IMPROVEMENT IN GENETIC YIELD POTENTIAL

OF SEMI-DWARF WHEAT IN THE

GREAT PLAINS OF THE USA

By

SARAH D. BATTENFIELD

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and Family Science

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Thesis Approved:

Dr. Arthur R. Klatt

Thesis Adviser

Dr. Jeffrey T. Edwards

Dr. William R. Raun

Dr. Sheryl A. Tucker

Dean of the Graduate College

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CHAPTER I

ABSTRACT

Recently, private companies and public entities have made significant investments in and improvements to their wheat (*Triticum aestivum* L.) breeding programs. Because of this increased interest, recent genetic improvements made in wheat through traditional plant breeding need to be analyzed. Many studies have noted the significant yield improvement from tall cultivars to semi-dwarf cultivars, but no studies have documented improvements made from the earliest semi-dwarfs to present-day cultivars. Thirty cultivars were tested including 2 tall varieties (Kharkof, 1921 and Triumph 64, 1964), and 28 semi-dwarf cultivars spanning the period from 1971 (TAM 101) to 2008 (Jackpot and TAM 401). Cultivars were tested in 2010 and 2011 at eleven locations across Oklahoma, Kansas, and Texas with adequate disease protection and fertilizer. Experimental design was a split-plot design with fungicide treatment as the main plot and cultivar as the sub-plot with three replications per location. Yields for cultivars protected by fungicide treatment were higher than those without fungicide at most locations. A significant yield increase of 13.68 kg ha^{-1} yr^{-1} or 0.93% per year of Kharkof yield was obtained across all locations with the tall cultivars included. When gain was restricted to only semi-dwarf cultivars (1971 to 2008), yield gain was reduced to 11.65 kg ha^{-1} yr^{-1} or 0.46% per year of TAM 101 yield. Yield gain among semi-dwarf cultivars in locations with significant fungicide effect was only 10.51 kg ha^{-1} yr^{-1} or 0.37% per year of TAM

101 yield, which more accurately represents gain in genetic yield potential made excluding defensive breeding efforts. No evidence of a yield plateau was found.

CHAPTER II

INTRODUCTION

Plant breeding and improved agronomic practices have resulted in significant yield increases in wheat (*Triticum aestivum* L.) over time. Wheat evolved as a cross between three separate grass species at least 10,000 years ago. Since that time humans have helped in the evolutionary process by domesticating the plant and harvesting types that could be replanted. Modern breeding efforts began in wheat during the late 1800s using the early knowledge of modern genetics and selecting for advanced agronomic and culinary properties of the plant (Sleper & Poehlman, 2006).

The first breeding efforts specific to the Great Plains of the USA began in the 1920s. At that time wheat in the area was mostly an introduced land race from Russia known as Turkey or Turkey Red and multiple selections made from this landrace. Crossing began and the first purposefully bred varieties in the area were released in the late 1940s. In the 1960s Dr. Norman Borlaug incorporated semi-dwarf genes into Mexican spring wheat cultivars producing shorter, higher yielding wheat cultivars, which provided a significant increase in yield. The semi-dwarf characteristic was incorporated into the Great Plains wheat cultivars by the 1970s. Since that time, incorporation of diverse germplasm with varying genes for pest and disease resistance, as well as agronomic type, has been useful for making yield gains. Additionally, in recent years breeders have had access to advanced genomic and statistical technologies to enhance their selection of modern wheat cultivars.

Throughout the past century there has also been significant improvement in agronomic practices of wheat. Fertilization methods, as well as pesticide, herbicide and fungicide practices have been extensively studied and have given rise to higher yields. Traditionally, genetic improvements have been responsible for approximately half of the yield increases over the past century (Rudd, 2009); however, this must be periodically analyzed. Also, over the last few years there has been a significant increase in investment in wheat breeding from the private sector. These investments have been made with the intent of possibly releasing transgenic (GMO) or hybrid wheat within the next 10 to 20 years. Therefore, it is vitally important to quantify yield gains that have been made in wheat due to traditional breeding efforts, especially in the semi-dwarf era.

The current study compared 30 Great Plains cultivars over 2 years at 11 locations. The primary purpose of this study was to determine the amount of yield increase due to breeding efforts in winter wheat in Kansas, Oklahoma and Texas from the semi-dwarf era to present (1970s to 2008). The most recent cultivars will be investigated for evidence of a yield plateau as hypothesized in Graybosch and Peterson (2010). Differences between awned and awnless cultivars of the Great Plains will be assessed. Additionally, yield stability will be determined and compared among old and new cultivars.

CHAPTER III

LITERATURE REVIEW

Previous genetic gain studies

Analysis of genetic gain can be conducted by studying a set of historical cultivars over multiple locations and years, as was done in this study, or by comparing historical yield data with a standard over time. Both types of studies have been conducted worldwide and average improvements equate to approximately 1% of yield of the oldest cultivars available per year (Fischer & Edmeades, 2010; Rudd, 2009). The two methods of determining increase in genetic yield potential over time each have advantages and disadvantages.

Comparing a specified set of historic cultivars over multiple years and locations targets the cultivars used, thus allowing for only the most relevant material to be tested. Additionally, all tests are conducted in the same site-years, which, if there are enough locations will reduce environmental bias. This method of testing in itself does favor newer varieties that have genetic disease resistance, but experimental design that includes fungicide can negate this bias. Finally, newer varieties are bred to be responsive and not lodge under high fertilizer input, favoring the newer cultivars, thus making the old cultivars compete with the newer cultivars in the modern environment.

Using the method of historical yield trials, results in comparing the newest germplasm materials and not necessarily farmer adopted varieties. Since these tests are often conducted over wide regional areas, they represent broad yield gains, instead of smaller gains made for specific adaptation, which is conducive to this type of study. Additionally, this method relies on the most advanced material compared to a long standing check variety, which has normally lost any resistance it may have once had. Because wheat breeders have traditionally selected for race-specific resistance to pathogens, this could be considered the equivalent of testing new, fungicide-treated materials against the oldest non-fungicide-treated materials. However, this method does allow for the greatest amount of varying materials to be tested and provides statistical stability with the numerous site-years tested (Graybosch and Peterson, 2010; Schmidt 1984; Schmidt and Worrall, 1983).

The multiple cultivars in several locations and years method has been used many times throughout the world. In North America, studies have been conducted in Ohio and Mexico to estimate genetic gains made in wheat. Twenty-four non-fungicide treated soft red winter wheat cultivars ranging in release date from 1871 to 1987 were studied over 16 site-years in Ohio. The authors reported an increased yield of 15.5 kg ha^{-1} $year^{-1}$ or 0.55% per year of the oldest cultivar with no evidence of a yield plateau (Berzonsky & Lafever, 1993). Eight elite semi-dwarf hard red spring wheat cultivars released between 1962 and 1988 in Mexico were examined in a randomized complete block design over six site-years. In this study, cultivars were irrigated on a schedule based on soil moisture, weeded, protected from foliar diseases with fungicides, and mesh nets were installed to prevent lodging. Authors reported genetic gains of 67 kg ha^{-1} $year^{-1}$ or 0.88% of the 1962 cultivar's yield and found no evidence of a yield plateau by 1988 (Sayre, et al., 1997).

In Europe, major studies have been conducted in England, France and Turkey to determine genetic yield gains made in wheat. In England 13 tall winter wheat cultivars released between 1830 and 1986, and including 5 semi-dwarf varieties released since 1981, were studied over 3 site-years to determine genetic gain. All cultivars were protected with best agronomic practices, fungicide for foliar disease protection and netting to prevent lodging. The study determined that from 1908 to 1985, yield had increased 0.81% of the oldest cultivar per year. The authors additionally reported that significant gains were made from tall varieties to semi-dwarf cultivars and that improvements were continuing among the semi-dwarf cultivars (Austin, et al., 1989).

A study of winter wheat in France tested 14 cultivars planted in 10 site-years with release dates from 1946 to 1992. This study included a randomized complete block of four treatments: presence or absence of fungicide treatment and high or low fertilization. The authors reported an average yield increase of 49 kg ha^{-1} per year. However, they did find a significant difference between treatments reporting only a 36 kg ha^{-1} per year increase at low fertilization and no-fungicide and an increase of 63 kg ha^{-1} per year with high fertilization and fungicide treated cultivars. Finally, they found that the newest cultivars showed the most stability and highest yields at high and low inputs (Brancourt-Hulmel, 2003).

Sixteen wheat cultivars released between 1976 and 1999 were tested for genetic gain over 2 site-years in Turkey. The study was then compared to Mediterranean regional averages from 1925 to 2006 and Turkish national yield averages from 1978 to 2006. Historical farmer data showed that yields increased 3.8% per year from 1925 to 2006, but when the period 1975 to 2006 was considered, yield gains dropped to 1.3% per year in the region or only 0.83% in Turkey. The authors reported that yield gains were lower over the entire Mediterranean region as compared to Turkey, but hypothesized that this was due to differences in availability of water. From the genetic gain study, yield gains of only 0.45% per year were attributed to genetics, whereas a 0.83% increase was found on farmers' fields, thus attributing approximately half of the yield gains to advances from breeding (Sener, et al., 2009).

In Asia, genetic gain studies have been conducted in Siberia and China to assess yield gains made in wheat due to breeding. Genetic gains in 47 hard red spring wheat cultivars released between 1900 and 1997 were studied in Siberia over 7 site-years. Yield gains over that period were reported to be 15.3 kg ha^{-1} $year^{-1}$ or 0.7% of the oldest group of materials per year (Morgounov, et al., 2010). Zhou et al. (2007) used 47 cultivars which were released between 1960 and 2000 to determine yield potential in the two major wheat growing areas of China. The testing of these cultivars was split among four separate locations for specific adaptation of the crops. The authors stated that in China yield gains have ranged from an increase of 0.48% per year of the yield of the oldest cultivars or 32.07 kg ha^{-1} $year^{-1}$ in Shandong and Hebei Provences to 1.23% per year of the oldest cultivars' yield or 64.27 kg ha^{-1} $year^{-1}$ in Beijing, with an 0.81% average yield increase per year for all of China.

Wheat in the Great Plains of the USA has been analyzed many times in different ways to determine genetic improvement in yield. The baseline study of several cultivars planted simultaneously for this area was conducted from 1985 to 1987 (Cox, et al., 1988). The trial was planted in three locations in Kansas over two years, in which one year had severe drought and the other was highly influenced by foliar diseases. The trial consisted of thirty-five cultivars without fungicide protection in a randomized complete block design with three replications per location. The authors demonstrated a yield increase of 16.2 kg ha^{-1} $year^{-1}$ or 1% of the average yield of the cultivar Turkey per year from 1919 to 1987. This study provided benchmark results from which the current project will compare previous findings and continue to present day cultivars. Donmez, et al. (2001) analyzed 14 Great Plains cultivars across 4 site-years in Kansas with a split-plot design, including mesh netting for lodging and fungicide treatment for foliar disease protection. The authors reported that wheat yields increased 0.44% of Turkey yield per year between the introduction of Turkey and 1996. Partitioning total genetic gain showed that wheat yields advanced 0.48% per year from the introduction of semi-dwarf wheat through the early 1990s and 0.63% per year within the 1990s. The large differences between the Cox (1988) and Donmez (2001) genetic yield potential were likely due to a smaller, less representative set of cultivars being tested. Khalil, et al. (2002) tested 12 historical cultivars released from 1919 to 1997 under grain-only and cattle-grazed conditions with a split plot design of fungicide or no fungicide treatment for 3 site-years. No differences between fungicide-treated and non-treated plots were reported. Yield potential for the grain-only trial reportedly increased 1.3% per year compared to the yield of Turkey or 18.8 kg ha^{-1} $year^{-1}$. The authors also reported that these yield increases were not affected by the exclusion of Turkey in the analyses, meaning there were no significant changes in the rate of genetic increase per year due to the tall cultivar inclusion or exclusion.

Estimation of yield gain using annual data from standardized yield trials has been previously studied in the Great Plains of the USA. Graybosch and Peterson (2010), Schmidt (1983), and Schmidt and Worrall (1984) each used the Northern Regional

Performance Nursery (NRPN) and Southern Regional Performance Nursery (NRPN) to estimate the gain in genetic yield potential of wheat, using Kharkof as a long term check variety. These specific performance nurseries were established by the USDA as yield trials for advanced materials. In the 1980s a study compared three year averages of the highest yielding line to the lowest yielding line in each of the regional yield trials across the USA to assess potential yield gains. The authors reported a rate of genetic gain of approximately 0.74% of Kharkof per year from 1959 to 1979 (Schmidt, 1983; Schmidt and Worrall, 1984). A more recent study (Graybosch and Peterson, 2010) of cultivars from 1959 to 2008 using the SRPN and NRPN investigated total yield gains made between 1984 and 2008. The authors stated that between 1959 and 2008 the yield of the SRPN had advanced between 1.1% and 1.3% of Kharkof yield per year, whereas the NRPN yield had only improved 0.79% to 0.85% of Kharkof yield per year. This methodology also displayed that there were no significant genetic yield progress when only considering cultivars released from 1984 to present. This indicates that in the modern wheat breeding era, yields have plateaued since 1984 to present, indicating no significant advancements in yield have been made in the period of 1984 to 2008.

Yield Stability

Yield stability is typically assessed by regressing yield in environment by yield of another factor such as cultivar or treatment. Stability, when referring to plant breeding, is often treated as the ability of a cultivar to perform consistently greater than mean yield across several environments or various conditions (Pfeiffer and Braun, 1989). Cultivars with low stability would have unpredictable yields in varying environments or not perform well in either low or high input conditions. Good-yielding, high-stability cultivars are often considered to be among the highest yielding, or ranking, within a group of cultivars in both high-yielding and low-yielding environments, and have a slope of 1 or greater (Pfeiffer and Braun, 1989). In other words, these cultivars are among the higher yielding varieties in low-input conditions and are responsive to higher inputs. If cultivar yields were regressed across all environments, these cultivars would, therefore, express an R^2 value approaching 1 as it fits a trend-line across all environments. In the present study, individual cultivars were assessed to find cultivars demonstrating highest stability across all trial locations and conditions.

Breeders also consider stability when determining how yields of groups of cultivars change over time, not necessarily considering specific cultivars. In this manner, average yields regressed over time would need to have a significant slope and an R^2 value approaching 1 to be considered stable (Calderini and Slafer, 1998). To this end, cultivars in the present study were grouped by agronomic type to determine stability of varying sets of cultivars.

Pfeiffer and Braun (1989) conducted stability analysis comparing groups of cultivars with or without derivations from the *Centro Internacional de Mejoramiento de Maiz y Trigo* (CIMMYT) breeding program. The groups analyzed were cultivars derived directly from CIMMYT germplasm, cultivars derived from crosses of CIMMYT germplasm bred by local programs, cultivars selected from crosses of local materials with CIMMYT germplasm, and local cultivars. The authors found that cultivars bred with CIMMYT materials, whether released locally or on a larger scale, had higher stability than those selected locally from non-CIMMYT materials, thus indicating that modern breeding from CIMMYT germplasm was increasing stability of global wheat yields.

Additionally, they identified that there was one cultivar with high stability which performed significantly better than the average, as well as all other varieties at all input levels.

The Brancourt-Hulmel (2003) study experimentally designed conditions for stability analysis by using a factorial treatment structure with and without fungicide and with high and low fertilizer inputs in addition to their cultivars. They found that modern, semi-dwarf cultivars imparted the best stability with high responsiveness in high input environments. Yield stability was also investigated in the Morgounov et al. (2010) study involving 47 cultivars in Siberia. Seven cultivars released within the most recent 20-year-period of the study were found to be responsive and stable, yielding higher at all locations than other varieties. This demonstrated an increase in breeding for stability in recent years in the Siberian study.

Yield stability of wheat as expressed by national production per unit area over time was conducted for 21 countries, which represented the majority of the global wheat production from 1900 to 1998. Yield reports show definite yield increases (in all but one country) likely corresponding to the Green Revolution in which both genetics and agronomic practices in wheat were substantially improved at the global level. The Green Revolution tended to increase yields worldwide, but in the past two to three decades, stability values have dropped for two-thirds of the countries studied. The authors interpret this shift in stability as possibly approaching the ceiling of genetic yield potential per environment. The authors warn that if agronomic practices and genetic yield potential are not improved by other means that are currently not available, then the current increasing population situation is bleak (Calderini and Slafer, 1998).

Awnless Cultivars

Even though the presence of awns, or beards, is a recessive trait in wheat, awned cultivars dominate the landscape of the hard red winter wheat region in the Great Plains of the USA. In 1929 it was documented that 98.7% of the hard red winter wheat in the USA had awns. However, only 31.8% of soft red winter, 7.3% of hard red spring and 18.2% of white wheat in the USA at the same time (these figures have changed over time) were bearded (Lamb, 1937). Several awnless cultivars have been released in the Great Plains, but typically do not compete with the yields achieved by awned cultivars released in this region based on Oklahoma yield trial data (Edwards, et al., 2010). Therefore, awnless cultivars are used primarily in situations where farmers use wheat for winter cattle forage and intend on continuing to graze the crop completely (graze-out), and maintain fewer acres for grain production than those with awns.

An anatomical and physiological study (Li, et al., 2006) was conducted to determine the photosynthetic contributions for both the flag leaf and awns in wheat maturation. Based on scanning electron microscope images, the wheat awn contains vascular bundles and stomata to the apex of the awn. In transmission electron microscope images, chloroplasts were found in the awn parenchyma cells which contained many thylakoids and grana. As wheat matured from dough-development through physiological maturity, flag leaf chloroplasts became less active and eventually ruptured, whereas awn chloroplasts continued to develop and increase their photosynthetic activity significantly above that of the flag leaf. This finding was also validated with phosphoenolpyruvate (PEP) carboxylase activity following a similar pattern through the same time period. Therefore, it was assumed that awns assist wheat by providing photosynthates in its final stages of kernel development and ripening. However, agronomic studies with comparisons in yields of awned and awnless varieties have been mixed.

Lamb (1937) attempted to determine if there was a difference in Ohio soft red winter wheat yield based on the presence or absence of awns. Researchers compared length of head, number of kernels per head, and thousand kernel weights for plants from segregating populations with and without awns. They found that while there was a difference in weights of kernels for awned and awnless segregates, there were no differences in overall yield among the two agronomic types. Thus, it was concluded at that time that breeding only for beardless cultivars would continue in the soft red winter wheat region because of preference for the awnless agronomic characteristic.

Martin et al. (2003) attempted to determine the contributions made by awns to wheat in Oklahoma. Using near isogenic lines (NILs) created for the presence or absence of awns and leaf rust resistance, the authors found a significant difference in yield in which awnless NILs yielded less than awned NILs. Presence of awns was also reported to increase grain quality over awnless types. However, leaf rust resistant awnless types were reported to yield similarly to leaf rust susceptible types with awns.

CHAPTER IV

MATERIALS AND METHODS

Treatments

Thirty (30) historic cultivars (Table 1) were studied over 2 years in 11 locations across Kansas, Oklahoma and Texas. The cultivars were tested in three replications per location under a split-plot design using fungicide treatment as the main plot and cultivars as sub-plot (Figure 1). Each cooperator randomized the plots and used plot sizes specified to their own needs, but the design was the same for all locations.

1 101	2 102	3 103	4 104	5 105	6 106	7 107	8 108	9 109	10 110	11 111	12 112	13 113	14 114	15 115	16 116	17 117	18 118	19 119	20 120	21 121	22 122	23 123	24 124	25 125	26 126	27 127	28 128	29 129	30 130
1 F 131	2 F 132	3 F 133	4 F 134	5 F 135	6 F 136	7 F 137	8 F 138	9 F 139	10 F 140	11 F 141	12 F 142	13 F 143	14 F 144	15 F 145	16 F 146	17 F 147	18 F 148	19 F 149	20 F 150	21 F 151	22 F 152	23 F 153	24 F 154	25 F 155	26 F 156	27 F 157	28 F 158	29 F 159	30 F 160
29 201	7 202	11 203	17 204	19 205	1 206	9 207	30 208	20 209	25 210	28 211	23 212	27 213	16 214	10 215	21 216	5 217	24 218	22 219	8 220	4 221	14 222	2 223	26 224	15 225	18 226	6 227	12 228	3 229	13 230
29 F 231	7 F 232	11 F 233	17 F 234	19 F 235	1 F 236	9 F 237	30 F 238	20 F 239	25 F 240	28 F 241	23 F 242	27 F 243	16 F 244	10 F 245	21 F 246	5 F 247	24 F 248	22 F 249	8 F 250	4 F 251	14 F 252	2 F 253	26 F 254	15 F 255	18 F 256	6 F 257	12 F 258	3 F 259	13 F 260
27 F 301	26 F 302	29 F 303	6 F 304	15 F 305	3 F 306	22 F 307	5 F 308	23 F 309	2 F 310	19 F 311	8 F 312	17 F 313	24 F 314	18 F 315	4 F 316	9 F 317	1 F 318	10 F 319	28 F 320	7 F 321	16 F 322	11 F 323	12 F 324	14 F 325	21 F 326	13 F 327	30 F 328	25 F 329	20 F 330
27 331	26 332	29 333	6 334	15 335	3 336	22 337	5 338	23 339	2 340	19 341	8 342	17 343	24 344	18 345	4 346	9 347	1 348	10 349	28 350	7 351	16 352	11 353	12 354	14 355	21 356	13 357	30 358	25 359	20 360

1 = FANNIN
2 = JACKPOT
3 = OGALLALA
4 = TAM W-101
5 = LONGHORN
6 = POSTROCK
7 = 2137
8 = WEATHERMASTER 135
9 = TAM 110
10 = KHARKOF
11 = TAM 111
12 = KARL 92
13 = TRIUMPH 64
14 = 2180
15 = JAGGER
16 = TAM 401
17 = TAM 112
18 = CHISHOLM
19 = SANTA FE
20 = CORONADO
21 = DELIVER
22 = OVERLEY
23 = 2174
24 = DUSTER
25 = FULLER
26 = ENDURANCE
27 = ARMOUR
28 = JAGALENE
29 = TAM 105
30 = CUSTER

Figure 1: Organization of plots in three replications per location with all thirty varieties randomized in both fungicide and no-fungicide main-plots per replication. (F represents fungicide treatment applied.)

Table 1: List of historic cultivars with year of release, breeding origin, and awn characteristic type.

Cultivar	Year	Origin	Presence of Awns
Kharkof	1919	landrace derived from Turkey red	Yes
Triumph 64	1964	Joseph Danne	Yes
TAM 101	1971	Texas A&M University	Yes
TAM 105	1979	Texas A&M University	Yes
Chisholm	1983	Oklahoma State University	Yes
Weather Master 135	Mid 80s	Unknown	No
2180	1988	Pioneer	Yes
Longhorn	1990	Agri-Pro	No
Karl 92	1992	Kansas State University	Yes
Ogallala	1992	Agri-Pro	Yes
Coronado	1994	Agri-Pro	Yes
Custer	1994	Oklahoma State University	Yes
Jagger	1994	Kansas State University	Yes
2137	1995	Kansas State University	Yes
TAM 110	1996	Texas A&M University	Yes
2174	1997	Oklahoma State University	Yes
Jagalene	2001	Agri-Pro	Yes
Fannin	2003	Agri-Pro	Yes
Overley	2003	Kansas State University	Yes
Santa Fe	2003	West Bred	Yes
TAM 111	2003	Texas A&M University	Yes
Deliver	2004	Oklahoma State University	No
Endurance	2004	Oklahoma State University	Yes
TAM 112	2004	Texas A&M University	Yes
Armour	2006	West Bred	Yes
Duster	2006	Oklahoma State University	Yes
Fuller	2006	Kansas State University	Yes
Postrock	2006	Agri-Pro	Yes
Jackpot	2008	Agri-Pro	Yes
TAM 401	2008	Texas A&M University	No

Trial locations were chosen to be representative of the majority of the wheat growing conditions in the southern Great Plains. Locations studied in Oklahoma were Lahoma, Lake Carl Blackwell, Perkins, Sweetwater (2010 only), and Stillwater (2011 only). Locations studied in Texas were Bushland, Chillicothe, Perryton, and Vernon. Locations studied in Kansas were Conway Springs, Gypsum, and Haven (Figure 2).

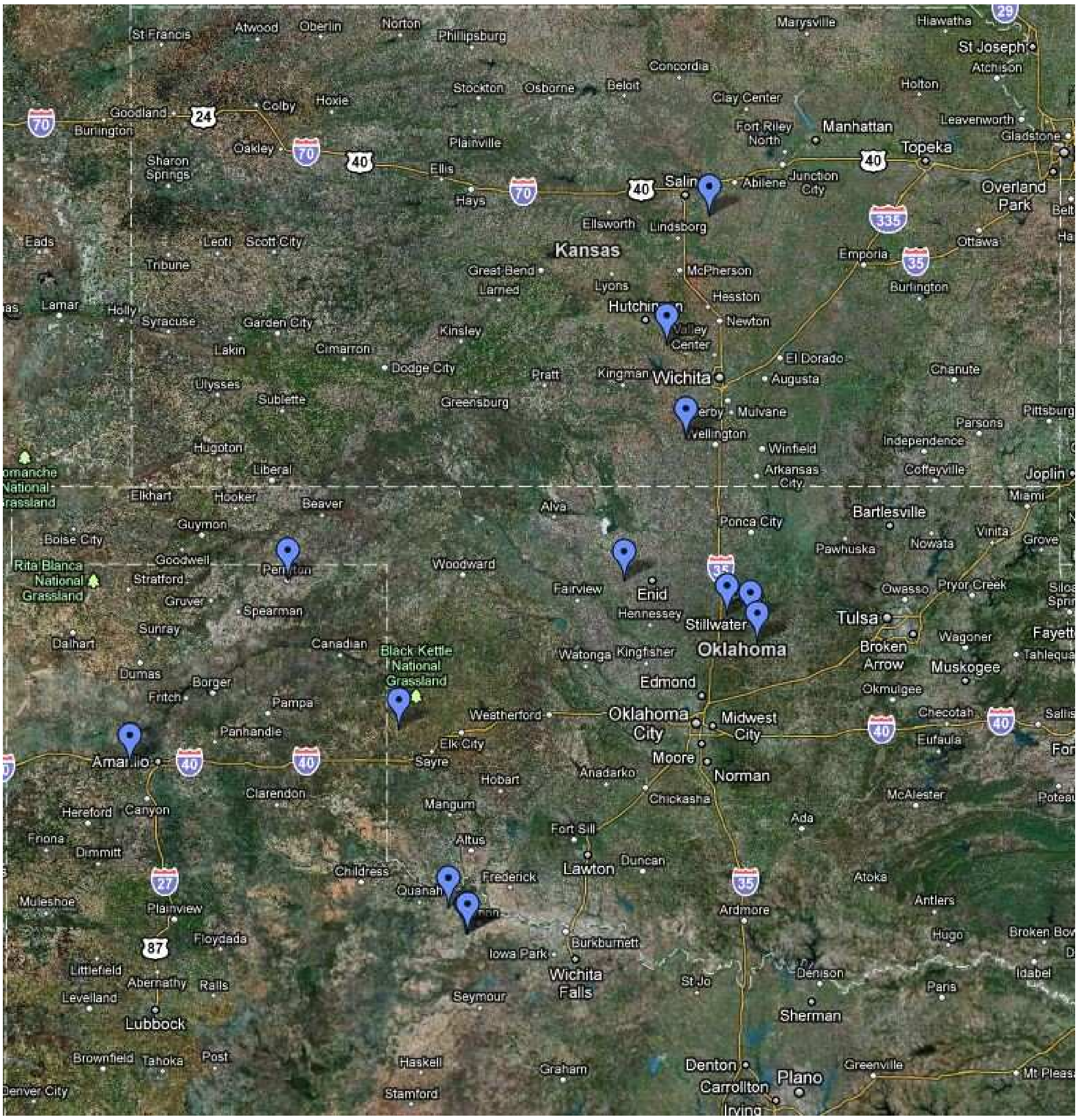

Figure 2: The arrows indicate locations of trials in a display area from Dallas in the south to the north Kansas border and the width of Oklahoma from west to east.

Perryton and Bushland represented the Texas High Plains region, and probably also represent the Oklahoma panhandle and southwestern Kansas. Perryton was irrigated, but Bushland was not, and both were severely affected by the 2011 drought.

Chillicothe and Vernon were chosen to represent the Rolling Plains of Texas. Vernon was irrigated, but Chillicothe was not, and again, both were severely affected by the 2011 drought. Sweetwater represented rain-fed wheat in western Oklahoma. Perkins, Stillwater, and Lake Carl Blackwell were chosen because of their varying conditions. Perkins is a dry, sandy location where irrigation was available, but irrigation was not used in 2010. Stillwater has a more uniform soil representative of the eastern wheat belt. Lake Carl Blackwell has a heavy clay soil and irrigation was available, but irrigation was not used in 2010 because of the rainfall and not used in 2011 because of mechanical problems. Lahoma, Conway Springs, and Haven were chosen to be representative of the bread basket where wheat is the main crop. Gypsum was chosen to represent growing conditions in north central Kansas.

The thirty cultivars used were planted on a large acreage in their era and represented popular cultivars in the Great Plains. Kharkof (year of release from Cox, et al., 1988) and Triumph 64 were included to show long term advances from tall wheat and where breeding advancements began. Improvements made from 1971 (TAM 101) to 2008 (Jackpot and TAM 401) represent the improvements made during the semi-dwarf era in the Great Plains. TAM 101, TAM 105, Chisholm, Weather Master 135, and 2180 represented the improvements made in the 1970s-1980s. Longhorn, Karl 92, Ogallala, Coronado, Custer, Jagger, 2137, TAM 110, and 2174 were cultivars from the 1990s. Jagalene, Fannin, Overley, Santa Fe, TAM 111, Deliver, Endurance, TAM 112, Armour, Duster, Fuller, Postrock, Jackpot and TAM 401 were cultivars released in the 2000s. Additionally, four awnless cultivars were included in this study: Weather Master 135, Longhorn, Deliver and TAM 401.

Prior to planting, all seeds were treated with tebuconazole and metalaxyl (Raxil-MD, Bayer) at the labeled recommended dosage to prevent seedling diseases. In the first year, all trials were planted in October and harvested in June, except the Sweetwater location which was not harvested until July, resulting in a loss of the awnless cultivars at that location.

Since the seed for the first year came from various locations and varying time of storage, the amount of seed sown was adjusted to allow for similar number of plants per plot due to differing germination percentage and thousand kernel weights. The second year seed amount was not adjusted because all cultivars were grown in increase plots at one location resulting in similar germination percentage and seed size.

In plots with fungicide treatment, complete season protection was accomplished by applying pyraclostrobin (Headline, BASF), azoxystrobin (Quilt, Syngenta), or propiconazole (Stratego, Bayer) at Feekes 5-6 and Feekes 9 at the recommended rates. Plots in Perryton, and Sweetwater, 2010, and Bushland, 2011 did not receive fungicide treatment, and thus were treated as a six replication, no fungicide trial. The first year of trials was much more severely affected by disease than the second. In 2010, stripe rust (*Puccinia striiformis*) was present throughout the Great Plains, which is becoming more commonplace. Additionally, leaf rust (*Puccinia triticina*) and powdery mildew (*Blumeria graminis* f. sp. tritici) were found in most 2010 plots. Powdery mildew was the main disease present in 2011. Incidences of barley yellow dwarf virus and soilborne mosaic virus were found in both years at some sites, but were not controlled by the fungicide treatments.

Plots were mechanically harvested when the material reached maturity. Weight of grain harvested was recorded for all plots. Test weight was recorded for most locations.

Analysis

Analyses of variance (ANOVA) were conducted for each site-year to determine mean yield, mean square error, and coefficient of variation, additionally significance of cultivar, fungicide and the interaction of cultivar and fungicide were determined. The proc glm model (SAS Institute, 2003) used to account for split-plot design of each trial was:

Yield = *rep fung rep*fung var var*fung*; h= *rep fung* e= *rep*fung*;

where *rep* is the replication within a single trial, *fung* is presence or absence of fungicide treatment and *var* was the wheat cultivar. Both replication and fungicide treatments were tested using replication by fungicide treatment interaction as the error term.

Genetic yield potential was analyzed by linear regression of yield (kg ha^{-1}) by year of cultivar release using proc glm (SAS Institute, 2003). The slope of this regression indicated increase in yield over time. Genetic gain was also represented as percent increase of the earliest benchmark cultivar in the comparison. Separate regression analyses were conducted for all cultivars without fungicide, only semi-dwarf cultivars without fungicide, all cultivars with fungicide, and semi-dwarf cultivars with fungicide treatment. Percent gain as a function of Kharkof mean yield was used as the standard gain for all cultivars. Percent gain as a function of TAM 101 mean yield was used as the standard for gain in the semi-dwarf era because it is the earliest released semi-dwarf in this study. A linear-plateau model was conducted to determine if genetic gains in yield have plateaued recently.

Yield stability was analyzed by plotting environment mean of specific site-year yield on the ‘x’ axis, and cultivar mean yield on the ‘y’ axis. Slopes and intercepts were determined for individual cultivars and compared to the average location mean slope for the whole trial.

There was concern that agronomic type might skew results, so subsamples of agronomic types were identified. Awnless cultivars were analyzed for differences from cultivars with awns. Tall cultivars were analyzed for differences from semi-dwarf cultivars. Yield increases among each of the two types were determined by stability differences against the whole.

CHAPTER V

RESULTS AND DISCUSSION

Treatments

Individual plot yields ranged from 6.5 kg ha^{-1} for Kharkof in Vernon 2011 to a plot of Duster which yielded 5440 kg ha^{-1} in Vernon in 2010. Average cultivar yields followed the same trend as individual plots with the lowest yielding cultivar being Kharkof and the highest yielding being Duster, 1551 and 3389 kg ha^{-1}, respectively. Mean yields pooled across all locations, with and without fungicide treatment, displayed the same pattern with the same low (Kharkof without fungicide – 1467 kg ha^{-1}; Kharkof with fungicide – 1659 kg ha^{-1}) and high yielding (Duster without fungicide – 3147 kg ha^{-1}; Duster with fungicide – 3697 kg ha^{-1}) cultivars (Table 2).

Fungicide treatment increased the mean yield of all cultivars. Many cultivars' mean yield increases due to fungicide were significant ($p < 0.05$), but a large number of cultivars had a p value between 0.05 and 0.13. Only Karl 92 ($p = 0.4$) and Triumph 64 ($p = 0.2$) were found to be non-responsive to fungicide treatment. Thus, at the cultivar level, there was a high level of impact of the fungicide treatment (Table 2).

Large differences were found between sites and years in this study, as is shown in Table 3. Mean trial yields ranged from 921 kg ha^{-1} at Bushland during 2011 to 4078 kg ha^{-1} at Haven during 2010. Trials with fungicide treatment had higher yields on average than those without fungicide treatment in all site-years except the 2011 trials at Chillicothe, Lahoma, Perryton, and Vernon. The locations that responded negatively to fungicide all experienced drought stress during the time of fungicide application, which may have led to yield reducing chemical burns. Fungicide treated plots yielded significantly more than those without fungicide only in Gypsum, Haven, and Vernon in 2010, and at Stillwater in 2011. The 2010 sites which responded positively to fungicide treatment had heavy infections of stripe rust and moderate leaf rust infections (data not shown). Stillwater in 2011 was infected with powdery mildew, which is not generally considered to significantly reduce yields in this region (data not shown).

Lake Carl Blackwell and Conway Springs in 2011 were excluded from analysis because of excessive variation, as indicated by high coefficient of variation and low R^2 compared to other site-years. The coefficient of variation in both of these locations was greater than 20. The excessive variation can also be described by the fact that R^2 for the ANOVA model at these two site-years explains less than half of the variation in the trial, while all other locations have R^2 of at least 0.63 combined with much lower R^2 values. The yield variation in these trials is likely due to drought during the 2011 season; however, other locations with more severe drought pressure did not have the same level of variation.

Table 2: Mean yield of cultivars and yield gain provided from fungicide treatment. Non-significance of fungicide is noted only on cultivars where $p > 0.1$.

Release	Variety	Grain yield: Mean without fungicide	Grain yield: Mean with fungicide treatment	Grain yield: Change in yield	Significance of fungicide treatment	
			kg ha^{-1}			
1921	Kharkof	1467	1659	+191	0.1114	NS
1964	Triumph 64	2236	2420	+184	0.2035	NS
1971	TAM 101	2496	2948	+453	0.0047	**
1979	TAM 105	2473	3022	+549	0.0018	**
1983	Chisholm	2501	2892	+391	0.0344	*
1985	Weather Master 135	2432	2821	+389	0.0221	*
1988	2180	2424	2876	+453	0.0106	**
1990	Longhorn	2259	2571	+313	0.0660	
1992	Ogallala	2485	2636	+151	0.0416	*
1992	Karl 92	2649	3027	+377	0.4231	NS
1994	Jagger	2503	2851	+348	0.0060	**
1994	Coronado	2635	2990	+355	0.0297	*
1994	Custer	2515	2950	+435	0.0713	
1995	2137	2609	2957	+348	0.0605	
1996	TAM 110	2672	3178	+506	0.0141	**
1997	2174	2726	3010	+285	0.0931	
2001	Jagalene	2421	2976	+554	0.0004	***
2003	TAM 111	2464	2784	+319	0.0198	*
2003	Santa Fe	2622	2984	+362	0.0246	*
2003	Overley	2657	3045	+388	0.0345	*
2003	Fannin	2707	3160	+453	0.0666	
2004	TAM 112	2530	2895	+365	0.0065	**
2004	Deliver	2995	3343	+348	0.0516	*
2004	Endurance	2817	3352	+536	0.0692	
2006	Postrock	2961	3349	+388	0.0162	*
2006	Armour	2787	3098	+311	0.0659	
2006	Fuller	2552	2963	+411	0.0717	
2006	Duster	3147	3697	+550	0.0087	**
2008	Jackpot	2783	3124	+341	0.0706	
2008	TAM 401	2610	2889	+279	0.1336	NS

*,**, *** Significantly different from zero at 0.05, 0.01, and <0.001 levels respectively. NS non-significant ($p > 0.1$).

Table 3: Site years with coefficient of variation, R^2 for ANOVA model, mean yields with and without fungicide treatment (kg ha^{-1}), change in yield due to fungicide treatment, and significance of fungicide treatment.

				Grain yield			
Location	Year	CV	R^2	Mean without fungicide	Mean with fungicide	Change in yield	Significance of fungicide treatment
					kg ha^{-1}		
Bushland	2010	5.03	0.927	2682	2733	50	0.6655
Chillicothe	2010	8.55	0.809	3521	3789	267	0.1217
Conway Springs	2010	12.07	0.824	2689	2992	304	0.1200
Gypsum	2010	7.72	0.838	2945	3344	399	0.0086**
Haven	2010	7.79	0.868	3500	4078	578	0.0005**
Lahoma	2010	11.43	0.818	1931	2157	227	0.1660
Lake Carl Blackwell	2010	10.94	0.811	2700	2786	85	0.8192
Perkins	2010	8.82	0.88	3757	4003	246	0.7258
Perryton	2010	4.86	0.916	3412	-	-	-
Sweetwater	2010	12.71	0.603	2535	-	-	-
Vernon	2010	13.18	0.807	2892	3896	1004	0.0023*
Bushland	2011	9.80	0.631	921	-	-	-
Chillicothe	2011	10.81	0.891	1002	988	-14	0.9021
Conway Springs †	2011	23.52	0.454	2102	2143	41	0.6278
Gypsum	2011	12.07	0.687	2967	3066	100	0.5215
Haven	2011	8.40	0.826	3126	3475	349	0.0415*
Lahoma	2011	16.23	0.625	2613	2470	-143	0.4923
Lake Carl Blackwell †	2011	23.38	0.494	1713	-	-	-
Perkins	2011	19.37	0.793	2367	2641	273	0.2235
Perryton	2011	5.39	0.931	3416	3387	-28	0.6792
Stillwater	2011	9.38	0.866	2645	2842	197	0.0323*
Vernon	2011	15.26	0.766	1514	1497	-17	0.5993

*,** Significantly different from zero at 0.05 and 0.01 levels respectively; †Excluded from further analyses due to excessive variation; - Fungicide not applied.

Stability Analysis

Semi-dwarf cultivar means for each location were plotted against the site-year environment mean to determine stability. The slopes of all semi-dwarf cultivars and the slope of the site-year environment mean were plotted (Figure 3). Based on these data individual cultivars performance relative to the average of all cultivars in a given yield level can be determined. This graph is very difficult to interpret alone, so trend differences are examined in separate figures and tables (Figures 4-8, Table 4).

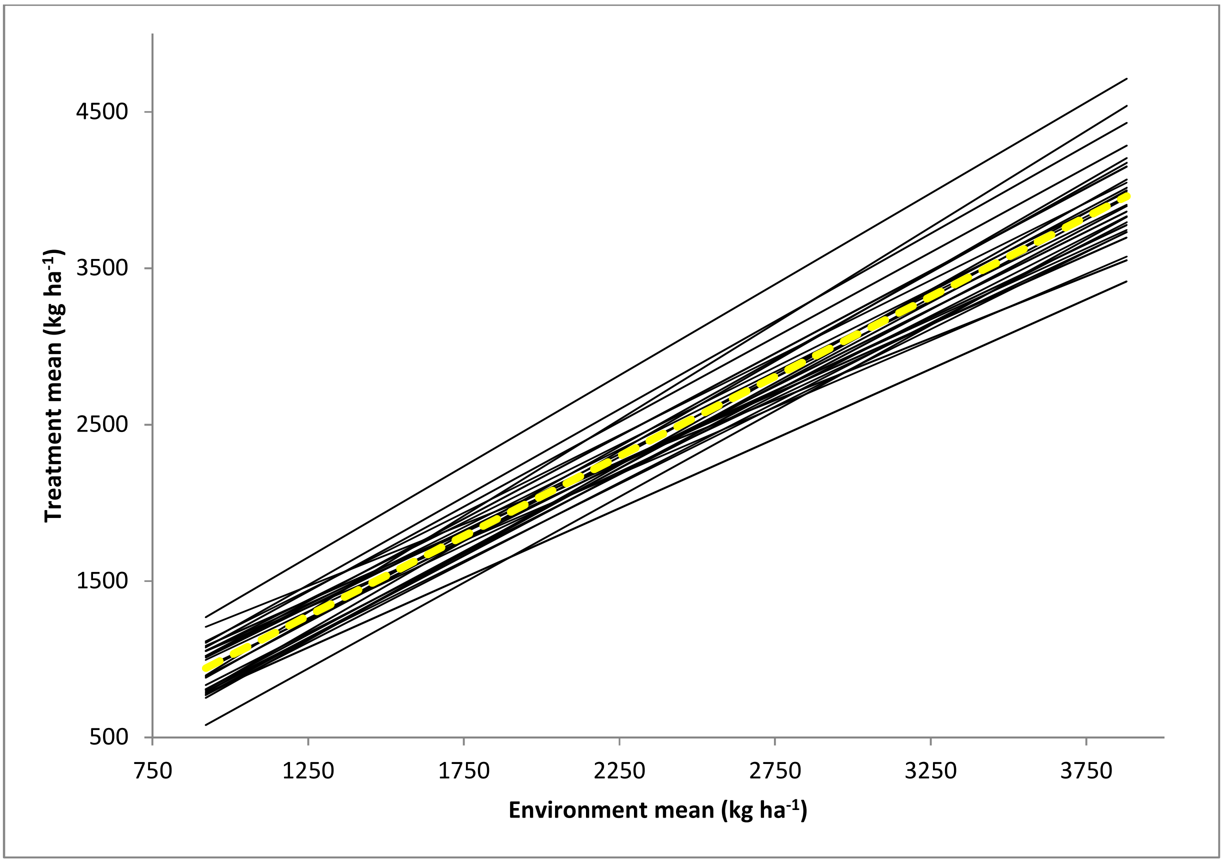

Figure 3: Stability analysis of all cultivars where slopes of treatment means are plotted against environment means and displayed for each cultivar. (Average slope is the average yield for all semi-dwarf cultivars at each location and is represented with a dashed line.)

Among this large set of stability slopes, trends appeared for cultivar responses to increasing input levels. Some cultivars yield similarly as compared to the mean in all input levels, as was displayed for individual low, medium, and high yielding varieties in Figure 4. Alternatively, some cultivars had varying responses to different input levels compared to the average slope (Figure 5). In sum, the best cultivars displayed average or greater than average yields in low, medium, and high input conditions, and had a slope greater than 1 (Figure 6). A table was made using the regression slopes compared to yield means at each input level. The trend of higher yield at all input levels was not found for any cultivars released before 1997. Half of the cultivars from 1997 forward displayed this trend, which indicated that yield stability has increased due to recent breeding efforts (Table 4). Additionally, awnless (Figure 7) and tall (Figure 8) cultivars were analyzed for stability and yield potential compared to average cultivar mean at all locations.

Cultivars were described as having high stability if they performed similarly compared to the average at all input levels. Cultivars with high stability were Kharkof, Triumph 64, Chisholm, 2180, Longhorn, Karl 92, TAM 110, 2174, Fannin, TAM 112, Deliver, Endurance, Fuller, Duster and Jackpot. The cultivars with high stability can be categorized as performing greater than average, approximately equal to average, or below average at all locations. Graphical representations of these three yield levels as compared to average are displayed in Figure 4.

Farmers prefer cultivars that can yield greater than average in low input situations, representative of bad years, and cultivars that can respond to increased inputs, representative of high inputs in good environmental years. Breeders strive to release cultivars that have good yield in poor conditions, are responsive to high inputs, and are broadly adapted, so they can be planted over a larger acreage. Therefore, cultivars with high stability and average or greater yield at all locations were selected as the best performing cultivars. Of the set of high stability cultivars, 2174, TAM 112, Endurance, Fuller, Duster, and Jackpot were the only cultivars with high yield, high stability (Figure 6). These cultivars likely have broad adaptation and a moderate level of abiotic stress tolerance. Each of these cultivars was released in 1997 or later, which seems to indicate an increase in breeding for stability over time in the Great Plains.

Cultivars were described as having less stability if they switched relative position compared to the average yield across environments. Graphical examples of this pattern are shown in Figure 5. Cultivars which displayed less stability in the trials were TAM 101, TAM 105, Weather Master 135, Ogallala, Custer, Jagger, Coronado, 2137, TAM 110, Jagalene, Overley, TAM 111, Fannin, Santa Fe, Armour, Postrock, and TAM 401. Some cultivars yielded well in low input environments, but have poorer performance in high input environments. This characteristic may be caused either by poor adaptation to different environments, non-responsiveness to higher inputs, susceptibility to diseases which are more common in higher yield situations, or a combination of the above. These cultivars were TAM 101, TAM 105, Weather Master 135, Jagger, Coronado, Jagalene, Overley, Santa Fe, and Postrock. Adversely, some cultivars perform better in higher input environments compared to average and less than average in low input environments; in other words, these cultivars perform well under good conditions, but not in poor conditions. This pattern may be due to lack of adaptation to all sites in the trial, poor response to low-water stress conditions, or simply selection for cultivars with high yields in good environments. These cultivars were Ogallala, Custer, TAM 110, TAM 111, Armour, and TAM 401 (Table 4).

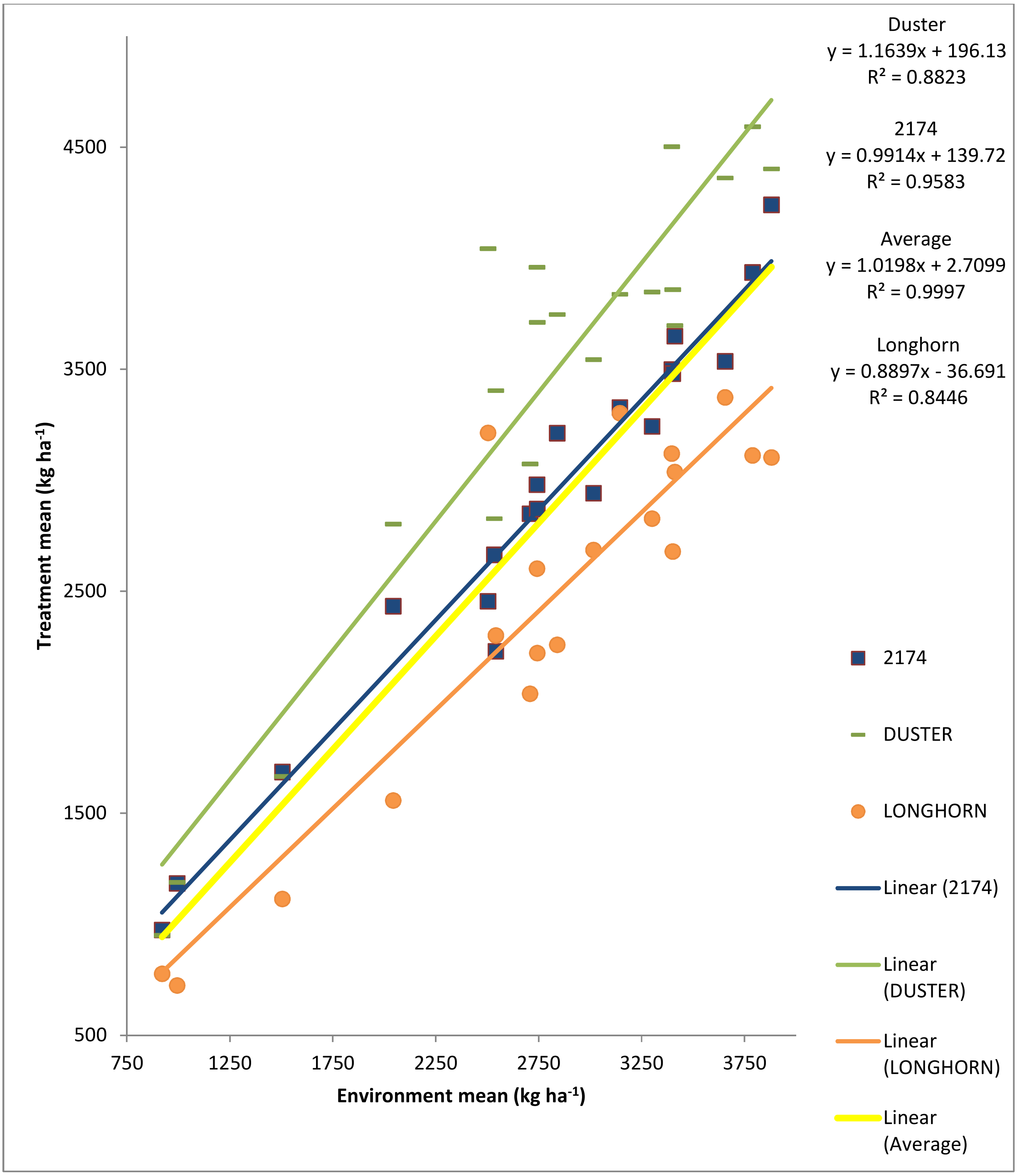

Figure 4: Examples of cultivars with high stability in high yield (Duster), medium yield (2174), and low yield (Longhorn) environments.

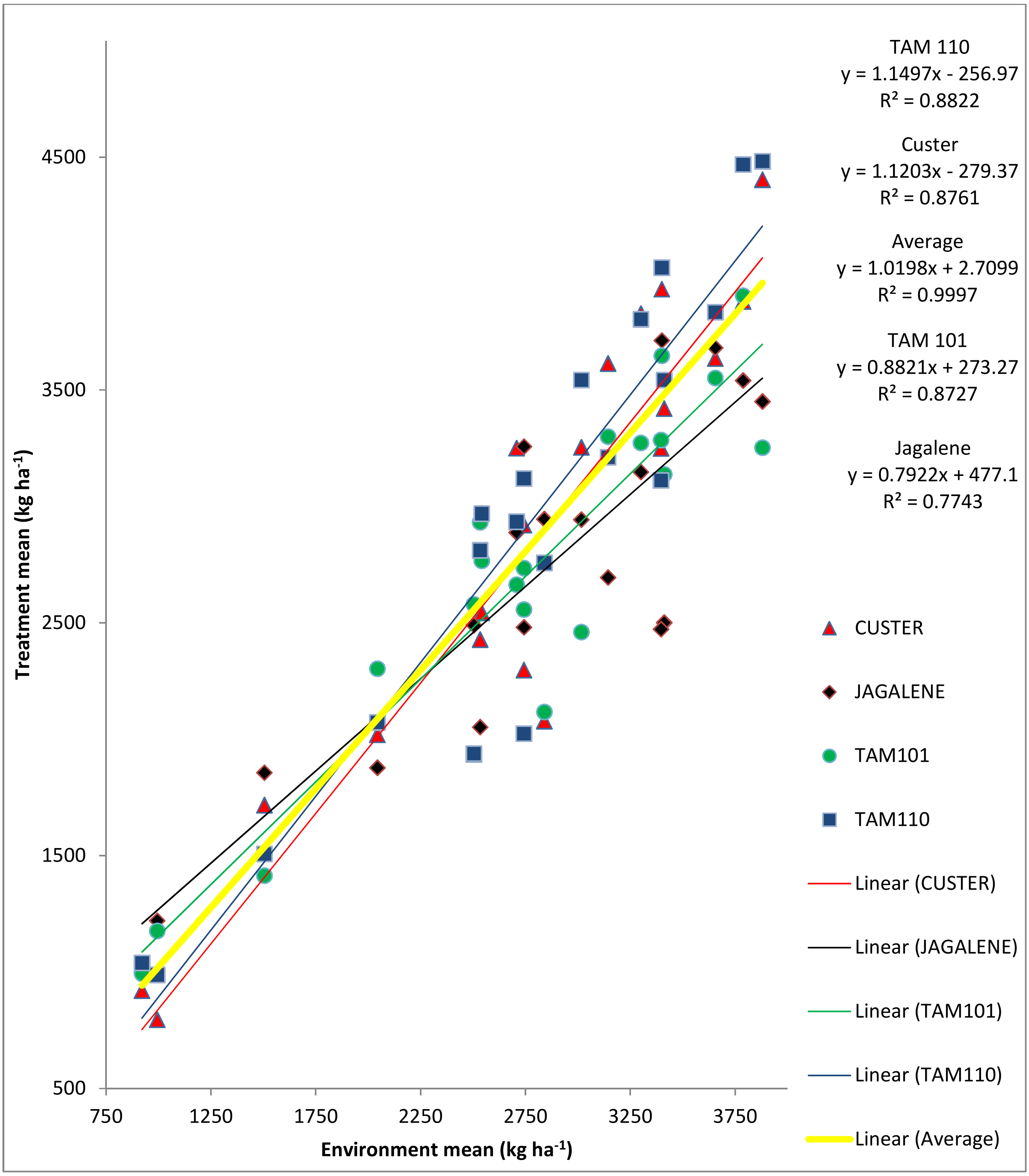

Figure 5: Examples of cultivars with low stability that change from being relatively high yielding at low input conditions to being relatively low yielding at high input locations, or vice versa.

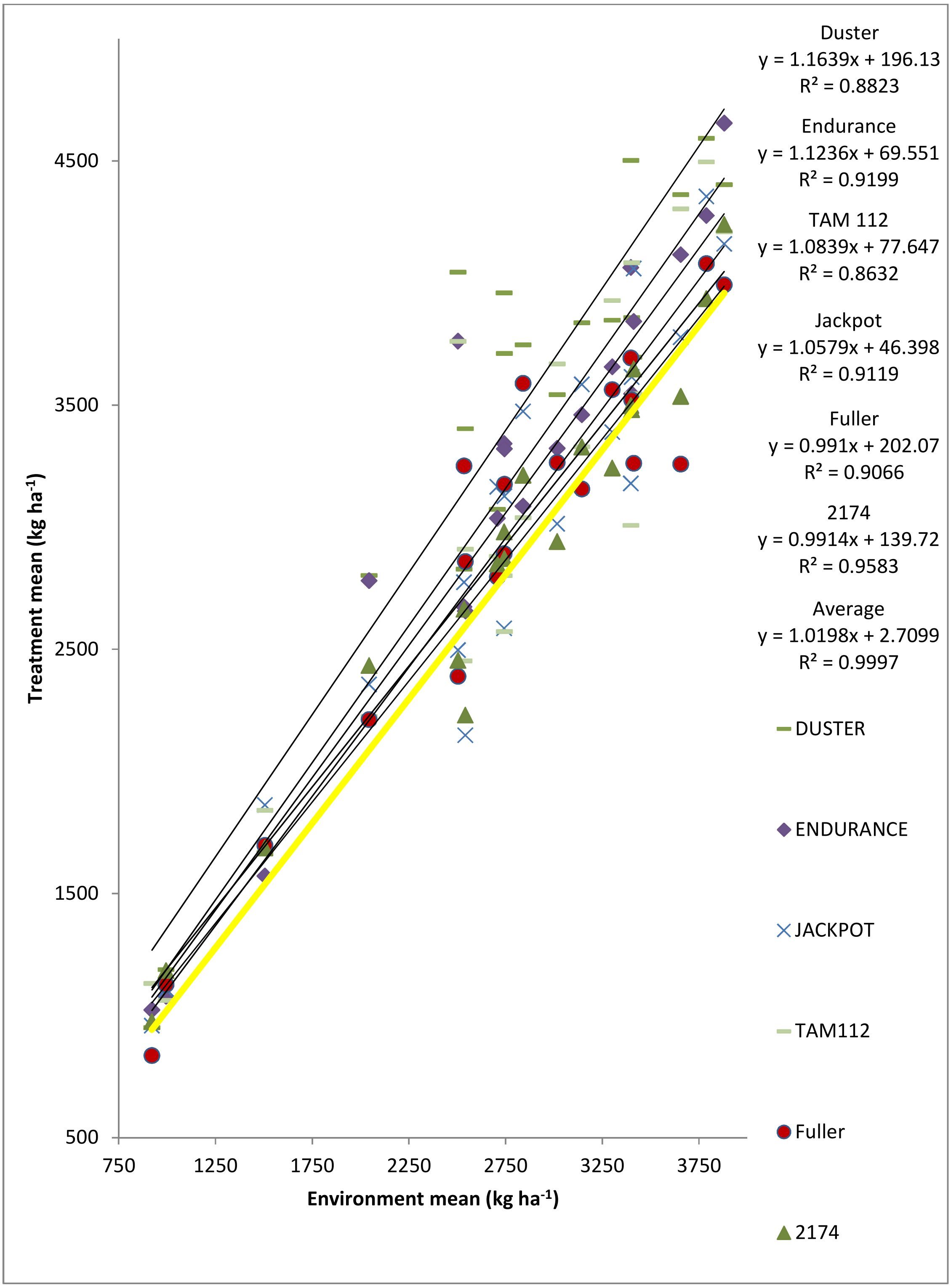

Figure 6: Cultivars with mean yield higher than average at all locations and where slope of regression line is approximately equal to or greater than 1.

Table 4: Stability analysis of all cultivars with year of release and agronomic type displayed along with R^2 value for stability slope and performance of cultivars compared to average yield of all semi-dwarf cultivars at three input levels.

Release	Cultivar	Presence of Awns	Stability R^2	Predicted yield at <1 tons goal	Predicted yield at 2.5 tons goal	Predicted yield >4 ton goal
1921	Kharkof Triumph	Yes	0.760	< Average	< Average	< Average
1964	64	Yes	0.851	< Average	< Average	< Average
1971	TAM 101	Yes	0.873	> Average	< Average	< Average
1979	TAM 105	Yes	0.871	> Average	< Average	< Average
1983	Chisholm	Yes	0.831	< Average	< Average	< Average
1985	Weather Master 135	No	0.839	> Average	< Average	< Average
1988	2180	Yes	0.925	< Average	< Average	< Average
1990	Longhorn	No	0.845	< Average	< Average	< Average
1992	Karl 92	Yes	0.855	< Average	< Average	< Average
1992	Ogallala	Yes	0.887	< Average	~ Average	> Average
1994	Custer	Yes	0.876	< Average	~ Average	> Average
1994	Jagger	Yes	0.938	> Average	< Average	< Average
1994	Coronado	Yes	0.944	~ Average	< Average	< Average
1995	2137	Yes	0.946	< Average	< Average	> Average
1996	TAM 110	Yes	0.882	< Average	> Average	> Average
1997	2174	Yes	0.958	> Average	> Average	> Average
2001	Jagalene	Yes	0.774	> Average	< Average	< Average
2003	Overley	Yes	0.893	> Average	~ Average	< Average
2003	TAM 111	Yes	0.909	< Average	> Average	> Average
2003	Fannin	Yes	0.910	< Average	< Average	< Average
2003	Santa Fe	Yes	0.933	> Average	~ Average	~ Average
2004	TAM 112	Yes	0.863	> Average	> Average	> Average
2004	Deliver	No	0.892	< Average	< Average	< Average
2004	Endurance	Yes	0.920	> Average	> Average	> Average
2006	Fuller	Yes	0.907	> Average	> Average	> Average
2006	Armour	Yes	0.907	< Average	> Average	> Average
2006	Postrock	Yes	0.956	~ Average	< Average	< Average
2006	Duster	Yes	0.882	> Average	> Average	> Average
2008	Jackpot	Yes	0.912	> Average	> Average	> Average
2008	TAM 401	No	0.936	< Average	< Average	~ Average

Tall and awnless Cultivars

Two sets of agronomic types responded poorly in stability and yield potential compared to the average of all cultivars. Awnless cultivars, Weather Master 135, Longhorn, Deliver, and TAM 401 yielded average or less than average in all yield input levels (Figure 6, Table 4). This is likely due to the trend that hard red winter awnless cultivars are bred with an emphasis for their ability to be used as forage-only cultivars. Tall cultivars, Kharkof and Triumph 64, yielded poorer than average at all input levels (Figure 7, Table 4). This is due to recent breeding efforts to develop semi-dwarf cultivars with greater harvest index and higher yield potential.

Since these agronomic types displayed lower yield potential, it was hypothesized that they would affect the regression analysis demonstrating overall genetic gain. The exclusion of awnless cultivars from the regression analysis did not significantly alter the results (data not shown). Conversely, tall cultivars did impact the overall yield gain, thus separate analyses were conducted where tall cultivars were included and excluded for overall rate of genetic gain.

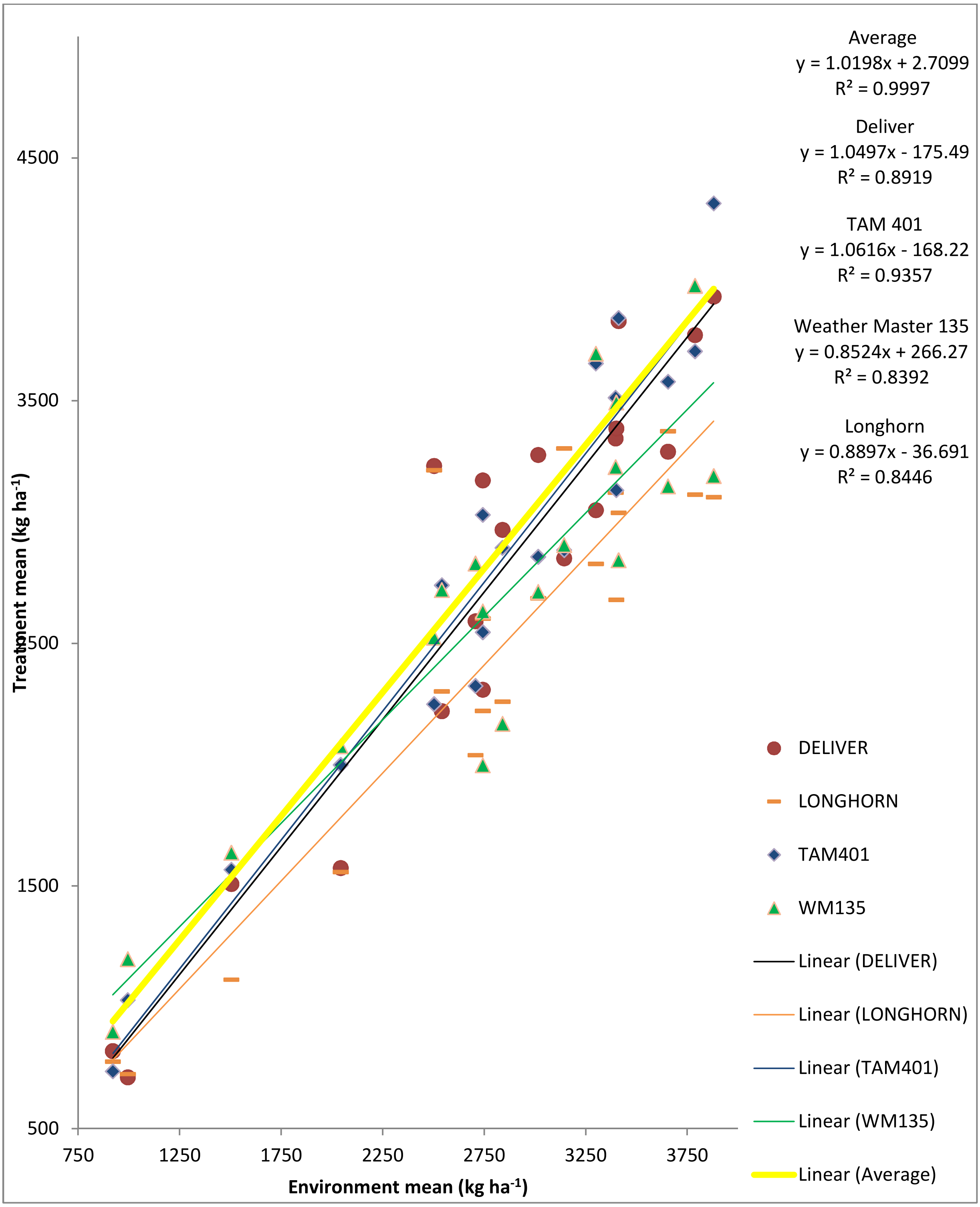

Figure 7: Stability slopes of awnless cultivars Deliver, TAM 401, Weather Master 135, and Longhorn plotted alongside average slope for all semi-dwarf cultivars.

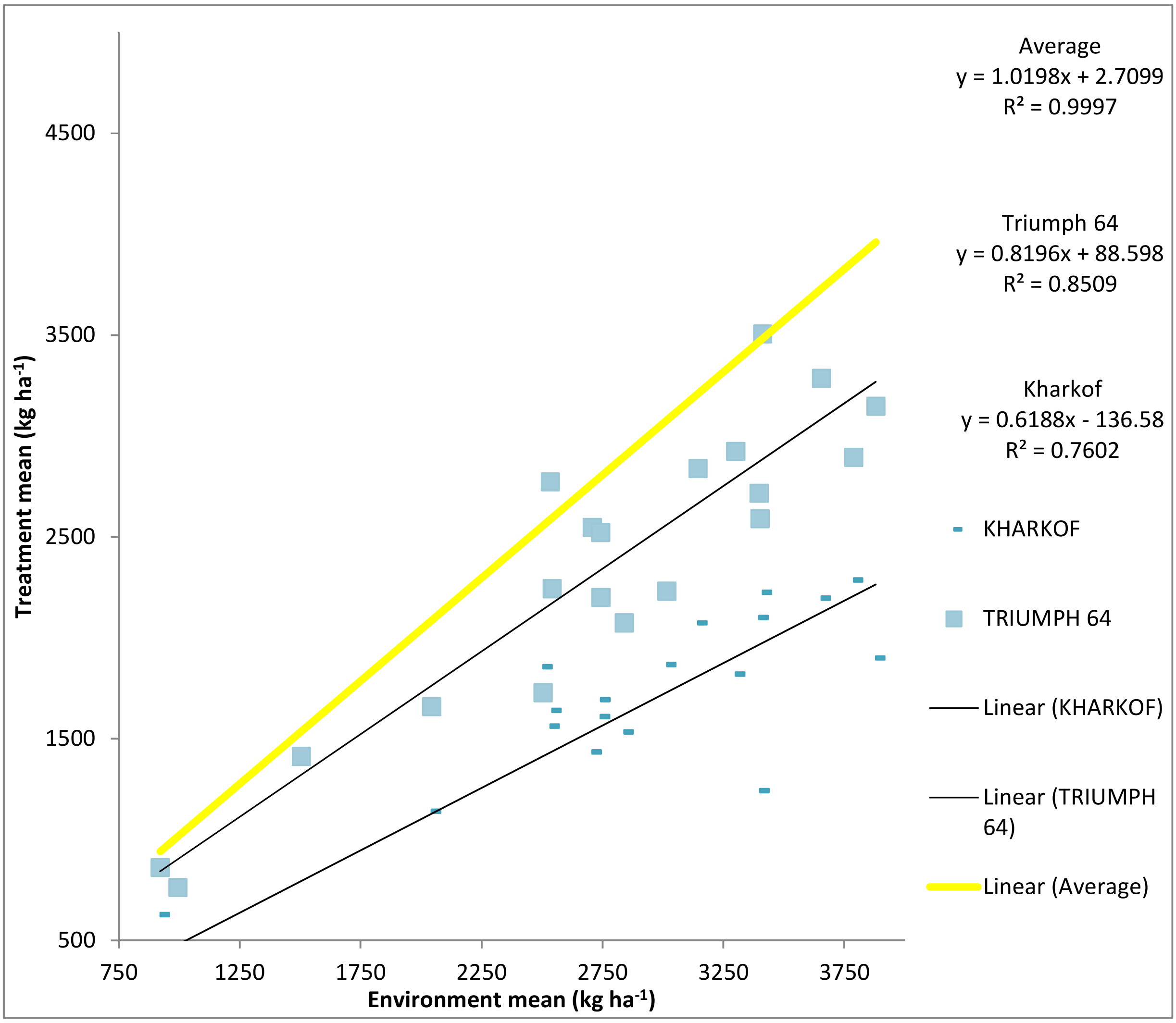

Figure 8: Stability slopes of tall cultivars Triumph 64 and Kharkof plotted alongside average slope for all semi-dwarf cultivars.

Genetic Yield Potential

Genetic yield potential gains were determined by linear regression of yield, expressed in kg ha^{-1}, by year of cultivar release. The slope of the regression indicated the increase in yield per year (kg ha^{-1} yr^{-1}). When all cultivars were pooled over all locations, fungicide treatment was significant, thus genetic yield potential was determined both with and without fungicide treatment.

Regression of all cultivars without fungicide resulted in a genetic yield gain of 13.68 kg ha^{-1} $year^{-1}$ or 0.93% of the mean of Kharkof per year (Figure 9). This yield gain equates to an increase in 1218 kg ha^{-1} (18.14 bu ac^{-1}) over 89 years. Regression of all cultivars with fungicide treatment resulted in a genetic yield gain of 15.63 kg ha^{-1} $year^{-1}$ or 0.94% of Kharkof mean yield per year (Figure 10). This gain is equivalent to 1390 kg ha^{-1} (20.69 bu ac^{-1}) over 89 years.

Since tall cultivars yielded significantly less than semi-dwarf cultivars, and since our objective was to determine the genetic gain in the semi-dwarf era, analyses were conducted for genetic gain excluding tall varieties. When genetic gain was narrowed to only semi-dwarf cultivars, or modern breeding efforts, yield gain was reduced to 11.65 kg ha^{-1} $year^{-1}$ or 0.46% of TAM 101 yield per year (Figure 11). The yield gain represented an improvement of 431 kg ha^{-1} (6.42 bu ac^{-1}) in the past 37 years. Finally, if the semi-dwarf genetic yield potential is partitioned into fungicide treatment only, genetic yield gain was 10.51 kg ha^{-1} $year^{-1}$ or 0.37% per year of TAM 101 yield (Figure 12). This resulted in a gain of 389 kg ha^{-1} (5.79 bu ac^{-1}) over 37 years. All slopes were significantly different from 0 ($p < 0.0001$).

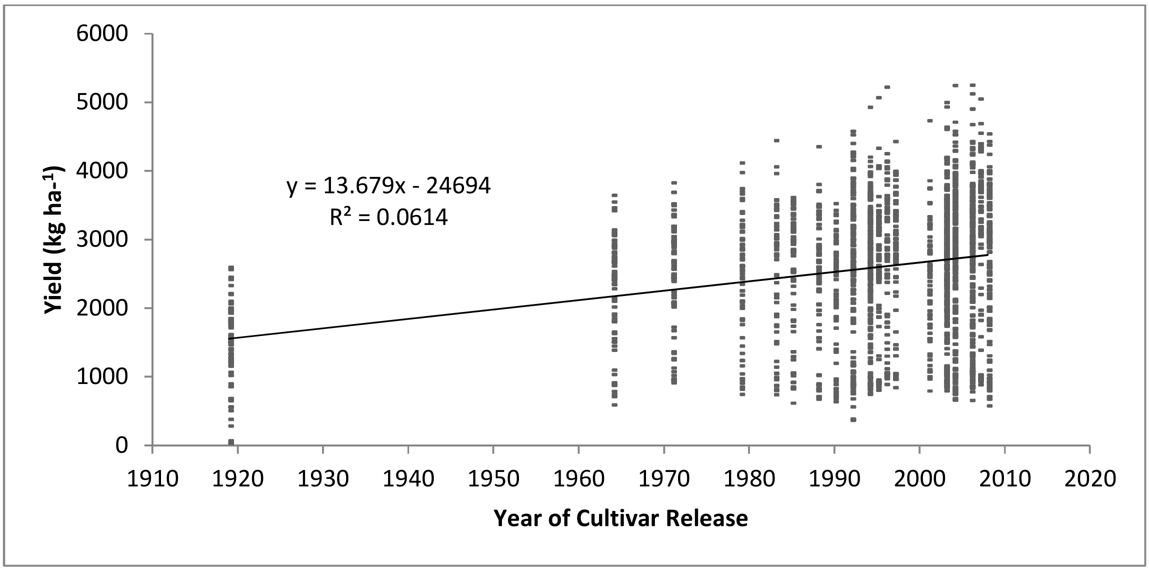

Figure 9: Regression of yield of all cultivars by year of release.

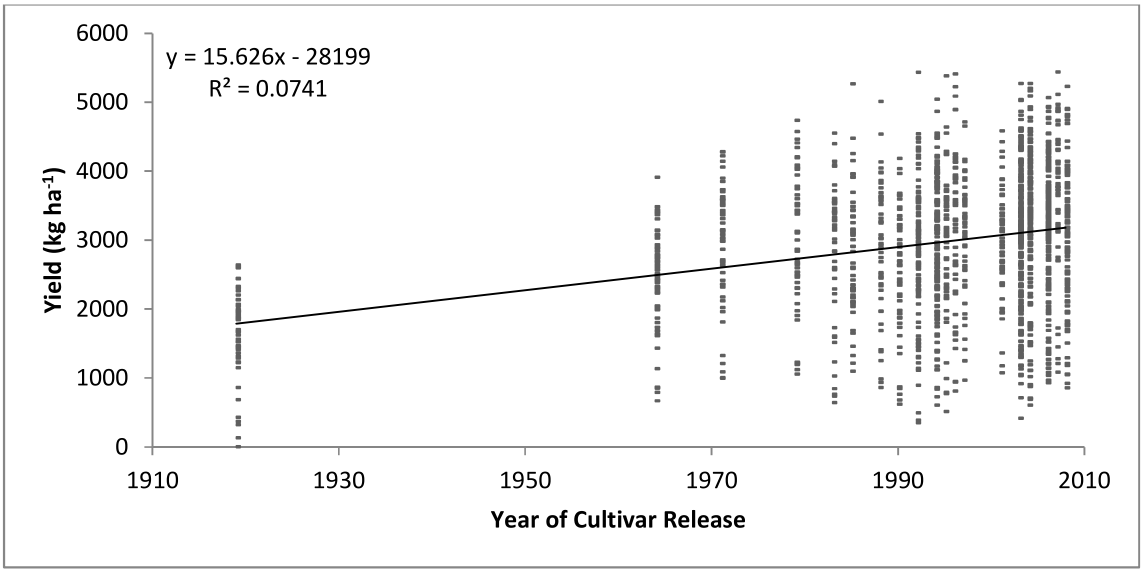

Figure 10: Regression of yield of cultivars with fungicide treatment by year of release.

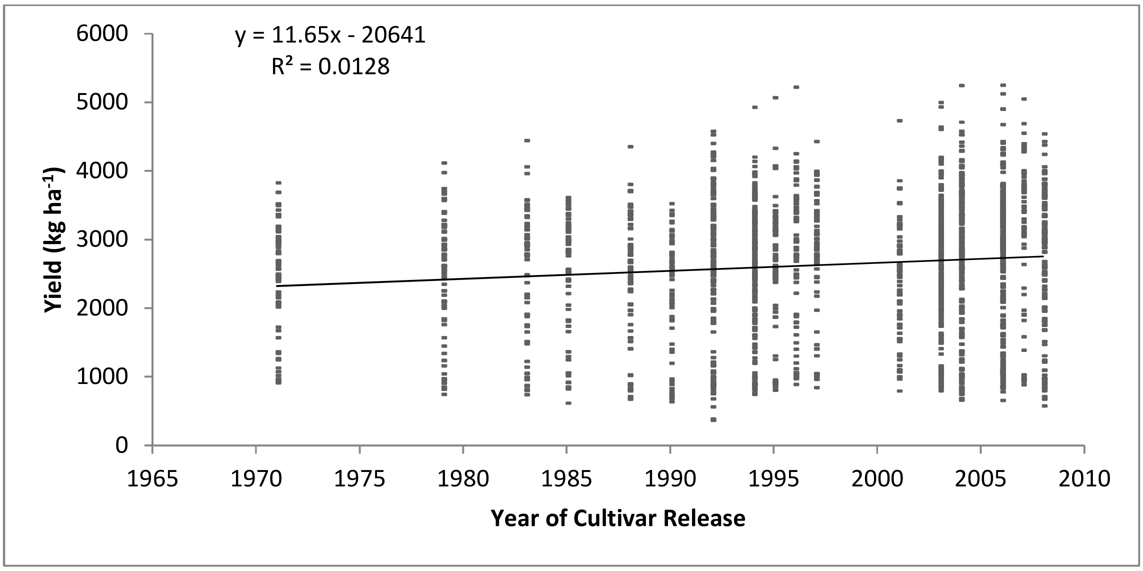

Figure 11: Regression of yield of all semi-dwarf cultivars by year of release.

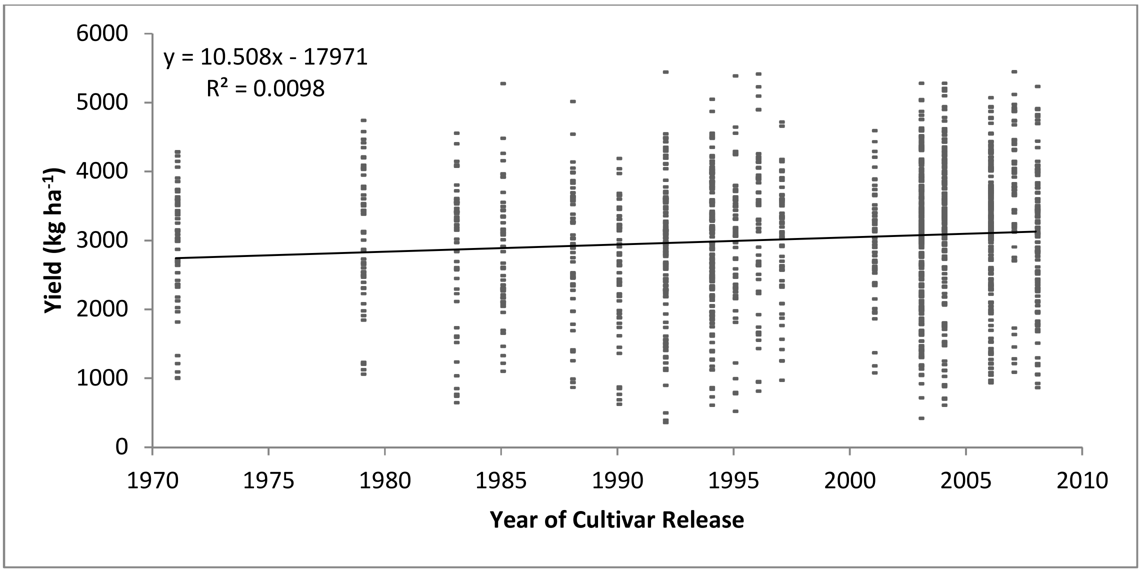

Figure 12: Regression of yield of semi-dwarf cultivars with fungicide treatment by year of release.

A linear-plateau model was evaluated to determine if there were 2 separate responses of yield and year, but no convergence criterion were met. This indicates that a single, linear relationship existed from 1919 to present and 1971 to present in both with and without fungicide treatment trials. This also suggests that genetic yield increases were consistent in a linear fashion over this time period, and that sub-set or separate relationships could not be identified.

Genetic gain in wheat over time is traditionally shown as a linear graph, indicating a gradual increase in yield over years. However, genetic yield increases do not occur with the release of each new cultivar. Traditionally, breeders speculate that yield increases are accumulated in a stair-step manner when a superior cultivar is released, resulting in a sizable yield gain. This event is then followed by the release of several cultivars with more or less equal yield potential over a period of several years. Eventually, another superior cultivar is released giving another jump in yield potential. This process is repeated over time with new superior yield boosting cultivars and several within the same yield potential.

The stair-step process seems to have occurred in this region, as can been seen by viewing mean cultivar yields plotted by year of release (Figure 13). Very small, if any, yield gains (7 kg ha yr^{-1}) were made from the introduction of the semi-dwarf cultivars until the introduction of TAM 110 in 1996 (Figure 14). TAM 110 appears to have been followed in similar yield potential by Overley, Santa Fe, Fuller, and Jackpot. After TAM 110, there appears to be another yield jump in 2004 with the release of Endurance and TAM 112, followed by Armour. Beyond this point Duster appears to have given another large yield gain. Currently, no statistical analyses have been found to validate the statistical accuracy of this stair-step trend.

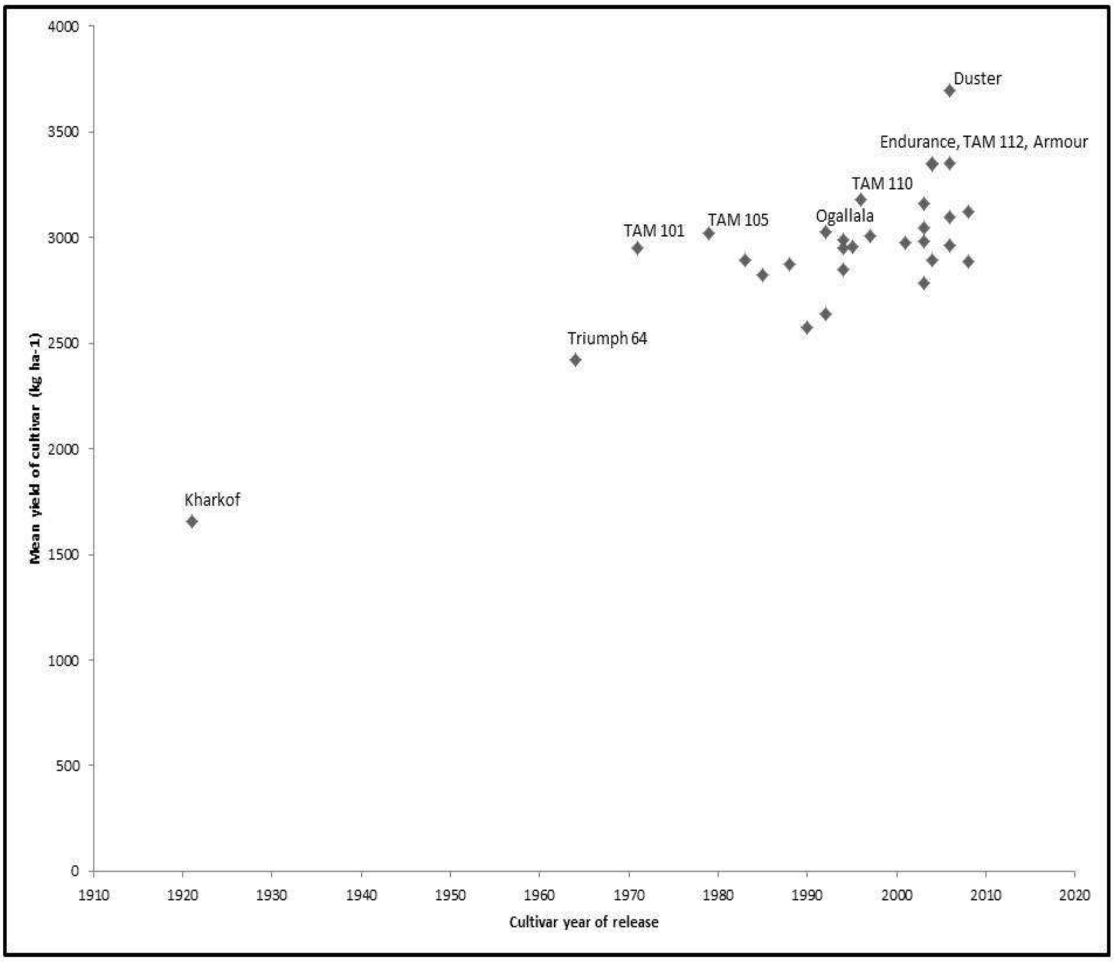

Figure 13: Mean yields of all cultivars with fungicide treatment plotted by year of release.

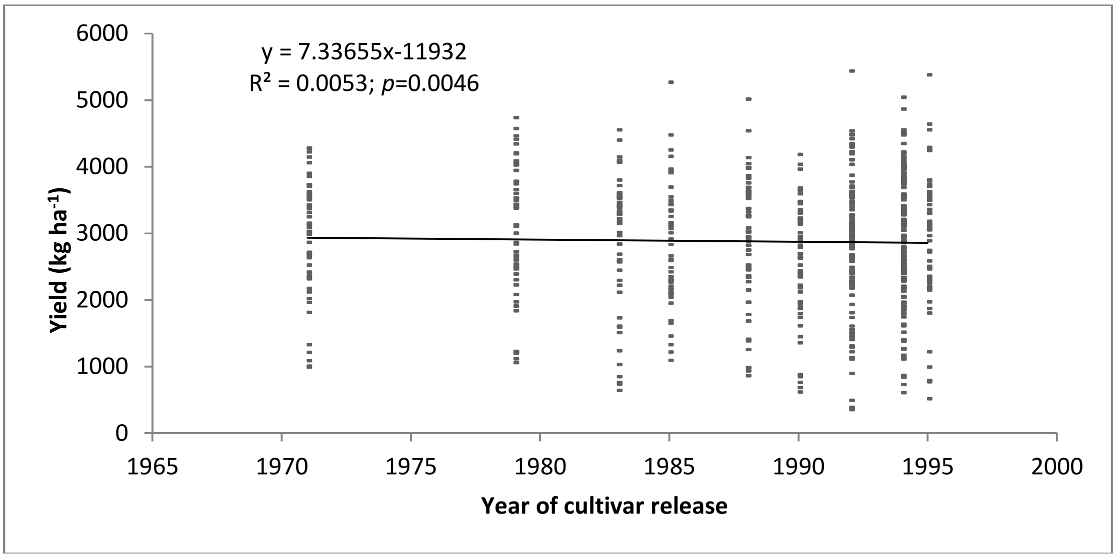

Figure 14: Regression of yield of cultivars released between 1971 and 1995.

CHAPTER VI

CONCLUSIONS

Large variations in yield were found from year-to-year for some sites and within individual years between sites. These variations were due primarily to differences in soil types, amount of available water, disease conditions, and management practices between sites, and available water between years, even in some irrigated sites. In both years, however, Kharkof was the significantly lowest yielding cultivar, and Duster was the significantly highest yielding cultivar. These data show that significant yield gains have been made from the earliest cultivars to modern cultivars under all input levels.

Almost all cultivars responded with significant yield gains when fungicide was applied. However, pooled cultivar means at certain locations did not respond in the same manner to fungicide treatment. Most mean yields of all cultivars at individual locations did not show significant increases from fungicide treatment; whole mean yields of all cultivars for whole locations only showed significant fungicide differences under heavy leaf or stripe rust pressure. Individual cultivars, however, responded to fungicide treatment with increased yield even when there was a lack of severe leaf or stripe rust. Thus, yield gains identified by adding fungicide must be considered for farmer use on an individual cultivar basis and economic threshold. However, for high yields, fungicide treatment may be beneficial even with the absence of obvious disease pressure according to our findings.

Awnless cultivars consistently performed poorer than their counterparts with awns. Also, if awnless cultivars are analyzed separately for genetic yield increase over time, the rate of genetic gain is significant, but significantly lower than that of the awned semi-dwarf cultivars. This increase in performance from awnless to awned cultivars may be due to physiologic alterations in photosynthesis performed during maturation; however, in other regions and marketing classes of wheat, awnless cultivars are preferred. Thus, the yield performance difference is more likely due to breeding resources not being delegated to improving awnless cultivars. This is an effective choice, though, since local producers do not have a preferential interest in using these varieties unless they are completely grazed by cattle.

Genetic yield potential has significantly increased since the initiation of breeding in the Great Plains. The increase in genetic yield potential from Kharkof to present is an increase of approximately 1% of Kharkof yield per year, which is the statistic that breeders commonly quote as the average genetic progress obtained from breeding in this region. However, a significant yield jump and large change in time from the tall varieties to semi-dwarf varieties presents a distinct new breeding era. Therefore, genetic advances in yield should be presented from the semi-dwarf era to present, and not from the introduction of tall varieties.

From the earliest semi-dwarf cultivars, yield gains amounted to 11.16 kg ha^{-1} yr^{-1} or 431 kg ha^{-1} (6.42 bu ac^{-1}) over the course of 37 years. Since these gains are from TAM 101 forward, yield gains are expressed in percent yield of TAM 101 per year, not Kharkof. Thus, the genetic yield gains annually occurring in Great Plains semi-dwarf cultivars amounts to 0.46% per year, which is significantly lower than that found among all cultivars including tall cultivars. This significant change in genetic gain per year excludes the significant increase in yield that was achieved with the introduction of the semi-dwarf cultivars. Also, these yield gains do not compare to those found in corn or some other crops, most likely because of strict quality standards, and adaptation to adverse environmental conditions that need to be maintained, probably at the expense of yield gains.

Wheat breeders have put large emphasis into making yield gains through breeding for genetic disease resistance, which has historically been an ongoing process of booms and busts with race specificity. Fungicide was applied in a split-block design to test for yield gains made due to genetic factors other than disease resistance. When genetic yield potential was determined for semi-dwarf cultivars with fungicide treatment, genetic yield gain dropped to 10.51 kg ha^{-1} yr^{-1} or 389 kg ha^{-1} (5.79 bu ac^{-1}) over the last 37 years, or 0.37% annual genetic gain as a function of TAM 101. This rate of gain more accurately represents the pure yield gains made in wheat without the influence of defensive breeding, or breeding for genetic disease resistance.

Although wheat breeding trends may significantly fit patterns of linear increase, they may not fit this trend in actuality. New cultivars are not released each year which yield 10.51 kg ha^{-1} greater than the cultivar from the previous year. Evidence of stair-step increasing trends, or higher yielding cultivars followed by similar yielding cultivars eventually replaced by a new higher yielding cultivar, can be seen in the results of this study. There are significant yield advances from Kharkof to Triumph 64, then from Triumph 64 to TAM 101, or from selections of introduced land races to the initiation of breeding, then from tall cultivars to semi-dwarf cultivars. From the introduction of the semi-dwarf cultivars, however, there appears to be no definite yield gains made in the 1970s through the early 1990s. In 1996 there is a small jump in genetic yield potential with the release of TAM 110, and subsequently released cultivars Overley, Santa Fe, Fuller, and Jackpot had similar yield potential. From that point, another yield jump occurred in 2004 with Endurance and TAM 112, followed by similarly yielding Armour. Another yield jump seems to have emerged in 2006 with Duster. If these step-wise yield gains continue to occur as often as in the past two decades, the rate of linear genetic yield increase may rise, and more statistical relevance may be given to the stair-step model of genetic yield increase.

In order for wheat breeding progress to continue at a higher rate, yield increases must be the primary focus of breeding programs. Traditionally, breeding for quality and marketability, disease resistance, and adaptation have taken large amounts of breeding time. According to the stability analyses, gains are being made in breeding for broad adaptation. Wheat breeding strategies relating to disease resistance are beginning to change, also. Some breeders are deploying strategies of horizontal or non-race specific resistance to various pathogens, in which several genes for resistance are stacked for longer-term, more durable resistance. Once these non-race specific genes are successfully transferred into adapted germplasm, the development of cultivars with durable resistance will be easier and will allow more time for the breeders to focus on pure yield gains. Also, private companies will likely have GMO wheat available in the next decade or two, which will allow for many new genetic avenues of lowering production costs, reducing yield limiting factors, and increasing genetic yield potential for wheat.

REFERENCES

Austin, R. B., M. A. Ford, and C. L. Morgan. 1989. Genetic improvement in the yield of winter wheat: A further evaluation. J. Agric. Sci. 112:295-301.

Berzonsky, W. A. and H. N. Lafever. 1993. Progress in Ohio soft red winter wheat breeding: Grain yield and agronomic traits of cultivars released from 1871 to 1987. Crop Sci. 33:1382-1386.

Brancourt-Hulmel, M., G. Doussinault, C. Lecomte, P. Berard, B. Le Buanec, and M. Trottet. 2003. Genetic improvement of agronomic traits of winter wheat cultivars released in France from 1946 to 1992. Crop Sci. 43:37-45.

Calderini, D. F., and G. A. Slafer. 1998. Changes in yield and yield stability in wheat during the 20th century. Field Crops Res. 57:335-347.

Cox, T. S., J. P. Shroyer, L. Ben-Hui, R. G. Sears, and T. J. Martin. 1988. Genetic improvement in agronomic traits of hard red winter wheat cultivars from 1919 to 1987. Crop Sci. 28:756-760.

Donmez, E., R. G. Sears, J. P. Shroyer, and G. M. Paulsen. 2001. Genetic gain in yield attributes of winter wheat in the Great Plains. Crop Sci. 41:1412-1419.

Edwards, J. E., R. D. Kochenower, R. E. Austin, J. D. Ladd, B. F. Carver, R. M. Hunger, J. D. Butchee, and C. J. Andrews. 2010. Oklahoma small grains variety performance tests. Okla. Coop. Ext. Serv.: CR-2141 and CR-2143.

Fischer, R. A. and G. O. Edmeades. 2010. Breeding and cereal yield progress. Crop Sci. 50:S-85-S-98.

Graybosch, R. A., and C. J. Peterson. 2010. Genetic improvement in winter wheat yields in the Great Plains of North America, 1959-2008. Crop Sci. 50:1882-1890.

Khalil, I. H., B. F. Carver, E. G. Krenzer, C. T. MacKown, and G. W. Horn, 2002. Genetic trends in winter wheat yield and test weight under dual-purpose and grain-only management systems. Crop Sci. 42:710-715.

Lamb, C. A. 1937. The relation of awns to the productivity of Ohio wheats. J. of the Amer. Soc. of Agron. 29:339-344.

Li, X., H. Wang, H. Li, L. Zhang, N. Teng, Q. Lin, J. Wang, T. Kuang, Z. Li, B. Li, A. Zhang, and J. Lin. 2006. Awns play a dominant role in carbohydrate production during the grain-filling stages in wheat (*Triticum aestivum*). Physiologia Plantarum. 127:701-709.

Martin, J. N., B. F. Carver, R. M. Hunger, T. S. Cox. 2003. Contribution to leaf rust resistance and awns to agronomic and grain quality performance in winter wheat. Crop Sci. 43:1712-1717.

Morgounov, A., V. Zykin, I. Belan, L. Roseeva, Y. Zelenskiy, H. F. Gomez-Becerra, H. Budak, and F. Bekes. 2010. Genetic gains for grain yield in high latitude spring wheat grown in Western Siberia in 1900-2008. Field Crops Res. 117:101-112.

Pfeiffer, W. H. and H. J. Braun. 1989. Yield stability in bread wheat. In: Anderson, J.R. and P.B.R. Hazell. Variability in Grain Yields. John Hopkins University Press. 157 - 174.

Rudd, J. C. 2009. Success in wheat improvement. In Wheat: Science and Trade (ed.) B. F. Carver. 387-395. Wiley-Blackwell: Ames, Iowa.

SAS Institute. 2003. 9.1 Foundation for 64-bit Microsoft® Windows®, Copyright © 2003. SAS Inst., Cary, NC.

Sayre, K. D., S. Rajaram, and R. A. Fischer. 1997. Yield potential progress in short bread wheats in Northwest Mexico. Crop Sci. 37:36-42.

Schmidt, J. W. 1984. Genetic contributions to yield gains in wheat. p. 89-101. *In* W. R. Fehr (ed.) Genetic contributions to yield gains of five major crop plants. ASA and CSSA Spec. Pub. 7, Madison, WI.

Schmidt, J. W. and W. D. Worrall. 1983. Trends in yield improvement through genetic gains. Proc 6th International Wheat Genetics Symposium, Kyoto, Japan. 691-700.

Sener, O., M. Arslan, Y. Soysal, and Erayman. 2009. Estimates of relative yield potential and genetic improvement of wheat cultivars in the Mediterranean region. Journal of Ag. Sci. 147:323-332.

Sleper, D. A. and J. M. Poehlman. 2006. Breeding field crops. 5th Ed. Blackwell Publishing: Ames, Iowa.

Zhou, Y., Z. H. He, X. X. Sui, X. C. Xia, X. K. Zhang, and G. S. Zhang. 2007. Genetic improvement of grain yield and associated traits in the northern China winter wheat region from 1960 to 2000. Crop Sci. 47:245-253.

VITA

Sarah Battenfield

Candidate for the Degree of

Master of Science

Thesis: IMPROVEMENT IN GENETIC YIELD POTENTIAL OF SEMI-DWARF WHEAT IN THE GREAT PLAINS OF THE USA

Major Field: Plant and Soil Sciences

Biographical:

Education:

Completed the requirements for the Master of Science Plant and Soil Sciences at Oklahoma State University, Stillwater, Oklahoma in December, 2011.

Completed the requirements for the Bachelor of Science in Human Development and Family Science at Oklahoma State University, Stillwater, Oklahoma in 2009.

Experience:

Graduate Research Assistant July 2009 – present
Dr. Art Klatt, OSU Wheat Improvement Team

- Conducted genetic improvement field trial over 2 years in 11 locations to assess genetic gain in yield over 37 year period
- Assessed wheat plants for genetic resistance to pathogens and agronomic type
- Assisted with all wheat breeding projects, including greenhouse management, emasculation and pollination, field trials, and field selection

Professional Memberships: American Society of Agronomy

ADVISER'S APPROVAL: Dr. Art Klatt

Name: Sarah D. Battenfield Date of Degree: December, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: IMPROVEMENT IN GENETIC YIELD POTENTIAL OF SEMI-DWARF WHEAT IN THE GREAT PLAINS OF THE USA

Pages in Study: 48 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Sciences

Scope and Method of Study:

Recently, private companies and public entities have made significant investments in and improvements to their wheat (*Triticum aestivum* L.) breeding programs. Because of this increased interest, recent genetic improvements made in wheat through traditional plant breeding need to be analyzed. Many studies have noted the significant yield improvement from tall cultivars to semi-dwarf cultivars, but no studies have documented improvements made from the earliest semi-dwarfs to present-day cultivars. Thirty cultivars were tested including 2 tall varieties (Kharkof, 1921 and Triumph 64, 1964), and 28 semi-dwarf cultivars spanning the period from 1971 (TAM 101) to 2008 (Jackpot and TAM 401). Cultivars were tested in 2010 and 2011 at eleven locations across Oklahoma, Kansas, and Texas with adequate disease protection and fertilizer. Experimental design was a split-plot design with fungicide treatment as the main plot and cultivar as the sub-plot with three replications per location. Yields for cultivars protected by fungicide treatment were higher than those without fungicide at most locations.

Findings and Conclusions:

A significant yield increase of 13.68 kg ha^{-1} yr^{-1} or 0.93% per year of Kharkof yield was obtained across all locations with the tall cultivars included. When gain was restricted to only semi-dwarf cultivars (1971 to 2008), yield gain was reduced to 11.65 kg ha^{-1} yr^{-1} or 0.46% per year of TAM 101 yield. Yield gain among semi-dwarf cultivars in locations with significant fungicide effect was only 10.51 kg ha^{-1} yr^{-1} or 0.37% per year of TAM 101 yield, which more accurately represents gain in genetic yield potential made excluding defensive breeding efforts. No evidence of a yield plateau was found.

ADVISER’S APPROVAL: Dr. Art Klatt