0.01	0.11	-0.35	-0.26
Nov-Mar											0.42	0.61	-0.57	-0.64*
Apr-Oct												0.98***	-0.47	0.12
Total-Rain													-0.55	-0.05
Avg Temp														0.22

Table C3. Oil Bayesian Information Criterion (BIC) Correlations (continued).

	Soil Type	Elevation	Plant Date	Soil Temp	AF Min#	AF Max	Nov Rain	Dec Rain	Jan Rain	Feb Rain	Mar Rain	Apr Rain	May Rain	June Rain
Bird Damage	-0.12	-0.03	-0.43	0.21	0.47	0.59	-0.03	-0.06	0.70	-0.54	-0.10	-0.28	0.23	0.19
Height	0.21	0.04	0.41	-0.44	0.11	-0.07	0.24	0.15	0.31	0.23	-0.21	0.35	0.26	0.66*
Disease	-0.16	-0.42	0.35	-0.38	0.12	0.04	0.35	0.01	-0.07	0.78**	0.31	-0.03	0.32	0.68*
Lodging	0.1	-0.32	0.02	-0.54	0.19	0.08	0.13	0.14	0.29	0.45	-0.01	0.58	-0.09	0.41
FA1	-0.06	0.17	-0.44	-0.19	-0.18	-0.06	-0.6	-0.45	0.14	-0.32	-0.52	0.11	-0.24	-0.19
FA2	0.25	0.68*	0.31	0.09	-0.62	-0.57	-0.18	-0.26	-0.43	-0.18	-0.74*	-0.17	0.16	-0.39
PF MaxTemp	0.13	0.04	-0.61	-0.52	-0.17	-0.14	-0.9***	-0.83**	-0.19	0.13	-0.47	0.45	-0.66*	0.02
PF MinTemp	-0.07	-0.19	-0.62	-0.77	-0.16	-0.21	-0.86	-0.75	0.03	0.23	-0.28	0.50	-0.75*	0.30
Avg Yield	-0.43	-0.58	-0.73*	-0.55	-0.15	-0.09	-0.66*	-0.59	0.12	0.30	0.12	0.13	-0.69*	0.15
Avg Oil	-0.37	-0.58	-0.19	0.15	0.18	0.30	0.43	0.27	0.38	0.21	0.41	-0.33	0.24	0.03
Nov-Mar	-0.41	-0.3	0.38	0.08	0.20	0.13	0.76*	0.67*	-0.16	0.43	0.81**	-0.25	0.37	0.12
Apr-Oct	0.18	0.27	0.51	0.32	0.62	0.53	0.55	0.44	-0.06	-0.08	0.35	-0.10	0.65*	0.39
Total-Rain	0.05	0.16	0.53	0.29	0.59	0.49	0.66*	0.55	-0.09	0.03	0.50	-0.15	0.66*	0.37
Avg Temp	0.07	0.05	-0.64*	-0.47	0.05	0.08	-0.8**	-0.62	-0.14	0.04	-0.29	0.53	-0.62	-0.01

Table C3. Oil Bayesian Information Criterion (BIC) Correlations (continued).

	July Rain	Aug Rain	Sept Rain	Oct Rain	MinTemp May‡‡	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
Bird Damage	-0.10	-0.16	0.27	0.22	-0.14	-0.24	-0.08	0.42	0.27	0.25	-0.07	0.13	0.73*	0.28
Height	-0.12	0.27	0.17	0.20	0.21	0.20	-0.03	0.40	0.23	-0.31	-0.31	-0.33	-0.06	-0.1
Disease	0.33	0.47	0.39	-0.03	0.34	0.63*	-0.07	0.42	0.37	-0.05	-0.05	-0.39	-0.04	-0.01
Lodging	-0.40	-0.08	-0.06	0.11	0.54	0.50	0.25	0.21	0.04	-0.06	-0.04	-0.06	0.22	0.03
FA1	-0.35	-0.48	-0.37	-0.3	-0.01	-0.17	0.45	-0.35	-0.45	0.41	0.36	0.67*	0.49	0.38
FA2	-0.01	-0.27	0.01	-0.34	-0.57	-0.51	-0.18	-0.30	-0.07	-0.27	0.12	0.06	-0.16	0.29
PF MaxTemp	-0.10	-0.09	-0.77**	-0.8**	0.32	0.24	0.84**	-0.73**	-0.82**	0.62	0.82**	0.92***	0.17	0.56
PF MinTemp	-0.12	0.10	-0.81**	0.73*	0.48	0.38	0.91***	-0.66*	-0.82**	0.57	0.67*	0.84**	0.05	0.30
Avg Yield	-0.12	-0.01	-0.56	-0.55	0.49	0.48	0.71*	-0.53	-0.59	0.65*	0.6	0.7*	0.22	0.17
Avg Oil	-0.16	-0.25	0.51	0.33	0.10	0.25	-0.30	0.49	0.55	0.04	-0.13	-0.26	0.58	0.04
Nov-Mar	0.39	0.21	0.48	0.33	0.00	0.21	-0.42	0.58	0.59	-0.45	-0.54	-0.7*	-0.23	-0.43
Apr-Oct	0.59	0.50	0.47	0.43	-0.13	-0.08	-0.38	0.71*	0.51	-0.27	-0.51	-0.56	-0.16	-0.17
Total-Rain	0.61	0.49	0.53	0.46	-0.12	-0.02	-0.44	0.76*	0.58	-0.35	-0.58	-0.66*	-0.20	-0.25
Avg Temp	-0.09	-0.16	-0.77**	-0.65*	0.36	0.21	0.86**	-0.58	-0.78**	0.60	0.66*	0.89***	0.25	0.49

Table C3. Oil Bayesian Information Criterion (BIC) Correlations (continued).

	Soil Type	Elevation	Plant Date	Soil Temp	AF Min	AF Max	Nov Rain	Dec Rain	Jan Rain	Feb Rain	Mar Rain	Apr Rain	May Rain	June Rain
Region	0.76*	0.64*	-0.09	0.31	0.28	0.36	-0.25	-0.33	-0.18	-0.33	-0.68*	0.26	0.17	-0.17
Soil Type		0.42	0.13	0.18	0.40	0.37	-0.2	-0.26	-0.31	0.01	-0.53	0.63	-0.01	-0.02
Elevation			0.28	0.23	0.02	-0.03	0.12	0.14	-0.48	-0.35	-0.42	0.08	0.34	-0.29
Plant Date				0.21	-0.17	-0.23	0.64*	0.46	-0.33	0.22	-0.06	-0.24	0.73*	0.04
Soil Temp					0.24	0.39	0.43	0.47	-0.03	-0.59	0.15	-0.46	0.44	-0.63
AF Min						0.96***	0.12	0.18	0.03	-0.06	0.37	0.42	0.09	0.25
AF Max							0.10	0.14	0.06	-0.13	0.31	0.29	0.14	0.09
Nov Rain								0.89***	-0.05	0.03	0.44	-0.43	0.78**	-0.13
Dec Rain									0.04	-0.22	0.55	-0.32	0.54	-0.30
Jan Rain										-0.42	0.05	-0.20	-0.09	0.29
Feb Rain											0.09	0.33	-0.04	0.41
Mar Rain												-0.23	0.01	0.07
April Rain													-0.49	0.25
May Rain														0.00

Table C3. Oil Bayesian Information Criterion (BIC) Correlations (continued).

	July Rain	Aug Rain	Sept Rain	Oct Rain	MinTemp May	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
Region	0.01	-0.19	-0.05	-0.17	-0.21	-0.27	0.06	-0.03	-0.08	0.20	0.37	0.33	0.38	0.75*
Soil Type	-0.08	0.05	-0.21	-0.06	0.22	0.13	0.19	-0.18	-0.24	0.22	0.42	0.24	0.02	0.50
Elevation	0.37	-0.11	0.02	-0.20	-0.66*	-0.67*	-0.22	0.15	0.13	-0.48	-0.18	-0.12	-0.16	0.36
Plant Date	0.14	0.09	0.64*	0.41	-0.26	-0.09	-0.62	0.43	0.55	-0.59	-0.52	-0.76*	-0.35	-0.31
Soil Temp	-0.02	-0.29	0.48	0.63*	-0.45	-0.50	-0.64*	0.27	0.42	-0.14	-0.32	-0.34	0.12	-0.14
AF Min	0.29	0.26	-0.04	0.25	0.35	0.25	0.19	0.37	0.04	0.28	0.02	0.06	0.22	0.20
AF Max	0.17	0.07	0.05	0.30	0.31	0.21	0.13	0.35	0.08	0.39	0.08	0.12	0.43	0.28
Nov Rain	0.19	-0.12	0.83**	0.62	-0.43	-0.27	-0.84**	0.84**	0.92***	-0.75*	-0.82**	-0.94***	-0.03	-0.34
Dec Rain	0.08	-0.20	0.57	0.69*	-0.42	-0.41	-0.71*	0.70*	0.72*	-0.73*	-0.89***	-0.81**	-0.12	-0.51
Jan Rain	-0.49	-0.02	0.11	0.47	0.13	-0.05	-0.06	0.17	0.10	0.16	-0.23	0.00	0.35	-0.34
Feb Rain	0.14	0.20	-0.02	-0.39	0.53	0.79**	0.29	-0.04	-0.04	0.09	0.33	-0.02	-0.08	0.21
Mar Rain	0.41	0.32	0.13	0.31	0.09	0.13	-0.16	0.34	0.25	-0.14	-0.44	-0.37	-0.26	-0.56
April Rain	-0.11	0.12	-0.67*	-0.36	0.63	0.48	0.73*	-0.34	-0.58	0.33	0.50	0.51	-0.02	0.40
May Rain	0.23	-0.14	0.92***	0.50	-0.50	-0.31	-0.78**	0.83**	0.88***	-0.54	-0.61	-0.75*	0.21	-0.01

Table C3. Oil Bayesian Information Criterion (BIC) Correlations (continued).

	July Rain	Aug Rain	Sept Rain	Oct Rain	MinTemp May	MinTemp June	MinTemp July	MinTemp Aug	MinTemp Sept	MaxTemp May	MaxTemp June	MaxTemp July	MaxTemp Aug	MaxTemp Sept
June Rain	0.29	0.73*	-0.06	-0.15	0.47	0.53	0.33	0.20	-0.05	0.19	0.06	0.00	-0.10	-0.02
July Rain		0.63	0.04	-0.34	-0.29	-0.12	-0.07	0.29	0.17	-0.24	-0.17	-0.23	-0.43	0.07
Aug Rain			-0.20	-0.18	0.25	0.29	0.21	-0.02	-0.17	0.09	0.00	-0.08	-0.63	-0.27
Sept Rain				0.63	-0.44	-0.23	-0.88***	0.79**	0.94***	-0.49	-0.62	-0.81**	0.25	-0.17
Oct Rain					-0.08	-0.18	-0.63	0.53	0.56	-0.23	-0.65*	-0.59	0.14	-0.57
MinTemp May						0.92***	0.70*	-0.35	-0.54	0.71*	0.56	0.47	0.10	0.05
MinTemp June							0.57	-0.22	-0.34	0.59	0.54	0.30	0.09	0.13
MinTemp July								-0.65*	-0.88***	0.72*	0.76*	0.87***	0.04	0.35
MinTemp Aug									0.90***	-0.55	-0.72*	-0.75*	0.27	-0.08
MinTemp Sept										-0.67*	-0.74*	-0.87***	0.20	-0.15
MaxTemp May											0.80**	0.82**	0.36	0.32
MaxTemp June												0.86**	0.22	0.64*
MaxTemp July													0.26	0.50
MaxTemp Aug														0.56

† FA1/FA2: Common factor 1 or 2

‡ Pre-flowering: a fifteen day period of temperature was recorded starting ten days before the plot reached mid-flower

§ Total rainfall between November-March (Nov-Mar) and April-October (Apr-Oct)

¶ Average temperature from May through September

Average Flower Minimum/Maximum: temperature during the flowering period was calculated 10 days before and after the plot was in mid-flower

‡‡ Minimum/maximum average temperatures recorded for the month

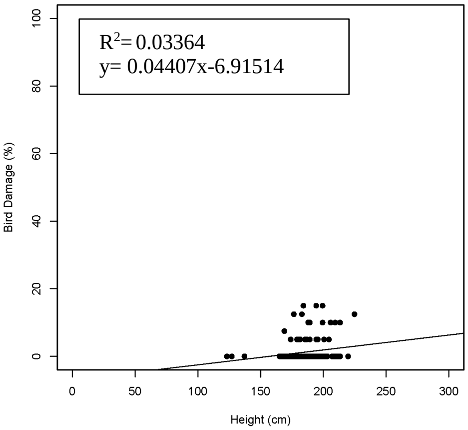

Figure C1. Relationship between height and bird damage at Carrington 2012. Slope is significant at P ≤ 0.05.

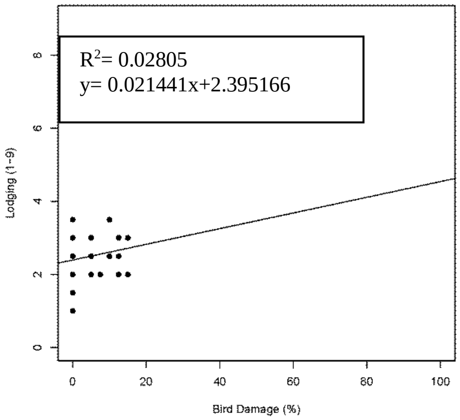

Figure C2. Relationship between lodging and bird damage at Carrington 2012. Slope is significant at P ≤ 0.05.

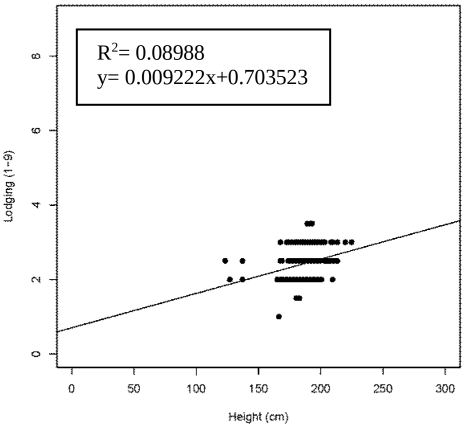

Figure C3. Relationship between height and lodging at Carrington 2012. Slope is significant at P ≤ 0.001.

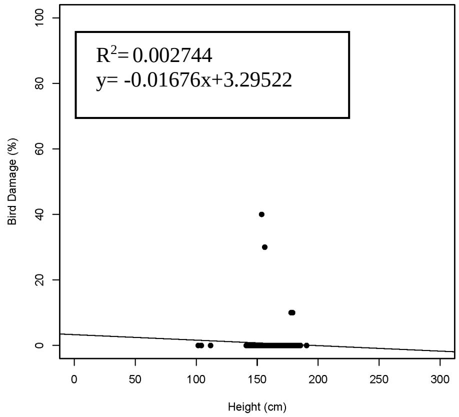

Figure C4. Relationship between bird damage and height at Carrington 2013. Slope is non-significant.

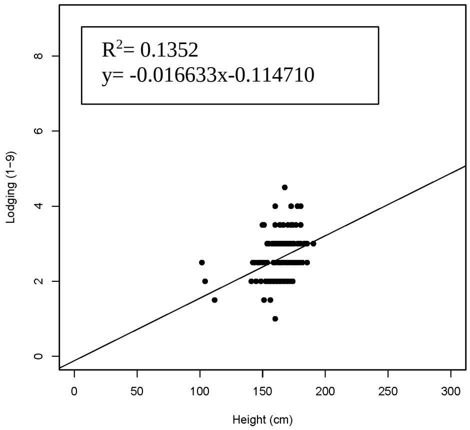

Figure C5. Relationship between lodging and height at Carrington 2013. Slope is significant at P ≤ 0.001.

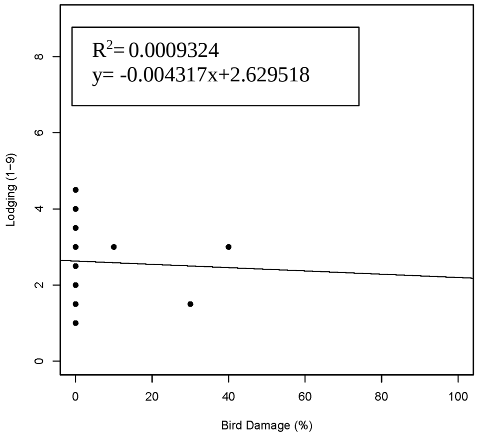

Figure C6. Relationship between lodging and bird damage at Carrington 2013. Slope is non-significant.

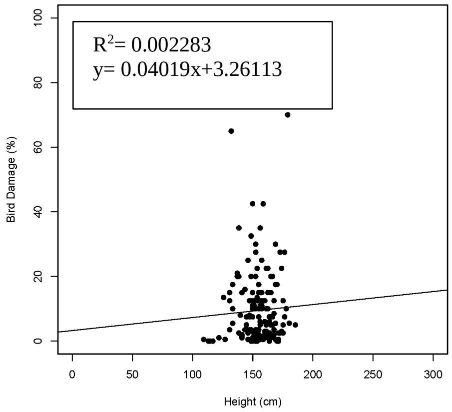

Figure C7. Relationship between bird damage and height at Crookston 2012. Slope is non-significant.

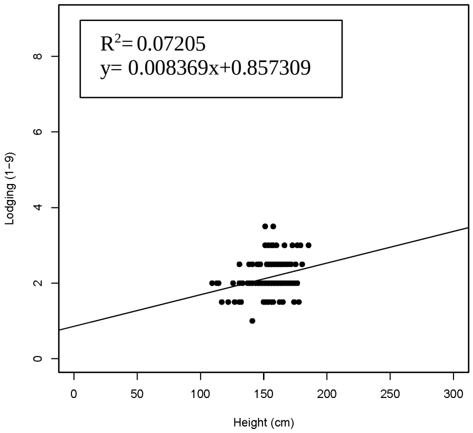

Figure C8. Relationship between lodging and height at Crookston 2012. Slope is significant at P ≤ 0.001.

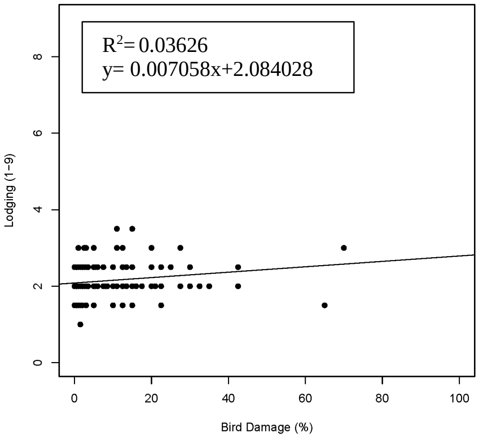

Figure C9. Relationship between lodging and bird damage at Crookston 2012. Slope is significant at P ≤ 0.05.

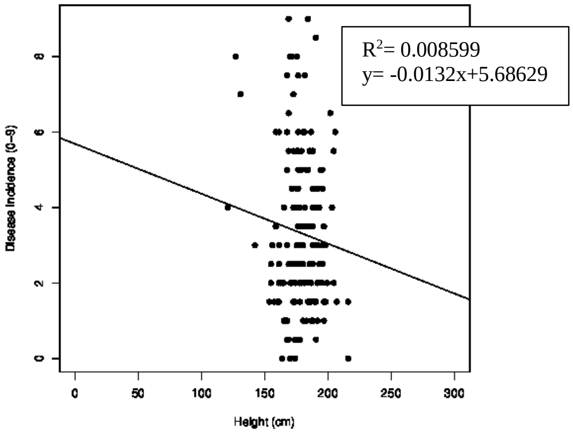

Figure C10. Relationship between disease incidence and height at Crookston 2013. Slope is non-significant.

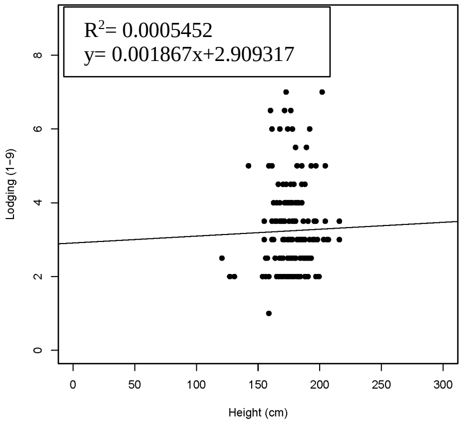

Figure C11. Relationship between lodging and height at Crookston 2013. Slope is non-significant.

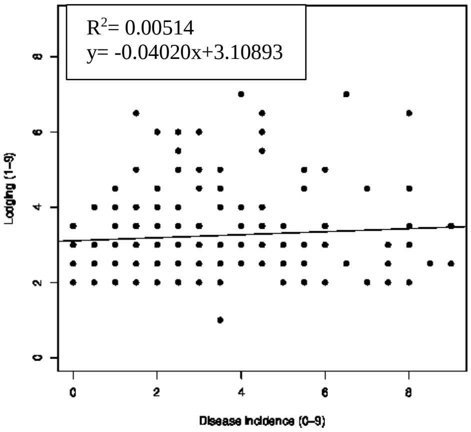

Figure C12. Relationship between lodging and disease incidence at Crookston 2013. Slope is non- significant.

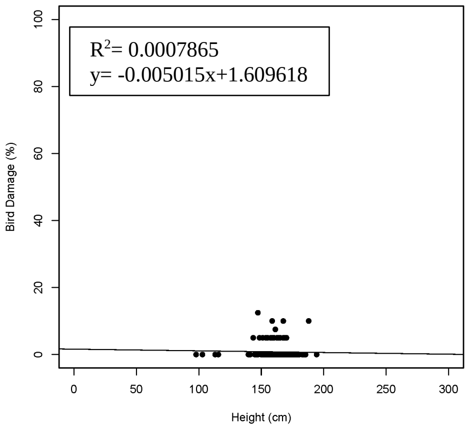

Figure C13. Relationship between bird damage and height at Eureka in 2012. Slope is non-significant.

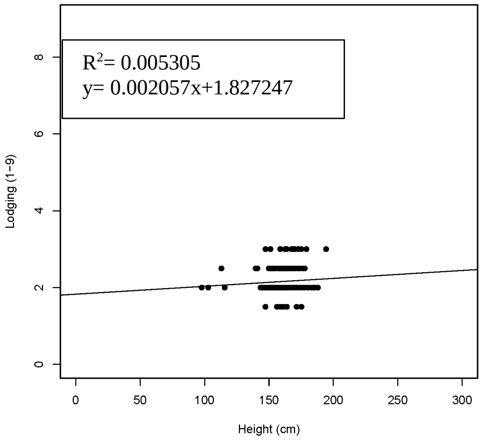

Figure C14. Relationship between lodging and height at Eureka in 2012. Slope is non-significant.

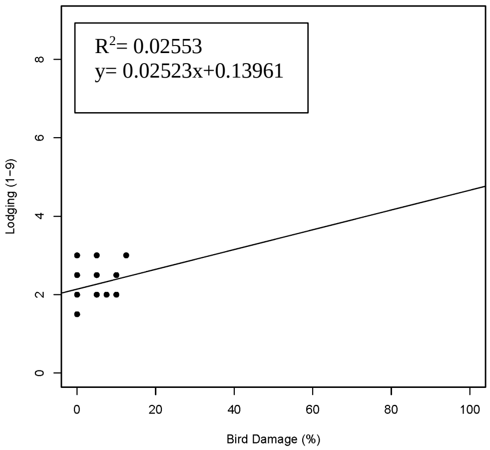

Figure C15. Relationship between lodging and bird damage at Eureka in 2012. Slope is significant at $P \leq 0.05$.

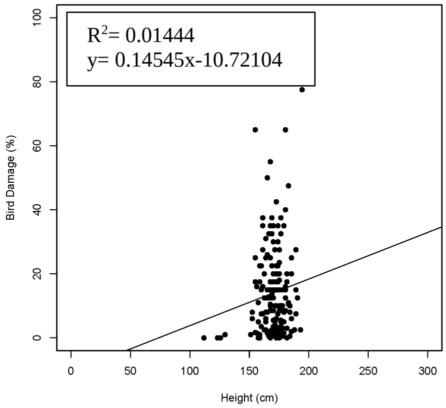

Figure C16. Relationship between bird damage and height at Mandan 2012. Slope is non-significant.

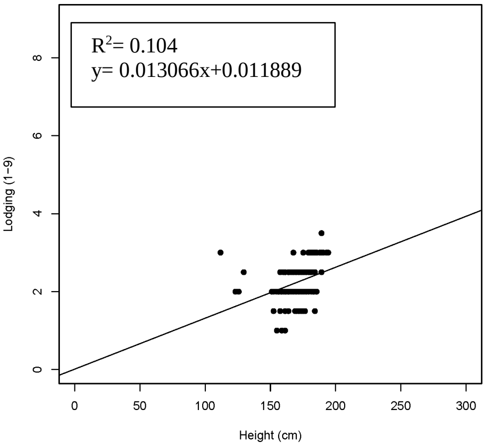

Figure C17. Relationship between lodging and height at Mandan 2012. Slope is significant at $P \leq 0.001$.

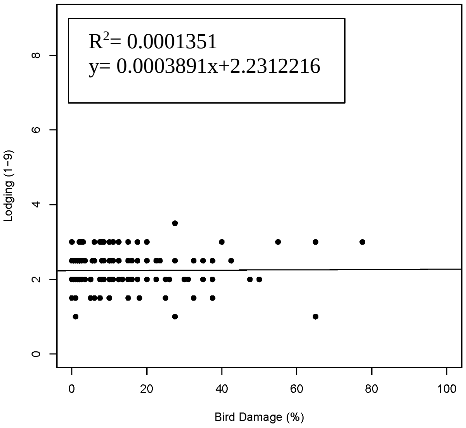

Figure C18. Relationship between lodging and bird damage at Mandan 2012. Slope is non-significant.

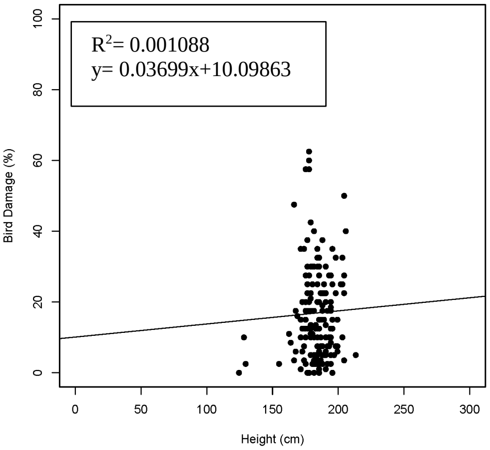

Figure C19. Relationship between bird damage and height at Mandan 2013. Slope is non-significant.

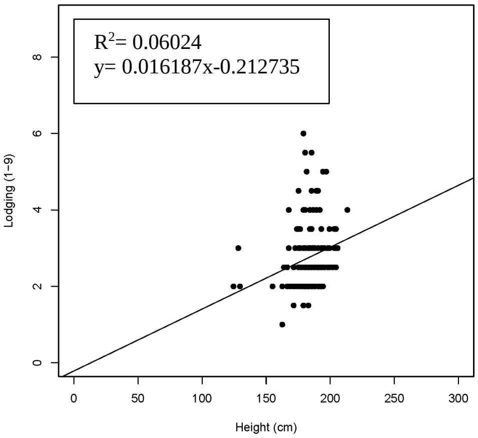

Figure C20. Relationship between lodging and height at Mandan 2013. Slope is significant at $P \leq 0.01$.

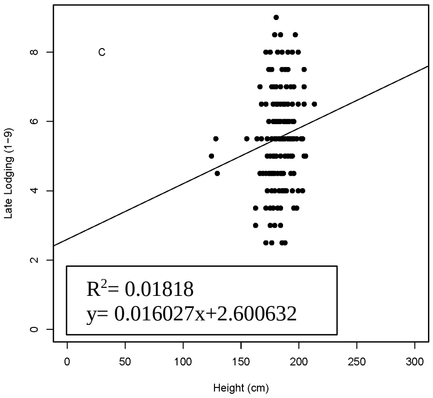

Figure C21. Relationship between late lodging and height at Mandan 2013. Slope is non-significant

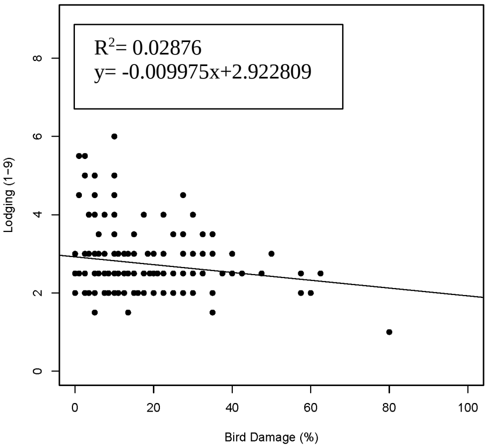

Figure C22. Relationship between lodging and bird damage at Mandan 2013. Slope is significant at P ≤ 0.05.

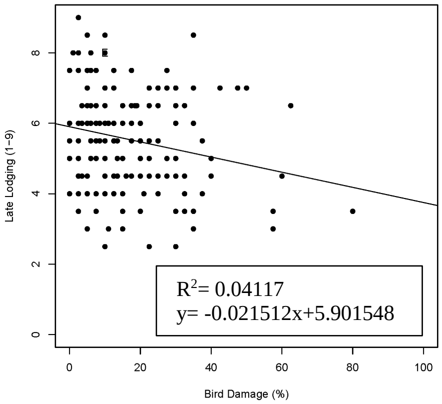

Figure C23. Relationship between late lodging and bird damage at Mandan 2013. Slope is significant at P ≤ 0.01.

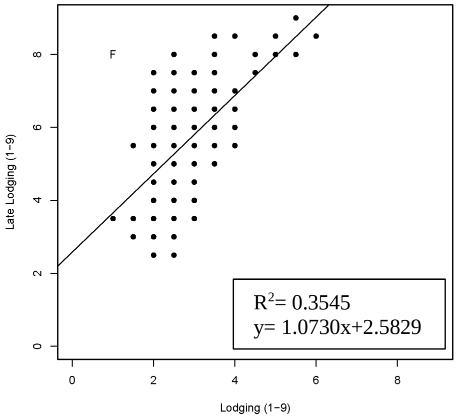

Figure C24. Relationship between late lodging and lodging at Mandan 2013. Slope is significant at P ≤ 0.001.

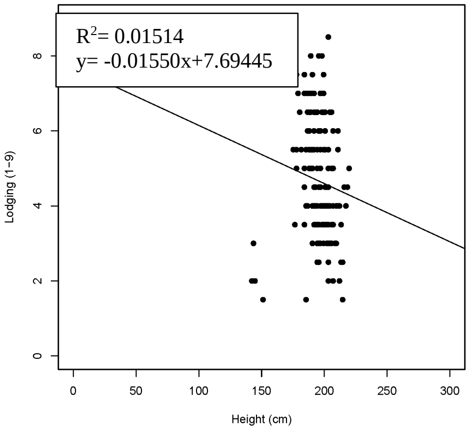

Figure C25. Relationship between lodging and height at Velva 2012. Slope is non-significant.

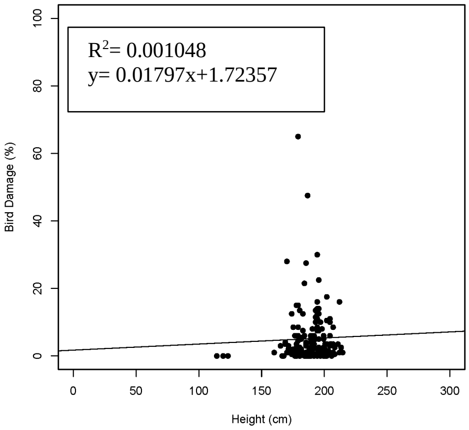

Figure C26. Relationship between bird damage and height at Velva 2012. Slope is non-significant.

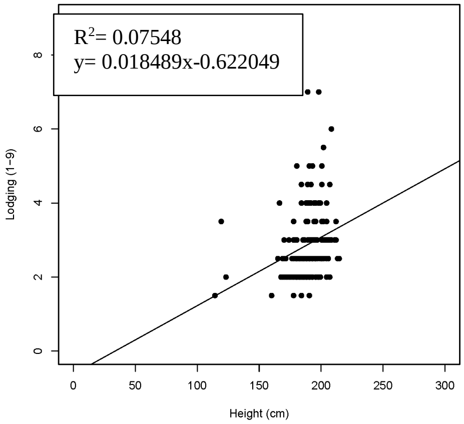

Figure C27. Relationship between lodging and height at Velva 2013. Slope is significant at $P \leq 0.001$.

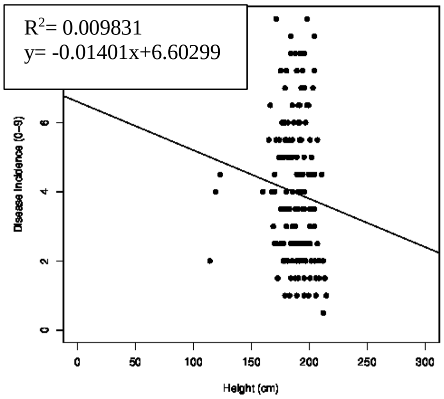

Figure C28. Relationship between disease incidence and height at Velva 2013. Slope is non-significant.

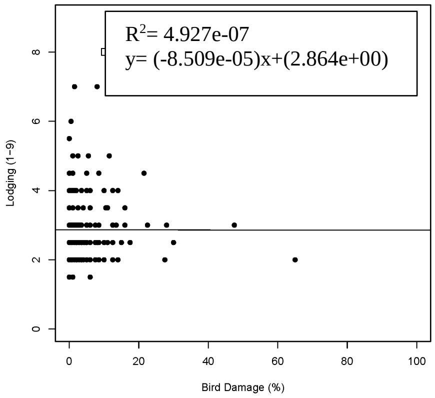

Figure C29. Relationship between lodging and bird damage at Velva 2013. Slope is non-significant.

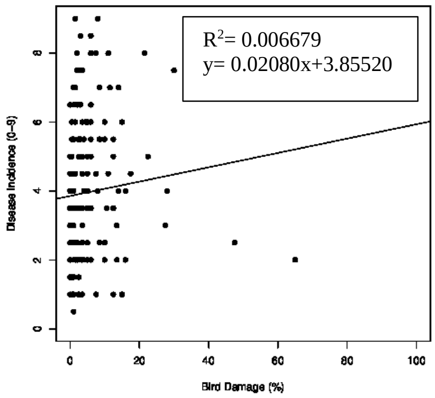

Figure C30. Relationship between disease incidence and bird damage at Velva 2013. Slope is non-significant.

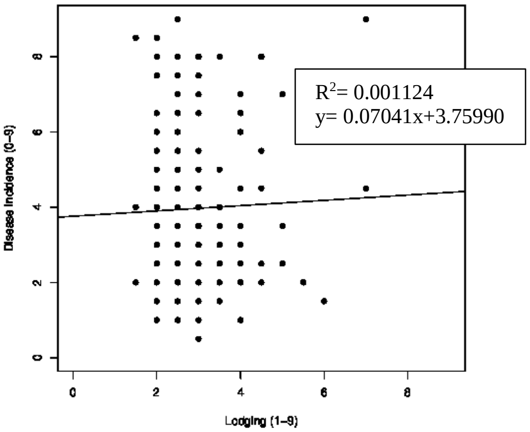

Figure C31. Relationship between disease incidence and lodging at Velva 2013. Slope is non-significant.

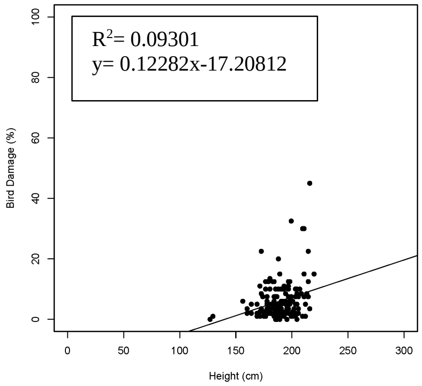

Figure C32. Relationship between bird damage and height at Wyndmere 2012. Slope is non-significant.

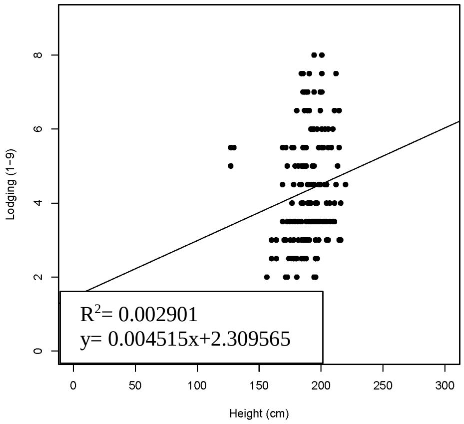

Figure C33. Relationship between lodging and height at Wyndmere 2012. Slope is significant at $P \leq 0.05$.

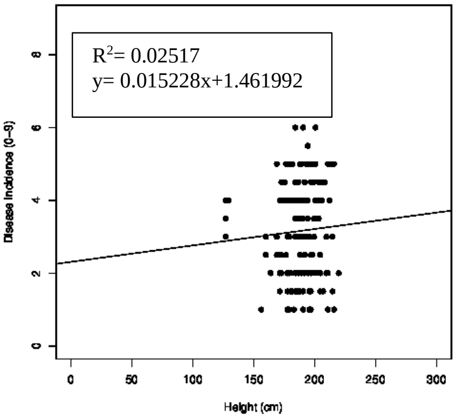

Figure C34. Relationship between disease incidence and height at Wyndmere 2012. Slope is non-significant.

APPENDIX D. MODELS TESTED AND RANK CHANGES

Table D1. Models tested for assessment of GxE with optimum number of common factors as assessed by Akaike information criterion (AIC) and Bayesian information criterion (BIC) scores.

			BIC		**AIC**	
Trait	**Model**	**Covariates**	Common Factors	Score	Common Factors	Score
Oil	Lattice	None	1	8018.0	1	7871.4
Oil	Lattice	Lodging	2	8030.1	2	7791.8
Oil	Lattice	Height	1	7989.8	1	7818.7
Oil	Lattice	BD†	2	8019.1	2	7799.2
Oil	Lattice	Flower	2	8030.4	2	7822.7
Oil	Lattice	Maturity	2	8051.5	2	7807.2
Oil	Lattice	DI‡	1	8030.7	1	7851.8
Oil	Lattice	Lodging-BD	2	8036.7	2	7780.1
Oil	Lattice	Lodging-DI	2	8037.2	2	7792.8
Oil	Lattice	Lodging-Height	2	7998.4	2	7735.6
Oil	Lattice	Height-BD	2	7985.8	2	7723.0
Oil	Lattice	Height-DI	2	7982.4§	2	7731.9
Oil	Lattice	BD-DI	1	8037.2	1	7860.1
Oil	Lattice	Lodging-BD-Height	2	7999.7	2	7706.5§
Oil	Lattice	Lodging-BD-DI	1	8043.7	1	7842.1
Oil	Lattice	Lodging-Height-DI	1	8000.0	1	7786.1
Oil	Lattice	Lodging-BD-DI-Height	2	8013.6	2	7714.2
Oil	Lattice	Height-DI-BD	2	7988.2	2	7719.4
Oil	Lattice	Flower-Lodging	2	8046.5	2	7802.2
Oil	Lattice	Flower-Height	2	7995.4	2	7757.2
Oil	Lattice	Flower-BD	1	8034.3	2	7812.0
Oil	Lattice	Flower-DI	1	8032.7	3	7837.2
Oil	Lattice	Flower-Maturity	1	8046.9	3	7838.4
Oil	Lattice	Flower-Lodging-Height	2	7995.1	2	7732.3
Oil	Lattice	Flower-Lodging-BD	1	8052.9	3	7806.2
Oil	Lattice	Flower-Lodging-Maturity	0	8078.2	1	7866.2
Oil	Lattice	Flower-Lodging-DI	2	8059.9	2	7803.3
Oil	Lattice	Flower-Height-BD	2	7985.6	2	7741.3
Oil	Lattice	Flower-Height-Maturity	2	8006.7	2	7756.2
Oil	Lattice	Flower-Height-DI	2	7989.6	2	7751.3
Oil	Lattice	Flower-BD-Maturity	1	8062.9	2	7813.3
Oil	Lattice	Flower-BD-DI	0	8052.0	2	7809.5
Oil	Lattice	Flower-Maturity-DI	1	8061.6	3	7831.1
Oil	Lattice	Maturity-Lodging	2	8056.6	2	7793.9

Table D1. Models tested for assessment of GxE with optimum number of common factors as assessed by Akaike information criterion (AIC) and Bayesian information criterion (BIC) scores (continued).

			BIC		**AIC**	
Trait	**Model**	**Covariates**	Common Factors	Score	Common Factors	Score
Oil	Lattice	Maturity-BD	2	8058.3	2	7795.6
Oil	Lattice	Maturity-DI	1	8048.1	1	7870.9
Oil	Lattice	Maturity-Lodging-DI	2	8053.7	2	7791.0
Oil	Lattice	Maturity-Lodging-BD	1	8071.9	1	7845.9
Oil	Lattice	Maturity-Lodging-Height	2	8018.2	2	7724.9
Oil	Lattice	Maturity-Height-BD	2	8018.6	2	7725.4
Oil	Lattice	Maturity-Height-DI	1	8024.1	1	7816.4
Oil	Lattice	Maturity-BD-DI	1	8054.6	1	7859.1
Oil	RCBD	Lodging-BD	2	8124.9	2	7886.6
Oil	RCBD	Lodging-DI	2	8128.7	2	7896.5
Oil	RCBD	Lodging-Height	2	8097.7	2	7841.1
Oil	RCBD	Height-BD	2	8124.7	2	7855.9
Oil	RCBD	Height-DI	2	8098.4	2	7866.2
Oil	RCBD	BD-DI	2	8139.5	2	7919.5
Oil	RCBD	Lodging-BD-Height	2	8113.0	2	7831.9
Oil	RCBD	Lodging-BD-DI	1	8159.8	1	7946.0
Oil	RCBD	Lodging-Height-DI	1	8124.5	2	7844.4
Oil	RCBD	Lodging-BD-DI-Height	2	8132.5	2	7833.2
Oil	RCBD	Height-DI-BD	1	8146.5	1	7914.3
Oil	RCBD	Flower-Lodging	0	8130.7	1	7948.5
Oil	RCBD	Flower-Height	1	8101.9	3	7908.2
Oil	RCBD	Flower-BD	0	8143.1	1	7974.0
Oil	RCBD	Flower-DI	2	8139.0	2	7919.0
Oil	RCBD	Flower-Maturity	1	8147.3	2	7927.8
Oil	RCBD	Flower-Lodging-Height	0	8114.0	2	7887.4
Oil	RCBD	Flower-Lodging-BD	0	8146.9	2	7891.1
Oil	RCBD	Flower-Lodging-Maturity	2	8137.7	2	7868.8
Oil	RCBD	Flower-Lodging-DI	1	8135.9	2	7945.5
Oil	RCBD	Flower-Height-BD	2	8111.3	2	7860.8
Oil	RCBD	Flower-Height-Maturity	2	8103.7	2	7841.0
Oil	RCBD	Flower-Height-DI	1	8111.2	3	7901.1
Oil	RCBD	Flower-BD-Maturity	1	8165.8	2	7922.5
Oil	RCBD	Flower-BD-DI	0	8152.8	2	7909.6

Table D1. Models tested for assessment of GxE with optimum number of common factors as assessed by Akaike information criterion (AIC) and Bayesian information criterion (BIC) scores (continued).

			BIC		**AIC**	
Trait	**Model**	**Covariates**	Common Factors	Score	Common Factors	Score
Oil	RCBD	Flower-Maturity-DI	1	8150.8	2	7918.2
Oil	RCBD	Maturity-Lodging	2	8148.0	2	7897.5
Oil	RCBD	Maturity-Height	2	8127.1	2	7864.4
Oil	RCBD	Maturity-BD	1	8184.8	1	7983.2
Oil	RCBD	Maturity-DI	2	8157.8	2	7919.5
Oil	RCBD	Maturity-Lodging-DI	0	8011.5	0	7852.6
Oil	RCBD	Maturity-Lodging-BD	2	8115.3	2	7877.0
Oil	RCBD	Maturity-Lodging-Height	2	8128.0	2	7840.8
Oil	RCBD	Maturity-Height-BD	1	8155.0	1	7916.7
Oil	RCBD	Maturity-Height-DI	2	8127.1	2	7864.4
Oil	RCBD	Maturity-BD-DI	2	8173.3	2	7910.6
Oil	RCBD	None	2	8127.8	2	7938.4
Oil	RCBD	Lodging	2	8116.8	2	7896.8
Oil	RCBD	Height	2	8102.4	3	7863.8
Oil	RCBD	BD	0	8158.5	1	7982.8
Oil	RCBD	Flower	0	8127.0	2	7927.4
Oil	RCBD	Maturity	2	8155.2	2	7929.1
Oil	RCBD	DI	2	8115.5	2	7926.1
Yield	Lattice	None	1	4425.0	2	4250.2
Yield	Lattice	Lodging	0	3981.9	1	3802.7
Yield	Lattice	Height	0	4426.2	2	4219.5
Yield	Lattice	BD	1	4413.9	2	4193.4
Yield	Lattice	Flower	1	4445.6	2	4246.7
Yield	Lattice	Maturity	0	4467.2	2	4249.6
Yield	Lattice	DI	0	4394.1	2	4218.4
Yield	Lattice	Lodging-BD	0	3961.4	1	3735.2
Yield	Lattice	Lodging-Height	0	4007.2	1	3795.0
Yield	Lattice	Lodging-DI	0	3971.2	1	3792.3
Yield	Lattice	Height-BD	0	4407.5	2	4164.4
Yield	Lattice	Height-DI	0	4405.9	2	4188.0
Yield	Lattice	BD-DI	0	4374.0	2	4159.7
Yield	Lattice	Lodging-BD-Height	0	3987.1	1	3727.2
Yield	Lattice	Lodging-BD-DI	0	3942.1§	2	3722.8

Table D1. Models tested for assessment of GxE with optimum number of common factors as assessed by Akaike information criterion (AIC) and Bayesian information criterion (BIC) scores (continued).

			BIC		**AIC**	
Trait	**Model**	**Covariates**	Common Factors	Score	Common Factors	Score
Yield	Lattice	Lodging-Height-DI	0	4004.6	1	3786.4
Yield	Lattice	Lodging-BD-DI-Height	0	3975.6	1	3715.9§
Yield	Lattice	Height-DI-BD	0	4375.9	2	4128.9
Yield	Lattice	Flower-Lodging	0	4002.3	2	3806.3
Yield	Lattice	Flower-Height	0	4448.7	1	4242.1
Yield	Lattice	Flower-BD	0	4446.2	2	4195.5
Yield	Lattice	Flower-DI	0	4415.7	1	4245.5
Yield	Lattice	Flower-Maturity	0	4482.3	1	4294.1
Yield	Lattice	Flower-Lodging-Height	0	4026.6	1	3791.0
Yield	Lattice	Flower-Lodging-BD	0	3983.8	1	3735.4
Yield	Lattice	Flower-Lodging-Maturity	0	4032.0	1	3802.0
Yield	Lattice	Flower-Lodging-DI	0	3991.6	1	3796.8
Yield	Lattice	Flower-Height-BD	0	4441.5	2	4163.2
Yield	Lattice	Flower-Height-Maturity	0	4477.9	1	4247.1
Yield	Lattice	Flower-Height-DI	0	4418.6	1	4215.6
Yield	Lattice	Flower-BD-Maturity	0	4483.6	1	4244.1
Yield	Lattice	Flower-BD-DI	0	4398.4	2	4160.2
Yield	Lattice	Flower-Maturity-DI	1	4476.4	2	4218.9
Yield	Lattice	Maturity-Lodging	0	4027.4	2	3805.1
Yield	Lattice	Maturity-Height	0	4479.9	2	4220.1
Yield	Lattice	Maturity-BD	0	4457.7	2	4197.9
Yield	Lattice	Maturity-DI	0	4433.2	2	4221.2
Yield	Lattice	Maturity-Lodging-DI	0	4016.7	2	3794.7
Yield	Lattice	Maturity-Lodging-BD	0	3998.2	1	3735.3
Yield	Lattice	Maturity-Lodging-Height	0	4052.8	2	3796.5
Yield	Lattice	Maturity-Height-BD	0	4452.6	1	4194.9
Yield	Lattice	Maturity-Height-DI	0	4444.2	2	4189.8
Yield	Lattice	Maturity-BD-DI	0	4412.8	2	4163.5
Yield	RCBD	Lodging-BD	0	4063.8	1	3846.4
Yield	RCBD	Lodging-DI	0	4102.9	1	3913.8
Yield	RCBD	Lodging-Height	0	4129.2	1	3905.6
Yield	RCBD	Height-BD	0	4577.3	2	4345.2
Yield	RCBD	Height-DI	0	4569.5	2	4362.8

Table D1. Models tested for assessment of GxE with optimum number of common factors as assessed by Akaike information criterion (AIC) and Bayesian information criterion (BIC) scores (continued).

			BIC		AIC	
Trait	**Model**	**Covariates**	Common Factors	Score	Common Factors	Score
Yield	RCBD	Height	0	4605.2	1	4426.0
Yield	RCBD	BD	1	4585.9	2	4382.8
Yield	RCBD	Flower	1	4623.2	2	4430.2
Yield	RCBD	Maturity	1	4650.8	1	4473.7
Yield	RCBD	DI	0	4567.6	2	4398.5

† Bird damage (BD)

‡ Disease Incidence (DI)

§ Top scores for oil and yield AIC and BIC

Table D2**.** Hybrid oil means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions‡‡ (BLUP) for the oil model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model.

Hybrid	Oil Type	Oil	BLUP AIC	± SE	BLUP BIC	± SE
		-------------------------------g/kg---------------------				
CMS HA 60 x RHA 373	trad†	354	360	3.93	361	3.82
CMS HA 64 x RHA 373	trad	389	394	3.93	395	3.82
CMS HA 89 x RHA 373	trad	415	414	3.96	414	3.85
CMS HA 99 x RHA 373	trad	417	416	3.95	417	3.85
CMS HA 113 x RHA 373	trad	414	415	3.93	415	3.81
CMS HA 124 x RHA 373	trad	409	410	3.94	409	3.83
CMS HA 224 x RHA 373	trad	414	416	3.96	416	3.85
CMS HA 232 x RHA 373	trad	402	412	5.20	413	5.09
CMS HA 234 x RHA 373	trad	404	405	3.92	406	3.82
CMS HA 277 x RHA 373	trad	411	411	3.93	412	3.82
CMS HA 289 x RHA 373	trad	424	423	3.93	424	3.82
CMS HA 290 x RHA 373	trad	405	406	3.91	407	3.81
CMS HA 291 x RHA 373	trad	407	408	3.92	409	3.82
CMS HA 300 x RHA 373	trad	455	450	3.92	450	3.82
CMS HA 301 x RHA 373	trad	429	430	3.92	431	3.82
CMS HA 302 x RHA 373	trad	450	446	3.92	446	3.82
CMS HA 303 x RHA 373	trad	432	429	3.92	429	3.82
CMS HA 335 x RHA 373	trad	390	393	3.92	393	3.82
CMS HA 336 x RHA 373	trad	369	386	5.21	386	5.09
CMS HA 337 x RHA 373	trad	399	404	3.92	404	3.82
CMS HA 339 x RHA 373	trad	365	372	3.96	373	3.87
CMS HA 341 x RHA 373	ns‡	389	393	3.96	393	3.85
CMS HA 342 x RHA 373	ns	386	392	4.03	392	3.93
CMS HA 343 x RHA 373	ns	399	399	3.95	400	3.85
CMS HA 370 x RHA 373	trad	400	402	3.97	401	3.87
CMS HA 371 x RHA 373	trad	409	408	3.94	408	3.83
CMS HA 372 x RHA 373	trad	409	409	3.94	409	3.84
CMS HA 378 x RHA 373	trad	418	418	3.97	418	3.87
CMS HA 379 x RHA 373	trad	413	416	3.97	416	3.87
CMS HA 380 x RHA 373	trad	406	407	3.92	407	3.82
CMS HA 382 X RHA 373	trad	392	394	3.95	395	3.84
CMS HA 383 X RHA 373	trad	414	414	3.92	414	3.82

Table D2**.** Hybrid oil means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions‡‡ (BLUP) for the oil model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Oil Type	Oil	BLUP AIC	± SE	BLUP BIC	± SE
		--------------------------g/kg----------------------------				
CMS HA 384 X RHA 373	trad	447	443	3.91	444	3.82
CMS HA 385 X RHA 373	trad	390	394	3.92	394	3.82
CMS HA 390 X RHA 373	trad	418	418	3.93	419	3.83
CMS HA 393 X RHA 373	trad	413	413	3.92	414	3.82
CMS HA 394 X RHA 373	trad	405	404	3.93	405	3.83
CMS HA 402 X RHA 373	trad	407	406	3.93	407	3.84
CMS HA 403 X RHA 373	trad	422	420	3.94	420	3.83
CMS HA 404 X RHA 373	trad	430	430	3.93	429	3.82
CMS HA 405 X RHA 373	trad	432	429	3.93	428	3.83
CMS HA 406 X RHA 373	trad	418	417	3.92	417	3.82
CMS HA 407 X RHA 373	trad	391	393	3.94	393	3.83
CMS HA 410 X RHA 373	trad	428	423	4.01	424	3.91
CMS HA 411 X RHA 373	trad	436	433	3.92	433	3.82
CMS HA 412 X RHA 373	trad	445	443	3.92	443	3.82
CMS HA 413 X RHA 373	trad	410	411	3.92	412	3.82
CMS HA 414 X RHA 373	trad	412	412	3.92	412	3.82
CMS HA 421 X RHA 373	trad	416	414	3.94	414	3.83
CMS HA 422 X RHA 373	trad	417	416	3.96	416	3.86
CMS HA 424 X RHA 373	trad	386	387	3.92	388	3.82
CMS HA 429 X RHA 373	trad	439	435	3.93	435	3.83
CMS HA 430 X RHA 373	trad	434	435	3.95	435	3.85
CMS HA 431 X RHA 373	trad	417	418	3.94	418	3.84
CMS HA 432 X RHA 373	trad	432	430	3.93	429	3.82
CMS HA 433 X RHA 373	trad	404	407	3.92	406	3.82
CMS HA 434 X RHA 373	ns	385	390	3.91	390	3.82
CMS HA 435 X RHA 373	ns	418	418	3.93	419	3.83
CMS HA 441 X RHA 373	trad	434	431	3.94	431	3.83
CMS HA 442 X RHA 373	ns	391	396	3.92	396	3.82
CMS HA 444 X RHA 373	ns	410	411	3.95	411	3.84
CMS HA 445 X RHA 373	ns	385	389	3.93	389	3.82
CMS HA 446 X RHA 373	ns	425	426	3.93	426	3.82
CMS HA 451 X RHA 373	trad	422	421	3.92	420	3.82
CMS HA 452 X RHA 373	trad	413	413	3.92	414	3.82
CMS HA 456 X RHA 373	ns	415	413	3.93	413	3.83

Table D2**.** Hybrid oil means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions‡‡ (BLUP) for the oil model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Oil Type	Oil	BLUP AIC	± SE	BLUP BIC	± SE
					--------------g/kg-------------------------	
CMS HA 457 X RHA 373	ns	400	400	3.92	400	3.82
CMS HA 465 X RHA 373	ns	391	393	3.93	393	3.83
CMS HA 466 X RHA 373	ns	392	393	3.92	394	3.82
CMS HA 467 X RHA 373	ns	393	394	3.92	395	3.82
CMS HA 469 X RHA 373	ns	404	404	3.95	404	3.85
CMS HA 821 X RHA 373	trad	454	449	3.92	449	3.82
CMS HA 822 X RHA 373	trad	423	424	3.93	425	3.83
CMS HA 850 X RHA 373	trad	445	443	3.93	442	3.83
CMS HA 851 X RHA 373	trad	432	432	3.95	431	3.85
CMS HA 852 X RHA 373	trad	404	406	3.94	406	3.83
CMS HA 853 X RHA 373	trad	443	440	3.93	441	3.83
CMS HA 412HO X RHA 373	ns	444	441	3.93	442	3.82
CMS HA 60 X RHA 377	trad	392	396	3.92	397	3.82
CMS HA 64 X RHA 377	trad	422	426	3.95	426	3.86
CMS HA 89 X RHA 377	trad	451	448	3.95	447	3.85
CMS HA 99 X RHA 377	trad	446	444	3.92	444	3.82
CMS HA 113 X RHA 377	trad	438	439	3.93	439	3.83
CMS HA 224 X RHA 377	trad	428	433	3.92	432	3.82
CMS HA 232 X RHA 377	trad	426	426	3.91	426	3.82
CMS HA 234 X RHA 377	trad	432	433	3.94	433	3.84
CMS HA 277 X RHA 377	trad	432	430	4.00	430	3.90
CMS HA 289 X RHA 377	trad	448	446	3.91	446	3.82
CMS HA 290 X RHA 377	trad	444	442	3.93	442	3.83
CMS HA 291 X RHA 377	trad	402	416	5.22	416	5.11
CMS HA 300 X RHA 377	trad	457	455	3.92	455	3.82
CMS HA 301 X RHA 377	trad	459	459	3.92	458	3.82
CMS HA 302 X RHA 377	trad	472	466	3.93	466	3.83
CMS HA 303 X RHA 377	trad	460	457	3.92	457	3.82
CMS HA 335 X RHA 377	trad	437	437	3.92	436	3.81
CMS HA 336 X RHA 377	trad	419	422	3.97	422	3.86
CMS HA 337 X RHA 377	trad	436	435	3.95	435	3.85
CMS HA 338 X RHA 377	trad	429	429	3.92	429	3.82
CMS HA 339 X RHA 377	trad	410	411	3.97	411	3.86

Table D2**.** Hybrid oil means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions‡‡ (BLUP) for the oil model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Oil Type	Oil	BLUP AIC	± SE	BLUP BIC	± SE
		-------------------------g/kg-------------------------				
CMS HA 430 X RHA 377	trad	451	450	3.96	450	3.85
CMS HA 431 X RHA 377	trad	444	441	4.15	440	4.07
CMS HA 432 X RHA 377	trad	459	455	3.95	454	3.85
CMS HA 433 X RHA 377	trad	428	429	3.92	429	3.82
CMS HA 434 X RHA 377	ns	409	409	3.92	410	3.82
CMS HA 435 X RHA 377	ns	444	442	3.95	442	3.85
CMS HA 441 X RHA 377	trad	455	453	3.92	452	3.83
CMS HA 442 X RHA 377	ns	417	416	4.03	416	3.94
CMS HA 444 X RHA 377	ns	438	438	3.95	438	3.85
CMS HA 445 X RHA 377	ns	400	404	3.96	404	3.85
CMS HA 446 X RHA 377	ns	445	447	3.93	447	3.83
CMS HA 451 X RHA 377	trad	445	441	3.92	441	3.82
CMS HA 452 X RHA 377	trad	448	445	3.92	444	3.82
CMS HA 456 X RHA 377	ns	446	440	3.96	440	3.86
CMS HA 457 X RHA 377	ns	432	430	3.92	431	3.82
CMS HA 465 X RHA 377	ns	417	418	3.96	419	3.86
CMS HA 466 X RHA 377	ns	415	415	3.92	415	3.82
CMS HA 467 X RHA 377	ns	415	416	3.95	417	3.85
CMS HA 469 X RHA 377	ns	431	429	3.99	430	3.88
CMS HA 821 X RHA 377	trad	470	465	3.95	465	3.85
CMS HA 822 X RHA 377	trad	437	439	3.92	439	3.82
CMS HA 850 X RHA 377	trad	466	464	3.92	464	3.82
CMS HA 851 X RHA 377	trad	454	452	3.98	452	3.89
CMS HA 852 X RHA 377	trad	421	422	3.92	422	3.82
CMS HA 853 X RHA 377	trad	454	455	3.91	455	3.82
CMS HA 412HO X RHA 377	ns	460	457	3.92	457	3.82
Croplan 3080	ns	458	454	3.93	454	3.83
Mycogen 8H449CLDM	ho§	468	464	3.93	464	3.83
Pannar 7813NS	ns	434	429	3.92	429	3.82
412 HO/464	ns	435	433	3.92	433	3.82
412HO/468	ns	455	450	3.92	450	3.82
467/464	ns	395	399	3.94	399	3.84
467/468	ns	410	407	3.92	408	3.82

Table D2. Hybrid oil means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions‡‡ (BLUP) for the oil model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Oil Type	Oil	BLUP AIC	± SE	BLUP BIC	± SE
		------------------------	------------------------g/kg	------------------------	------------------------	
Pioneer 63ME80	ns	441	440	3.93	440	3.83
Syngenta 3733 NS/DM	ns	438	437	3.96	437	3.86
Falcon	ns	429	430	3.93	429	3.83
894	trad	426	426	3.93	425	3.83
Genosys 12G26	ho	445	440	6.32	438	6.24
Genosys 12G29	ho	427	420	6.35	419	6.32
Croplan 559 CL	ns	454	438	6.29	438	6.26
Mycogen 8N358	ns	459	446	6.27	445	6.23
Croplan 545 CL	ns	444	435	6.31	434	6.28
Pioneer 63ME70	ns	453	438	6.27	437	6.25
Cobalt II	ho	431	425	6.26	424	6.23
Camaro II	ns	452	444	6.25	444	6.22

† traditional oil type

‡ NuSun® oil type

§ high oleic oil type

¶ not reported due to unbalanced data (<10 environments)

SE = standard error; $LSD_{0.05}$ = least significant difference at the 0.05 probability level; CV= coefficient of variation

‡‡ BLUP values allow for a comparison of the hybrids that were placed in a different number of environments and were calculated with the oil mean and standard error

Table D3. Hybrid yield means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions (BLUP) for the yield model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model.

Hybrid	Yield	BLUP AIC	± SE	BLUP BIC	± SE
	------------------------------kg ha^{-1}------------------------------				
CMS HA 60 x RHA 373	2795	2676	121	2602	120
CMS HA 64 x RHA 373	2274	2133	121	2189	120
CMS HA 89 x RHA 373	2395	2395	126	2372	122
CMS HA 99 x RHA 373	2298	2266	127	2234	124
CMS HA 113 x RHA 373	2342	2013	121	2071	120
CMS HA 124 x RHA 373	2410	2207	121	2219	120
CMS HA 224 x RHA 373	2021	1981	122	2022	120
CMS HA 232 x RHA 373	nr¶	1916	133	1956	138
CMS HA 234 x RHA 373	2081	1897	121	1917	120
CMS HA 277 x RHA 373	2839	2449	121	2490	120
CMS HA 289 x RHA 373	2700	2476	121	2442	120
CMS HA 290 x RHA 373	2804	2473	121	2440	120
CMS HA 291 x RHA 373	2312	2112	121	2084	120
CMS HA 300 x RHA 373	2583	2261	121	2291	120
CMS HA 301 x RHA 373	2278	2137	121	2128	120
CMS HA 302 x RHA 373	2626	2323	121	2339	121
CMS HA 303 x RHA 373	2341	2130	121	2099	120
CMS HA 335 x RHA 373	2422	2101	123	2144	123
CMS HA 336 x RHA 373	nr	2358	134	2311	138
CMS HA 337 x RHA 373	2356	2273	121	2251	120
CMS HA 339 x RHA 373	2343	2124	121	2123	120
CMS HA 341 x RHA 373	2005	2159	126	2114	122
CMS HA 342 x RHA 373	2401	2275	127	2257	124
CMS HA 343 x RHA 373	2533	2397	126	2414	122
CMS HA 370 x RHA 373	2268	2152	126	2140	122
CMS HA 371 x RHA 373	2735	2554	121	2554	120
CMS HA 372 x RHA 373	2300	2324	121	2309	120
CMS HA 378 x RHA 373	2057	1850	123	1874	122
CMS HA 379 x RHA 373	1913	1770	122	1756	120
CMS HA 380 x RHA 373	2427	2246	121	2248	120
CMS HA 382 X RHA 373	2317	2304	125	2243	122

Table D3. Hybrid yield means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions (BLUP) for the yield model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Yield	BLUP AIC	± SE	BLUP BIC	± SE
	--------------------------------kg ha^{-1}--------------------------------				
CMS HA 383 X RHA 373	2609	2427	121	2444	120
CMS HA 384 X RHA 373	2338	2235	121	2233	120
CMS HA 385 X RHA 373	2299	2154	121	2147	120
CMS HA 390 X RHA 373	2035	1910	122	1928	121
CMS HA 393 X RHA 373	2230	2032	121	2018	120
CMS HA 394 X RHA 373	2526	2200	121	2217	120
CMS HA 402 X RHA 373	2348	2139	121	2113	120
CMS HA 403 X RHA 373	2591	2271	121	2324	120
CMS HA 404 X RHA 373	2392	2163	121	2185	120
CMS HA 405 X RHA 373	2688	2457	121	2436	120
CMS HA 406 X RHA 373	2703	2477	121	2418	120
CMS HA 407 X RHA 373	2614	2404	121	2379	120
CMS HA 410 X RHA 373	2704	2524	122	2476	122
CMS HA 411 X RHA 373	2536	2306	121	2273	120
CMS HA 412 X RHA 373	2646	2418	121	2387	120
CMS HA 413 X RHA 373	2174	2022	121	2078	120
CMS HA 414 X RHA 373	2333	2221	122	2232	120
CMS HA 421 X RHA 373	2108	2054	121	2046	120
CMS HA 422 X RHA 373	2118	2074	126	2060	122
CMS HA 424 X RHA 373	2426	2231	121	2251	120
CMS HA 429 X RHA 373	2230	2087	121	2076	120
CMS HA 430 X RHA 373	2238	2235	126	2212	122
CMS HA 431 X RHA 373	2049	1938	121	1923	120
CMS HA 432 X RHA 373	2372	2230	121	2164	120
CMS HA 433 X RHA 373	2325	2164	121	2167	120
CMS HA 434 X RHA 373	2166	2103	121	2088	120
CMS HA 435 X RHA 373	1891	1854	122	1884	121
CMS HA 441 X RHA 373	2290	2179	121	2169	120
CMS HA 442 X RHA 373	2604	2383	121	2370	120
CMS HA 444 X RHA 373	2479	2352	121	2295	120
CMS HA 445 X RHA 373	2240	2014	121	2043	120
CMS HA 446 X RHA 373	2392	2047	121	2067	120
CMS HA 451 X RHA 373	2593	2388	121	2360	120

Table D3. Hybrid yield means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions (BLUP) for the yield model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Yield	BLUP AIC	± SE	BLUP BIC	± SE
	---------------------------------kg ha^{-1}---------------------------------				
CMS HA 452 X RHA 373	2748	2485	121	2464	120
CMS HA 456 X RHA 373	2454	2249	121	2224	120
CMS HA 457 X RHA 373	2438	2272	121	2219	120
CMS HA 465 X RHA 373	2211	2196	121	2178	120
CMS HA 466 X RHA 373	2516	2334	121	2313	120
CMS HA 467 X RHA 373	2330	2130	121	2139	120
CMS HA 469 X RHA 373	2208	2146	126	2135	122
CMS HA 821 X RHA 373	2482	2235	121	2257	120
CMS HA 822 X RHA 373	2423	2218	121	2195	120
CMS HA 850 X RHA 373	2466	2169	121	2187	120
CMS HA 851 X RHA 373	1938	1795	121	1827	120
CMS HA 852 X RHA 373	2404	2278	121	2256	120
CMS HA 853 X RHA 373	2458	2185	121	2176	120
CMS HA 412HO X RHA 373	2748	2520	126	2533	122
CMS HA 60 X RHA 377	2301	2286	121	2314	120
CMS HA 64 X RHA 377	1832	1928	126	1982	122
CMS HA 89 X RHA 377	1863	1970	126	1988	122
CMS HA 99 X RHA 377	1869	1814	121	1852	120
CMS HA 113 X RHA 377	1996	1693	121	1801	120
CMS HA 224 X RHA 377	1973	1936	122	1972	121
CMS HA 232 X RHA 377	1655	1711	121	1743	120
CMS HA 234 X RHA 377	1944	1812	121	1861	120
CMS HA 277 X RHA 377	2706	2334	122	2385	121
CMS HA 289 X RHA 377	2575	2261	121	2305	120
CMS HA 290 X RHA 377	2506	2255	121	2308	120
CMS HA 291 X RHA 377	nr	2180	133	2248	138
CMS HA 300 X RHA 377	2318	2213	121	2192	120
CMS HA 301 X RHA 377	1957	1960	121	2011	120
CMS HA 302 X RHA 377	2285	2230	121	2245	120
CMS HA 303 X RHA 377	2157	2122	121	2124	120
CMS HA 335 X RHA 377	2129	2127	121	2158	120
CMS HA 336 X RHA 377	2008	2072	122	2140	121
CMS HA 337 X RHA 377	2103	2096	126	2136	122

Table D3. Hybrid yield means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions (BLUP) for the yield model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Yield	BLUP AIC	± SE	BLUP BIC	± SE
	---------------------------------kg ha^{-1}	---------------------------------			
CMS HA 338 X RHA 377	2072	1966	121	2025	120
CMS HA 339 X RHA 377	1879	1889	123	1965	122
CMS HA 341 X RHA 377	1667	1944	126	1963	122
CMS HA 342 X RHA 377	1890	1854	122	1860	121
CMS HA 343 X RHA 377	1802	1906	121	1903	120
CMS HA 370 X RHA 377	2043	2125	121	2119	120
AC60	1736	1572	127	1679	126
Mycogen 8N270 CLDM	2395	2129	121	2145	120
CMS HA 378 X RHA 377	nr	2148	134	2169	138
CMS HA 379 X RHA 377	2227	2063	121	2059	120
CMS HA 380 X RHA 377	nr	2052	133	2018	138
CMS HA 382 X RHA 377	2178	2256	121	2174	120
CMS HA 383 X RHA 377	2292	2286	121	2293	120
CMS HA 384 X RHA 377	2421	2359	121	2302	120
CMS HA 385 X RHA 377	1917	1924	121	1906	120
CMS HA 390 X RHA 377	nr	1887	134	1946	138
CMS HA 393 X RHA 377	1973	1855	122	1898	121
CMS HA 394 X RHA 377	2292	2053	121	2120	120
CMS HA 402 X RHA 377	1936	2051	134	2057	126
CMS HA 403 X RHA 377	1913	1819	121	1894	120
CMS HA 404 X RHA 377	2201	2046	121	2064	120
CMS HA 405 X RHA 377	2163	2032	121	2024	120
CMS HA 406 X RHA 377	1859	1937	121	1923	120
CMS HA 407 X RHA 377	1956	1921	126	1969	122
CMS HA 410 X RHA 377	2052	2169	126	2164	122
CMS HA 411 X RHA 377	2162	2226	125	2192	122
CMS HA 412 X RHA 377	nr	2577	133	2531	138
CMS HA 413 X RHA 377	1850	1962	126	1958	122
CMS HA 414 X RHA 377	2314	2269	121	2254	120
CMS HA 421 X RHA 377	2056	2035	126	2041	122
CMS HA 422 X RHA 377	1806	1901	122	1881	120
CMS HA 423 X RHA 377	1848	2018	122	1947	121
CMS HA 424 X RHA 377	1869	2033	122	2046	121

Table D3. Hybrid yield means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions (BLUP) for the yield model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Yield	BLUP AIC	± SE	BLUP BIC	± SE
	--------------------------------	---kg ha^{-1}---		--------------------------------	
CMS HA 425 X RHA 377	nr	1947	139	1976	140
CMS HA 429 X RHA 377	1984	2119	121	2120	120
CMS HA 430 X RHA 377	1985	2187	126	2158	122
CMS HA 431 X RHA 377	2139	2186	121	2169	120
CMS HA 432 X RHA 377	2241	2290	126	2258	122
CMS HA 433 X RHA 377	2064	2013	121	2052	120
CMS HA 434 X RHA 377	1916	2073	121	2101	120
CMS HA 435 X RHA 377	2051	2068	126	2037	122
CMS HA 441 X RHA 377	2165	2180	121	2232	120
CMS HA 442 X RHA 377	1946	2012	126	2044	122
CMS HA 444 X RHA 377	2016	2096	127	2106	124
CMS HA 445 X RHA 377	1761	1726	126	1776	122
CMS HA 446 X RHA 377	1887	1837	121	1859	120
CMS HA 451 X RHA 377	2467	2272	121	2248	120
CMS HA 452 X RHA 377	2368	2255	121	2257	120
CMS HA 456 X RHA 377	2479	2386	126	2333	122
CMS HA 457 X RHA 377	2347	2337	121	2296	120
CMS HA 465 X RHA 377	1994	2158	125	2118	122
CMS HA 466 X RHA 377	2066	2104	121	2106	120
CMS HA 467 X RHA 377	2291	2249	125	2248	122
CMS HA 469 X RHA 377	1673	1978	134	1933	127
CMS HA 821 X RHA 377	2366	2377	126	2333	122
CMS HA 822 X RHA 377	2105	2079	121	2072	120
CMS HA 850 X RHA 377	1933	1849	121	1909	120
CMS HA 851 X RHA 377	1470	1559	125	1628	123
CMS HA 852 X RHA 377	2172	2113	121	2145	120
CMS HA 853 X RHA 377	2120	2028	121	2065	120
CMS HA 412HO X RHA 377	2516	2344	121	2378	120
Croplan 3080	2737	2389	121	2438	120
Mycogen 8H449CLDM	2895	2665	121	2662	120
Pannar 7813NS	2673	2398	121	2401	120
USDA 412 HO/464	2121	1900	121	1938	120
USDA 412HO/468	2609	2289	121	2305	120

Table D3. Hybrid yield means for 10 environments in 2012-2013 with Best Linear Unbiased Predictions (BLUP) for the yield model selected by Akaike Information Criterion (AIC) model and Bayesian Information Criterion (BIC) model (continued).

Hybrid	Yield	BLUP AIC	± SE	BLUP BIC	± SE
	---------------------------------kg ha^{-1}---------------------------------				
USDA 467/464	1999	1829	121	1859	120
USDA 467/468	2450	2185	121	2164	120
Pioneer 63ME80	2516	2248	122	2266	122
Syngenta 3733 NS/DM	2753	2589	126	2529	122
Nuseed Falcon	2485	2368	121	2358	120
894	2304	2223	122	2235	120
Genosys 12G26	nr	2126	186	2093	159
Genosys 12G29	nr	2212	186	2175	158
Croplan 559 CL	nr	2438	185	2414	158
Mycogen 8N358	nr	2448	185	2391	158
Croplan 545 CL	nr	2405	185	2365	158
Pioneer 63ME70	nr	2325	185	2286	158
Nuseed Cobalt II	nr	2395	185	2331	158
Nuseed Camaro II	nr	2359	185	2278	158
± SE #		27		27	
LSD$_{0.05}$		75		77	
CV (%)		17%		17%	

† traditional oil type

‡ NuSun ® oil type

§ high oleic oil type

¶ not reported due to unbalanced data (<10 environments)

SE = standard error; LSD$_{0.05}$ = least significant difference at the 0.05 probability level; CV= coefficient of variation

‡‡ BLUP values allow for a comparison of the hybrids that were placed in a different number of environments and were calculated with the yield mean and standard error

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location.

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12+	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 302 X RHA 377	466	1	444	1	467	9	475	15	514	1	456	2	476	4	488	3	468	5	439	52	491	1
CMS HA 821 X RHA 377	465	2	425	8	465	13	509	1	491	15	445	9	476	5	479	6	466	8	461	8	483	5
CMS HA 412 X RHA 377	465	3	437	2	-	-	485	6	-	-	445	8	482	2	-	-	457	20	-	-	479	7
Mycogen 8H449CLDM	464	4	408	31	485	1	491	3	494	11	452	4	489	1	451	53	463	11	460	9	484	4
CMS HA 850 X RHA 377	464	5	422	12	467	10	453	45	496	8	466	1	466	11	492	2	461	14	458	13	477	8
CMS HA 384 X RHA 377	461	6	428	7	465	14	485	5	491	14	431	25	481	3	482	4	469	4	468	3	475	12
CMS HA 411 X RHA 377	459	7	413	24	466	11	481	9	504	4	435	18	465	12	482	5	441	41	468	2	481	6
CMS HA 429 X RHA 377	459	8	418	16	453	41	470	21	495	9	443	12	470	9	479	7	452	26	466	5	469	19
CMS HA 301 X RHA 377	458	9	431	6	471	6	447	65	479	43	452	3	475	6	474	12	475	1	430	79	457	46
CMS HA 303 X RHA 377	457	10	422	11	471	4	471	19	509	2	433	22	447	45	468	20	460	16	450	23	466	25
CMS HA 412HO X RHA 377	457	11	425	9	456	31	470	23	478	45	443	11	468	10	465	27	474	2	466	4	456	48
CMS HA 300 X RHA 377	455	12	390	64	462	19	477	12	508	3	424	39	461	15	469	19	465	10	455	16	462	37
CMS HA 853 X RHA 377	455	13	416	18	443	70	447	64	488	17	451	6	453	30	470	16	455	21	458	14	459	42
Croplan 3080	454	14	433	5	462	22	490	4	492	13	428	31	457	23	448	63	451	28	449	26	472	16
CMS HA 432 X RHA 377	454	15	415	19	457	29	485	7	480	41	425	37	448	41	469	17	467	7	472	1	466	26
CMS HA 410 X RHA 377	452	16	434	4	447	58	492	2	481	39	417	49	470	8	473	13	446	33	454	19	459	43
CMS HA 378 X RHA 377	452	17	411	29	-	-	455	41	-	-	441	13	459	20	-	-	460	15	-	-	463	32
CMS HA 441 X RHA 377	452	18	385	77	456	33	478	10	488	19	420	44	454	29	496	1	445	35	461	7	466	24
CMS HA 851 X RHA 377	452	19	424	10	472	3	459	34	476	50	452	5	429	82	468	22	459	19	454	18	452	61
CMS HA 421 X RHA 377	451	20	408	33	444	65	481	8	499	7	428	32	434	70	468	23	465	9	454	21	487	2
412HO/468	450	21	407	35	462	21	477	11	485	24	427	34	460	18	460	41	462	12	430	78	476	9

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12+	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 300 x RHA 373	450	22	412	25	459	26	475	14	486	22	431	26	463	14	460	40	451	30	440	48	472	15
CMS HA 430 X RHA 377	450	23	403	40	463	18	445	68	478	44	436	15	461	17	462	32	460	18	460	10	443	75
CMS HA 379 X RHA 377	449	24	412	28	468	8	456	38	465	67	434	20	461	16	451	56	452	25	448	30	453	55
CMS HA 821 X RHA 373	449	25	394	60	461	24	472	18	483	31	430	28	472	7	461	35	446	32	442	41	476	10
CMS HA 89 X RHA 377	447	26	405	37	468	7	461	32	487	20	419	45	450	34	464	30	455	23	445	38	465	28
CMS HA 446 X RHA 377	447	27	411	30	448	52	444	70	473	55	444	10	441	58	446	66	434	58	448	28	463	35
CMS HA 405 X RHA 377	446	28	404	39	461	23	466	26	462	74	433	21	439	63	461	36	460	17	458	15	465	30
CMS HA 302 x RHA 373	446	29	434	3	428	115	453	47	481	40	420	43	455	28	478	8	435	51	447	32	475	13
CMS HA 289 X RHA 377	446	30	413	23	464	15	453	48	481	37	421	42	455	27	469	18	430	65	442	42	457	47
CMS HA 414 X RHA 377	446	31	419	13	440	85	469	24	484	26	429	30	449	36	465	28	448	31	427	87	462	36
Mycogen 8N358	445	32	-	-	474	2	-	-	475	51	-	-	-	-	463	31	-	-	423	101	-	-
CMS HA 404 X RHA 377	445	33	366	121	458	27	447	63	488	16	435	19	458	22	466	26	467	6	454	20	455	53
CMS HA 423 X RHA 377	445	34	396	54	445	62	474	16	486	21	432	23	427	89	446	67	446	34	447	31	470	18
CMS HA 452 X RHA 377	444	35	400	50	455	34	450	54	494	10	415	52	445	50	472	15	455	22	449	25	445	72
CMS HA 406 X RHA 377	444	36	383	84	463	17	458	36	483	33	409	67	452	31	450	58	453	24	448	29	466	23
CMS HA 403 X RHA 377	444	37	413	22	463	16	428	104	472	58	446	7	447	43	473	14	417	90	423	99	429	110
CMS HA 384 X RHA 373	444	38	394	56	452	43	441	81	472	57	415	54	464	13	456	44	469	3	435	64	475	11
CMS HA 99 X RHA 377	444	39	401	45	456	32	463	30	503	5	421	41	441	57	461	38	427	69	427	89	463	33
Camaro II	444	40	-	-	453	38	-	-	492	12	-	-	-	-	450	59	-	-	414	122	-	-
CMS HA 412 X RHA 373	443	41	382	86	445	61	473	17	484	25	426	36	449	35	460	39	433	59	440	46	458	45
CMS HA 390 X RHA 377	443	42	419	14	-	-	444	71	-	-	427	35	448	38	-	-	429	67	-	-	448	68

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12+	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 850 X RHA 373	442	43	416	17	449	48	446	67	483	34	429	29	452	32	441	80	418	89	463	6	455	51
CMS HA 435 X RHA 377	442	44	398	52	444	67	470	22	457	85	432	24	440	62	441	79	441	43	446	35	467	21
CMS HA 290 X RHA 377	442	45	414	20	447	54	448	60	499	6	418	47	441	56	438	88	443	39	439	51	452	56
CMS HA 412HO X RHA 373	442	46	397	53	456	30	468	25	475	52	415	53	443	51	451	54	425	72	445	36	467	22
CMS HA 393 X RHA 377	442	47	400	51	449	49	452	50	488	18	411	59	452	33	475	11	434	55	438	56	434	94
CMS HA 422 X RHA 377	441	48	394	58	438	89	464	27	483	29	424	38	430	79	449	60	440	45	436	61	461	40
CMS HA 451 X RHA 377	441	49	400	49	447	56	461	33	466	64	410	62	446	46	468	21	440	44	443	40	471	17
CMS HA 853 X RHA 373	441	50	393	61	448	51	449	57	480	42	419	46	445	49	455	46	437	50	439	50	464	31
CMS HA 385 X RHA 377	441	51	418	15	453	36	464	28	484	27	413	57	431	74	462	33	441	40	429	81	458	44
CMS HA 456 X RHA 377	440	52	412	26	435	104	457	37	481	38	416	50	441	60	456	43	444	38	440	47	487	3
Pioneer 63ME80	440	53	365	122	462	20	440	86	473	56	417	48	456	24	475	10	430	66	459	12	437	86
Mycogen 8N270 CLDM	440	54	389	68	453	40	426	108	466	62	435	17	460	19	448	64	435	52	426	90	439	84
CMS HA 431 X RHA 377	440	55	412	27	453	42	450	55	459	80	410	63	426	93	444	70	461	13	455	17	456	49
CMS HA 113 X RHA 377	439	56	404	38	459	25	412	138	466	65	437	14	442	54	475	9	426	71	432	71	424	125
CMS HA 822 X RHA 377	439	57	381	92	447	59	449	56	457	83	428	33	455	25	438	87	435	53	425	94	452	60
Croplan 559 CL	438	58	-	-	471	5	-	-	483	30	-	-	-	-	452	51	-	-	411	131	-	-
CMS HA 444 X RHA 377	438	59	384	79	438	91	452	51	482	36	424	40	436	67	452	49	432	63	432	69	474	14
Genosys 12G26	438	60	-	-	440	83	-	-	483	28	-	-	-	-	419	127	-	-	439	53	-	-
Pioneer 63ME70	437	61	-	-	441	78	-	-	483	32	-	-	-	-	442	76	-	-	446	33	-	-
Syngenta 3733 NS/DM	437	62	380	95	435	101	475	13	467	61	404	72	448	40	442	77	426	70	459	11	434	97
CMS HA 380 X RHA 377	436	63	401	47	-	-	440	85	-	-	414	55	422	101	-	-	445	37	-	-	460	41

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12†	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 335 X RHA 377	436	64	394	59	440	81	452	52	473	53	405	71	441	59	455	45	439	47	431	73	435	92
CMS HA 413 X RHA 377	436	65	395	55	439	87	462	31	443	124	412	58	434	69	464	29	445	36	437	60	465	27
CMS HA 337 X RHA 377	435	66	384	81	440	80	459	35	485	23	408	69	418	104	452	52	434	54	434	65	456	50
CMS HA 429 X RHA 373	435	67	401	46	453	39	451	53	455	89	403	78	448	42	454	47	451	29	420	108	451	62
CMS HA 430 X RHA 373	435	68	386	76	446	60	456	39	443	125	393	94	455	26	467	25	433	61	430	77	440	78
Croplan 545 CL	434	69	-	-	451	44	-	-	465	66	-	-	-	-	434	99	-	-	427	86	-	-
CMS HA 394 X RHA 377	434	70	402	44	426	121	432	93	478	46	411	60	448	37	451	57	415	93	426	92	418	135
CMS HA 234 X RHA 377	433	71	402	43	448	53	429	103	432	147	436	16	446	47	433	101	429	68	441	43	426	117
CMS HA 411 X RHA 373	433	72	384	80	454	35	453	49	463	72	403	75	426	92	457	42	433	60	446	34	437	87
412 HO/464	433	73	375	100	453	37	449	58	482	35	403	77	431	75	426	118	451	27	432	68	448	69
CMS HA 224 X RHA 377	432	74	414	21	444	68	430	99	439	137	430	27	459	21	422	126	411	104	405	148	429	109
CMS HA 383 X RHA 377	432	75	391	63	437	95	454	44	463	73	405	70	433	71	452	48	439	48	430	75	452	57
CMS HA 851 X RHA 373	431	76	408	32	449	47	440	83	477	48	403	76	429	80	445	69	399	132	435	63	435	90
CMS HA 457 X RHA 377	431	77	394	57	422	132	455	40	466	63	410	64	427	91	436	96	441	42	430	76	440	76
CMS HA 301 x RHA 373	431	78	390	65	412	149	448	62	453	102	415	51	432	72	436	94	423	78	420	107	465	29
CMS HA 441 X RHA 373	431	79	374	103	447	57	448	59	469	59	391	99	439	65	467	24	406	115	438	54	462	39
CMS HA 469 X RHA 377	430	80	366	119	438	92	470	20	450	110	399	85	416	111	439	82	432	64	448	27	-	-
CMS HA 277 X RHA 377	430	81	403	42	441	77	432	94	448	113	411	61	428	83	446	65	423	79	440	49	435	89
Pannar 7813NS	429	82	386	74	457	28	454	43	464	71	399	86	435	68	439	83	434	56	415	121	452	58
CMS HA 382 X RHA 377	429	83	403	41	441	79	442	76	461	79	384	115	426	95	462	34	425	73	436	62	446	71
CMS HA 303 x RHA 373	429	84	381	91	440	86	441	82	455	90	383	117	427	90	452	50	437	49	441	45	467	20

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12+	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 335 X RHA 377	436	64	394	59	440	81	452	52	473	53	405	71	441	59	455	45	439	47	431	73	435	92
CMS HA 413 X RHA 377	436	65	395	55	439	87	462	31	443	124	412	58	434	69	464	29	445	36	437	60	465	27
CMS HA 337 X RHA 377	435	66	384	81	440	80	459	35	485	23	408	69	418	104	452	52	434	54	434	65	456	50
CMS HA 429 X RHA 373	435	67	401	46	453	39	451	53	455	89	403	78	448	42	454	47	451	29	420	108	451	62
CMS HA 430 X RHA 373	435	68	386	76	446	60	456	39	443	125	393	94	455	26	467	25	433	61	430	77	440	78
Croplan 545 CL	434	69	-	-	451	44	-	-	465	66	-	-	-	-	434	99	-	-	427	86	-	-
CMS HA 394 X RHA 377	434	70	402	44	426	121	432	93	478	46	411	60	448	37	451	57	415	93	426	92	418	135
CMS HA 234 X RHA 377	433	71	402	43	448	53	429	103	432	147	436	16	446	47	433	101	429	68	441	43	426	117
CMS HA 411 X RHA 373	433	72	384	80	454	35	453	49	463	72	403	75	426	92	457	42	433	60	446	34	437	87
412 HO/464	433	73	375	100	453	37	449	58	482	35	403	77	431	75	426	118	451	27	432	68	448	69
CMS HA 224 X RHA 377	432	74	414	21	444	68	430	99	439	137	430	27	459	21	422	126	411	104	405	148	429	109
CMS HA 383 X RHA 377	432	75	391	63	437	95	454	44	463	73	405	70	433	71	452	48	439	48	430	75	452	57
CMS HA 851 X RHA 373	431	76	408	32	449	47	440	83	477	48	403	76	429	80	445	69	399	132	435	63	435	90
CMS HA 457 X RHA 377	431	77	394	57	422	132	455	40	466	63	410	64	427	91	436	96	441	42	430	76	440	76
CMS HA 301 x RHA 373	431	78	390	65	412	149	448	62	453	102	415	51	432	72	436	94	423	78	420	107	465	29
CMS HA 441 X RHA 373	431	79	374	103	447	57	448	59	469	59	391	99	439	65	467	24	406	115	438	54	462	39
CMS HA 469 X RHA 377	430	80	366	119	438	92	470	20	450	110	399	85	416	111	439	82	432	64	448	27	-	-
CMS HA 277 X RHA 377	430	81	403	42	441	77	432	94	448	113	411	61	428	83	446	65	423	79	440	49	435	89
Pannar 7813NS	429	82	386	74	457	28	454	43	464	71	399	86	435	68	439	83	434	56	415	121	452	58
CMS HA 382 X RHA 377	429	83	403	41	441	79	442	76	461	79	384	115	426	95	462	34	425	73	436	62	446	71
CMS HA 303 x RHA 373	429	84	381	91	440	86	441	82	455	90	383	117	427	90	452	50	437	49	441	45	467	20

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12†	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
Falcon	429	85	383	85	449	46	438	87	462	75	403	79	443	53	431	106	408	107	438	57	434	96
CMS HA 433 X RHA 377	429	86	407	34	425	123	440	84	444	122	398	88	442	55	448	62	424	77	418	112	436	88
CMS HA 404 X RHA 373	429	87	381	90	444	64	441	80	444	121	408	68	447	44	443	72	414	102	433	67	450	63
CMS HA 432 X RHA 373	429	88	372	108	435	103	463	29	455	88	381	122	443	52	438	85	422	80	450	24	463	34
CMS HA 338 X RHA 377	429	89	401	48	443	69	422	117	473	54	402	80	423	100	443	74	414	98	445	37	426	120
CMS HA 405 X RHA 373	428	90	383	83	445	63	448	61	455	91	388	102	428	85	436	93	439	46	437	58	462	38
CMS HA 64 X RHA 377	426	91	381	93	449	50	413	136	476	49	400	84	446	48	446	68	414	101	398	157	405	153
CMS HA 446 X RHA 373	426	92	405	36	433	106	423	113	454	97	399	87	429	81	419	128	415	97	441	44	432	104
CMS HA 232 X RHA 377	426	93	390	66	438	90	434	91	437	141	394	92	448	39	451	55	414	100	429	83	428	114
894	425	94	382	87	442	75	442	74	456	87	382	119	427	88	443	73	424	74	426	91	439	83
CMS HA 822 X RHA 373	425	95	387	72	433	107	443	72	454	98	401	83	432	73	434	100	406	116	413	126	426	121
CMS HA 407 X RHA 377	425	96	362	132	466	12	427	106	477	47	404	73	403	137	418	130	422	82	425	95	417	138
CMS HA 402 X RHA 377	424	97	370	112	442	74	442	77	454	100	393	95	424	99	461	37	406	114	414	124	-	-
Cobalt II	424	98	-	-	444	66	-	-	461	77	-	-	-	-	412	139	-	-	406	144	-	-
CMS HA 410 X RHA 373	424	99	363	129	442	72	447	66	461	76	386	108	428	86	432	102	415	96	432	70	444	74
CMS HA 289 x RHA 373	424	100	358	138	443	71	453	46	464	70	398	89	414	117	432	103	415	91	427	88	435	93
CMS HA 343 X RHA 377	422	101	388	69	436	97	417	129	431	149	398	90	400	142	443	71	432	62	451	22	428	115
CMS HA 852 X RHA 377	422	102	387	71	440	82	422	118	457	86	409	66	411	123	425	121	424	76	409	136	423	126
CMS HA 341 X RHA 377	422	103	388	70	435	100	431	98	461	78	375	134	405	132	448	61	418	87	438	55	422	129
CMS HA 336 X RHA 377	422	104	392	62	438	93	419	126	464	69	394	93	416	112	429	111	404	124	417	116	415	141
CMS HA 451 X RHA 373	420	105	381	89	435	102	441	79	455	95	381	120	417	106	425	120	410	106	433	66	445	73

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12+	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 335 X RHA 377	436	64	394	59	440	81	452	52	473	53	405	71	441	59	455	45	439	47	431	73	435	92
CMS HA 413 X RHA 377	436	65	395	55	439	87	462	31	443	124	412	58	434	69	464	29	445	36	437	60	465	27
CMS HA 337 X RHA 377	435	66	384	81	440	80	459	35	485	23	408	69	418	104	452	52	434	54	434	65	456	50
CMS HA 429 X RHA 373	435	67	401	46	453	39	451	53	455	89	403	78	448	42	454	47	451	29	420	108	451	62
CMS HA 430 X RHA 373	435	68	386	76	446	60	456	39	443	125	393	94	455	26	467	25	433	61	430	77	440	78
Croplan 545 CL	434	69	-	-	451	44	-	-	465	66	-	-	-	-	434	99	-	-	427	86	-	-
CMS HA 394 X RHA 377	434	70	402	44	426	121	432	93	478	46	411	60	448	37	451	57	415	93	426	92	418	135
CMS HA 234 X RHA 377	433	71	402	43	448	53	429	103	432	147	436	16	446	47	433	101	429	68	441	43	426	117
CMS HA 411 X RHA 373	433	72	384	80	454	35	453	49	463	72	403	75	426	92	457	42	433	60	446	34	437	87
412 HO/464	433	73	375	100	453	37	449	58	482	35	403	77	431	75	426	118	451	27	432	68	448	69
CMS HA 224 X RHA 377	432	74	414	21	444	68	430	99	439	137	430	27	459	21	422	126	411	104	405	148	429	109
CMS HA 383 X RHA 377	432	75	391	63	437	95	454	44	463	73	405	70	433	71	452	48	439	48	430	75	452	57
CMS HA 851 X RHA 373	431	76	408	32	449	47	440	83	477	48	403	76	429	80	445	69	399	132	435	63	435	90
CMS HA 457 X RHA 377	431	77	394	57	422	132	455	40	466	63	410	64	427	91	436	96	441	42	430	76	440	76
CMS HA 301 x RHA 373	431	78	390	65	412	149	448	62	453	102	415	51	432	72	436	94	423	78	420	107	465	29
CMS HA 441 X RHA 373	431	79	374	103	447	57	448	59	469	59	391	99	439	65	467	24	406	115	438	54	462	39
CMS HA 469 X RHA 377	430	80	366	119	438	92	470	20	450	110	399	85	416	111	439	82	432	64	448	27	-	-
CMS HA 277 X RHA 377	430	81	403	42	441	77	432	94	448	113	411	61	428	83	446	65	423	79	440	49	435	89
Pannar 7813NS	429	82	386	74	457	28	454	43	464	71	399	86	435	68	439	83	434	56	415	121	452	58
CMS HA 382 X RHA 377	429	83	403	41	441	79	442	76	461	79	384	115	426	95	462	34	425	73	436	62	446	71
CMS HA 303 x RHA 373	429	84	381	91	440	86	441	82	455	90	383	117	427	90	452	50	437	49	441	45	467	20

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12+	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 393 X RHA 373	414	127	365	123	426	120	424	111	452	104	376	132	406	127	426	116	407	112	404	149	439	81
CMS HA 421 X RHA 373	414	128	371	109	428	114	442	75	455	94	379	127	396	149	412	140	408	108	416	118	449	66
CMS HA 452 X RHA 373	414	129	367	116	419	138	445	69	441	129	377	130	417	107	387	161	415	95	430	80	434	95
CMS HA 232 x RHA 373	413	130	375	102	-	-	401	152	-	-	409	65	415	115	-	-	400	130	-	-	410	150
CMS HA 456 X RHA 373	413	131	362	134	423	126	434	89	440	133	365	150	420	102	425	122	414	99	416	119	447	70
CMS HA 414 X RHA 373	412	132	346	154	419	139	421	120	443	123	392	97	412	120	442	75	389	154	411	130	439	82
CMS HA 277 x RHA 373	412	133	373	106	417	142	416	132	441	130	402	81	404	134	409	146	397	136	417	115	430	105
CMS HA 413 X RHA 373	412	134	355	145	423	129	418	127	450	108	387	104	405	131	425	119	402	128	412	129	427	116
CMS HA 339 X RHA 377	411	135	389	67	423	127	394	158	468	60	386	107	402	138	428	114	411	105	411	132	395	161
CMS HA 444 X RHA 373	411	136	356	141	400	160	410	141	441	128	372	137	405	129	426	117	415	92	423	100	450	64
CMS HA 434 X RHA 377	410	137	365	124	414	146	418	128	424	154	381	121	396	151	437	90	415	94	417	114	420	131
CMS HA 124 x RHA 373	409	138	386	75	425	124	405	147	440	132	365	148	417	108	431	105	394	143	424	96	404	154
CMS HA 372 x RHA 373	409	139	354	146	440	84	421	121	450	107	371	138	404	133	410	145	404	123	421	105	412	147
CMS HA 291 x RHA 373	409	140	364	126	429	112	406	146	450	105	378	128	396	153	423	124	393	146	405	146	429	108
CMS HA 371 x RHA 373	408	141	351	149	424	125	415	134	447	117	369	142	416	110	432	104	405	119	407	140	424	123
467/468	408	142	355	143	429	111	432	95	430	151	368	144	417	105	429	109	392	147	419	110	426	118
CMS HA 424 X RHA 377	408	143	362	135	418	141	408	142	447	114	385	110	391	158	410	144	406	118	414	125	413	146
CMS HA 425 X RHA 377	408	144	360	136	-	-	407	144	-	-	389	101	398	145	-	-	391	149	-	-	428	111
CMS HA 290 x RHA 373	407	145	364	125	435	99	429	100	465	68	413	56	439	64	205	168	434	57	424	97	440	79
CMS HA 402 X RHA 373	407	146	345	156	437	96	416	133	422	155	361	156	415	114	428	113	402	129	420	106	426	119
CMS HA 380 x RHA 373	407	147	350	151	407	155	419	125	454	101	370	139	430	78	408	147	382	156	406	141	434	98

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12†	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 403 X RHA 373	420	106	385	78	439	88	424	110	455	93	395	91	440	61	438	89	397	134	431	72	415	143
CMS HA 342 X RHA 377	419	107	381	94	442	73	441	78	432	148	378	129	384	163	438	86	421	85	444	39	433	102
Genosys 12G29	419	108	-	-	434	105	-	-	455	92	-	-	-	-	397	157	-	-	422	103	-	-
CMS HA 390 X RHA 373	419	109	380	96	431	109	423	115	436	142	401	82	426	94	434	98	397	135	418	111	435	91
CMS HA 370 X RHA 377	419	110	373	104	432	108	423	116	443	126	383	116	437	66	440	81	418	88	400	154	421	130
CMS HA 435 X RHA 373	419	111	369	114	420	136	455	42	450	106	403	74	396	150	423	123	413	103	406	142	440	80
CMS HA 465 X RHA 377	419	112	373	105	435	98	443	73	442	127	387	106	414	118	429	110	421	84	408	137	433	101
CMS HA 378 x RHA 373	418	113	379	98	450	45	431	97	440	135	385	111	425	97	437	92	393	145	425	93	415	142
CMS HA 431 X RHA 373	418	114	369	113	427	117	419	124	448	112	377	131	401	140	442	78	421	83	437	59	430	106
CMS HA 406 X RHA 373	417	115	350	150	447	55	434	90	452	103	374	136	414	116	436	95	403	126	421	104	448	67
CMS HA 99 x RHA 373	417	116	368	115	423	128	429	102	445	118	382	118	430	77	430	107	406	117	422	102	449	65
CMS HA 467 X RHA 377	417	117	363	128	427	118	426	107	459	81	384	113	415	113	439	84	419	86	416	117	402	158
CMS HA 422 X RHA 373	416	118	387	73	422	133	433	92	438	138	386	109	405	130	414	133	408	109	429	84	454	54
CMS HA 442 X RHA 377	416	119	362	133	427	116	417	131	457	82	380	123	425	98	436	97	395	141	415	120	434	99
CMS HA 379 x RHA 373	416	120	366	117	438	94	423	112	444	120	388	103	428	87	417	131	407	111	413	127	410	149
CMS HA 224 x RHA 373	416	121	375	99	422	131	417	130	438	140	387	105	425	96	413	137	406	113	414	123	440	77
CMS HA 291 X RHA 377	416	122	375	101	-	-	401	153	-	-	392	96	405	128	-	-	424	75	-	-	415	140
CMS HA 113 x RHA 373	415	123	382	88	413	148	407	143	454	99	384	112	430	76	428	112	391	151	424	98	423	127
CMS HA 466 X RHA 377	415	124	370	111	426	122	438	88	454	96	379	125	411	122	429	108	404	122	431	74	409	151
CMS HA 383 X RHA 373	414	125	366	120	405	156	424	109	449	111	376	133	420	103	426	115	422	81	417	113	430	107
CMS HA 89 x RHA 373	414	126	364	127	427	119	431	96	450	109	380	124	428	84	437	91	392	148	411	133	433	100

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12†	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 433 X RHA 373	406	148	366	118	411	151	427	105	425	153	369	140	400	141	406	152	395	138	427	85	417	137
CMS HA 234 x RHA 373	406	149	362	131	408	153	399	155	447	115	392	98	413	119	413	138	381	158	405	147	417	139
CMS HA 852 X RHA 373	406	150	363	130	421	134	403	148	457	84	369	141	396	152	414	135	395	140	408	139	418	136
CMS HA 394 X RHA 373	405	151	379	97	419	140	429	101	412	163	366	147	403	136	414	136	394	144	406	143	425	122
CMS HA 445 X RHA 377	404	152	372	107	415	145	386	165	439	136	379	126	391	157	418	129	381	157	410	134	424	124
CMS HA 469 X RHA 373	404	153	337	163	430	110	420	122	445	119	365	149	404	135	407	149	405	120	397	159	452	59
CMS HA 337 x RHA 373	404	154	344	157	405	157	414	135	417	158	364	153	397	146	415	132	403	127	412	128	418	134
CMS HA 370 x RHA 373	401	155	345	155	409	152	397	157	433	146	365	151	416	109	414	134	403	125	406	145	419	132
CMS HA 343 x RHA 373	400	156	352	147	417	144	423	114	435	143	364	152	384	162	399	156	395	137	400	153	428	112
CMS HA 457 X RHA 373	400	157	332	164	423	130	422	119	435	144	350	161	392	156	405	153	400	131	408	138	428	113
467/464	399	158	349	152	408	154	399	156	440	131	367	145	411	121	383	163	395	139	392	163	403	155
AC60	397	159	358	139	389	167	392	163	420	157	390	100	394	155	422	125	372	165	369	168	389	163
CMS HA 60 X RHA 377	397	160	358	137	394	166	394	159	447	116	369	143	383	164	412	142	377	161	393	162	398	160
CMS HA 442 X RHA 373	396	161	347	153	397	162	402	150	431	150	362	154	397	148	393	160	374	164	395	160	414	144
CMS HA 382 X RHA 373	395	162	331	165	395	164	412	139	435	145	342	166	411	124	404	154	391	152	394	161	438	85
CMS HA 64 x RHA 373	395	163	355	144	397	163	390	164	408	165	384	114	407	126	408	148	377	162	390	165	374	166
CMS HA 467 X RHA 373	395	164	340	160	421	135	413	137	414	162	355	157	399	143	403	155	389	153	397	158	402	157
CMS HA 385 X RHA 373	394	165	352	148	429	113	419	123	417	159	374	135	410	125	205	167	407	110	429	82	455	52
CMS HA 466 X RHA 373	394	166	371	110	413	147	406	145	405	166	352	159	385	161	406	150	378	160	403	151	401	159
CMS HA 335 x RHA 373	393	167	341	159	395	165	393	161	414	161	338	168	397	147	412	141	391	150	399	155	419	133
CMS HA 341 x RHA 373	393	168	325	167	411	150	400	154	427	152	343	165	386	160	411	143	387	155	409	135	410	148

Table D4. Oil Best Linear Unbiased Predictions (BLUP) Bayesian Information Criterion (BIC) and rank changes for each hybrid and location (continued).

Hybrid	BLUP BIC Mean	Overall BLUP Rank	Carr 12†	Carr12 Rank	Carr 13	Carr13 Rank	Crk 12	Crk12 Rank	Crk 13	Crk13 Rank	Eurk 12	Eur12 Rank	Mand 12	Mand12 Rank	Mand 13	Mand13 Rank	Velva 12	Velva12 Rank	Velva 13	Velva13 Rank	Wyn 12	Wyn12 Rank
CMS HA 407 X RHA 373	393	169	319	169	441	76	394	160	440	134	347	162	380	166	383	164	399	133	399	156	409	152
CMS HA 465 X RHA 373	393	170	342	158	417	143	393	162	404	167	350	160	401	139	395	158	395	142	391	164	422	128
CMS HA 342 x RHA 373	392	171	383	82	420	137	410	140	438	139	367	146	398	144	203	169	404	121	419	109	432	103
CMS HA 434 X RHA 373	390	172	337	162	405	158	403	149	415	160	355	158	368	168	406	151	366	166	403	150	392	162
CMS HA 445 X RHA 373	389	173	358	140	398	161	361	167	421	156	362	155	390	159	387	162	361	167	402	152	414	145
CMS HA 424 X RHA 373	388	174	356	142	402	159	402	151	409	164	344	163	381	165	395	159	375	163	390	166	403	156
CMS HA 336 x RHA 373	386	175	329	166	-	-	381	166	-	-	344	164	394	154	-	-	380	159	-	-	388	164
CMS HA 339 x RHA 373	373	176	323	168	380	168	360	168	391	168	339	167	373	167	376	165	344	169	379	167	376	165
CMS HA 60 x RHA 373	361	177	337	161	348	169	354	169	375	169	337	169	343	169	371	166	353	168	369	169	356	167

† Crookston (Crk) Carrington (Carr) Mandan (Mand) Velva (Velv) Eureka (Eurk) Wyndmere (Wyn), followed by the year

Table. D5. Spearman Correlation for oil content among locations and Best Linear Unbiased Predictions (BLUP) for the oil model selected by Bayesian Information Criterion (BIC).

	Carr12†	Carr13	Crk12	Crk13	Eurk12	Mand12	Mand13	Velva12	Velva13	Wyn12
BLUPBIC	0.88***	0.86***	0.87***	0.87***	0.92***	0.89***	0.89***	0.91***	0.82***	0.80***
Carr12		0.70***	0.71***	0.72***	0.84***	0.77***	0.77***	0.77***	0.72***	0.65***
Carr13			0.73***	0.77***	0.79***	0.77***	0.76***	0.79***	0.69***	0.64***
Crk12				0.76***	0.74***	0.75***	0.76***	0.84***	0.78***	0.85***
Crk13					0.80***	0.74***	0.75***	0.79***	0.68***	0.70***
Eurk12						0.83***	0.79***	0.82***	0.73***	0.69***
Mand12							0.80***	0.77***	0.70***	0.71***
Mand13								0.79***	0.74***	0.69***
Velva12									0.80***	0.80***
Velva13										0.72***

† Crookston (Crk) Carrington (Carr) Mandan (Mand) Velva (Velv) Eureka (Eurk) Wyndmere (Wyn), followed by the year