ABSTRACT

NELSON, PAUL THOMAS. Evaluation of elite exotic maize inbreds for use in long-term temperate breeding. (Under the direction of Major M. Goodman.)

The U.S. maize (*Zea mays L.*) germplasm base is narrow. While maize is a very diverse species, that diversity is not represented in U.S. maize production acreage. Most elite U.S. maize inbreds can be traced back to a small pool of inbreds that were developed decades ago. Increased genetic diversity can be obtained through breeding with exotic germplasm, especially tropical-exotic sources. However, setbacks are often encountered when working with tropical germplasm due to adaptation barriers. Furthermore, the pool of available tropical germplasm is large and diverse, making choices of tropical parents difficult. The maize breeding program at North Carolina State University has begun a large-scale screening effort to evaluate elite exotic maize inbreds, most of which are tropical-exotic in origin. The purpose of this research was to: 1) generate comparative yield-trial data for over 100 elite exotic maize inbreds, 2) determine the relative effectiveness of various testcross regimes, 3) identify sources of gray leaf spot (GLS) resistance among these elite exotic inbreds, and 4) promote the use of exotic maize germplasm to broaden the genetic base of U.S. maize.

Over 100 elite exotic maize inbreds were obtained from various international breeding programs. They were tested in replicated yield trials in North Carolina as 50%-exotic testcrosses by crossing them to a broad-base U.S. tester of Stiff Stalk (SS) × non-Stiff Stalk (NSS) origin. The more promising lines additionally entered 25%-tropical testcrosses with SS and NSS testers and were further evaluated in yield-trials. A dozen tropical inbred lines performed well overall—CML10, CML108, CML157Q, CML258, CML264, CML274, CML277, CML341, CML343, CML373, Tzi8, and Tzi9. Inbred lines CML157Q, CML343, CML373, and Tzi9 did not show significant line × tester interaction. Furthermore, it was determined that testcrossing to a single broad-based tester will suffice for initial screening purposes, allowing for elimination of the poorest performing lines. Testcrossing to additional SS and NSS testers may be of value when determining where the better performing materials will fit into a breeding program. It was further determined that most tropical lines can effectively be evaluated at the 50%-tropical level because many of the problems typically

associated unadapted tropical material were minimized through a single testcross to an adapted tester.

Each of the exotic lines was screened for GLS resistance either as inbreds per se, as testcrosses, or both. Many of the inbreds showed high levels of GLS resistance, including several lines that have good yield potential. These lines include CML108, CML258, CML274, CML277, CML343, and Tzi16.

The results presented in this thesis provide temperate breeders with information on a sizable pool of potentially useful exotic maize inbred lines. These lines certainly deserve further attention in breeding efforts to broaden the U.S. maize germplasm base. Many are already being used at North Carolina State University in both exotic × temperate and exotic × exotic breeding crosses and populations.

EVALUATION OF ELITE EXOTIC MAIZE INBREDS FOR USE IN LONG-TERM TEMPERATE BREEDING

by

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BIOGRAPHY

Paul Thomas Nelson is the sixth of nine children born to Thomas K. and Susan O. Nelson. He was born on the 26th of May, 1980, in Manhattan, Kansas where he spent the first 17 years of his life. At an early age he came to appreciate rural Kansas life, spending countless hours in the large family garden or mowing hay in the family's 30 acre pasture. At the beginning of his senior year his family moved to Utah, where he finished high school. In the fall of 1998 Paul's post high school education began at Ricks College in Rexburg, Idaho where he enrolled in the Department of Agronomy. After completing one year at Ricks College, Paul put his academic ambitions on hold for two years to serve full-time as a missionary for the Church of Jesus Christ of Latter-Day Saints. He was assigned to serve in Phnom Penh, Cambodia, where he learned the language and customs of the Cambodian people while delivering the message of the restored gospel of Jesus Christ. Upon returning home in 2001, he resumed his education at Rexburg, Idaho where Ricks College had now become Brigham Young University-Idaho. There he completed his Associates Degree in Agronomy and graduated in the spring of 2002. That same year, before transferring to Brigham Young University in Provo, Utah, Paul embarked on an 8-month internship in Waterloo, Iowa, where he worked at a soybean research station for Pioneer Hi-Bred International, Inc. This internship introduced Paul to applied research in plant breeding. He enjoyed the experience so much that he did another internship for Pioneer the following summer at a corn research station in Ithaca, Michigan.

Paul finished his undergraduate work at BYU-Provo and graduated in April of 2004. While doing his undergraduate work he enjoyed working in a plant genetics lab under the direction of Drs. Rick Jellen and Jeff Maughan. Under their supervision he engaged in DNA-marker work on quinoa (*Chenopodium quinoa*).

During his senior year at BYU, Paul met Lisa Marie Ewert, an attractive young nurse from California who was not only stunningly beautiful but gainfully employed as an RN. The two courted and were married in June of 2004. Immediately following their marriage Paul and Lisa moving to Raleigh, North Carolina, where Paul began his graduate career in

the NCSU corn breeding program under the mentorship of Dr. Major M. Goodman. While in North Carolina, Paul and Lisa expanded their family by one. Only hours after this thesis was submitted to Paul's committee for review, Lisa gave birth to their first child, Samuel Thomas Nelson.

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My graduate education was funded through a fellowship from Pioneer Hi-Bred International, Inc. and by the Initiative for Future Agriculture and Food Systems Grant no. 2001-52101-11507 from the USDA Cooperative State Research, Education, and Extension Service. The contribution of these institutions to my research and education is greatly appreciated.

As a member of the NCSU corn breeding program, my research would not have been possible without the assistance of outstanding technicians and fellow graduate students. Bill Hill's behind-the-scene management of field operations and data management has been invaluable to my project. Wayne Dillard has contributed countless man-hours to my project, spending nights and even weekends on the road planting and harvesting thesis experiments.

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I owe sincere gratitude to Mike Jines, my fellow graduate student in the NCSU corn breeding program. Mike has helped me transition into the life of a graduate student and corn breeder. On my first day in the program, he explained to me the difference between a Stiff Stalk and a Lancaster line. He helped me write my first SAS program, gave me advice about which classes to take (and which classes not to take) and showed me the "special places" to find seed when all other sources failed. Mike has had an exemplary influence on my education with his enthusiasm for statistical inference and breeding methods. Undoubtedly, I will be rubbing shoulders with Mike for the rest of my career, an association that I look forward to.

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– CHAPTER I –

Literature Review

Origin of Maize

The origin of maize, both ancestral and geographic, has been a topic of disagreement within the maize community for many years (Doebley, 2004; Iltis, 2000; Wilkes, 2004). This is partially because, unlike most cultivated crops, there is no "wild" maize. There is general agreement that teosinte, of the genus *Zea*, and the closest known relative to maize, played some role in maize evolution, though there are still varying opinions on what that role was (Doebley, 1990; Galinat, 1988; Goodman, 1988; Iltis, 2000; Wilkes, 2004). However, today the "teosinte hypothesis," which claims that maize was domesticated from the Mexican annual teosinte, *Z. mays* ssp. *Parviglumis* and that the origin of domestication is near the Balsis River drainage in Mexico (Doebley, 2004; Matsuoka, 2005; Vigouroux et al., 2005) is widely accepted. There is general consensus in the literature that maize was domesticated between 7,000 and 10,000 years ago (Doebley, 2004; Galinat, 1988; Goodman, 1988; Wilkes, 2004).

Ancestral Origin

Goodman (1988) summarized three predominant hypotheses on the evolution of teosinte and maize:

1) Teosinte and maize diverged from a hypothetical unknown common ancestor or "wild maize".
2) Maize was domesticated from teosinte, i.e. teosinte is "wild maize". Also known as the teosinte hypothesis.
3) Annual teosinte is descendant from a maize × perennial teosinte cross.

Wilkes (2004) outlines three similar theories. Iltis (2000) provides a history of the various theories on the origin of maize and of the controversy surrounding them.

With the advent of isozyme and DNA marker technology in the 1980's much of the controversy surrounding the origin of maize was put to rest. Doebley led the way with isozyme data by which he began to establish the teosinte hypothesis as the dominant

explanation for the origin of maize (Doebley, 1990; Doebley et al., 1987). Specifically, this theory is that maize was derived through a single domestication event of the Mexican annual teosinte, Z. *mays* ssp. *parviglumis* (Doebley, 2004; Matsuoka et al., 2002). This theory has become accepted in the literature as the dogma of maize evolution (Doebley, 2004; Matsuoka, 2005; Vigouroux et al., 2005). Today, much of the genetic work in maize evolution is aimed at identifying single genes and gene families that explain the morphological differences between teosinte and maize (Clark et al., 2004; Doebley and Stec, 1993; Doebley, 2004 ; Dorweiler et al., 1993; Dorweiler and Doebley, 1997; Wang et al., 2005; White and Doebley, 1999). However, as Wilkes points out (Wilkes, 2004), a few researchers are reluctant to fully adopt the teosinte hypothesis (Eubanks, 1995, 2001a, 2001b, 2001c; Goodman, 1965; Goodman, 1976; Goodman, 1988; Wilkes and Goodman, 1995; Bird, personal communication; Goodman, personal communication). The archeological evidence does not support the teosinte hypothesis as well as the molecular evidence. For example, maize cobs dating to ≈ 6000 B.P. do not show the morphological characteristics expected from a teosinte derivative (Brown, 1978; Wilkes, 2004). However, cobs dating to ≈ 3000 B.P. show greater resemblance to teosinte which may suggest a post-domestication introgression of teosinte into maize (Wilkes, 2004).

Temporal and Geographic Origin

There is general consensus in the literature that maize was domesticated between 7,000 and 10,000 years ago (Doebley, 2004; Galinat, 1988; Goodman, 1988; Wilkes, 2004). However, the geographic origin of domestication, like the ancestral origin, is speculative. Mangelsdorf (1974) introduced the idea of maize lineages from six different geographical regions ranging from Mexico to South America. Many advocate a Mexican origin because teosinte, the closest relative to maize, is essentially restricted to Mexico (Galinat, 1988; Goodman, 1988; Wilkes, 2004). Supporters of the teosinte hypothesis accept the Balsas River drainage in southwestern Mexico as the cradle of maize domestication (Matsuoka, 2005). This is the location of the populations of teosinte ssp. *parviglumis* that most closely resemble maize in isozyme and microsatellite analyses (Doebley, 1990; Matsuoka et al., 2002). Thus, the Balsas River drainage is becoming more widely accepted in the literature as the geographic origin of domestication.

The dispute over the origin of maize is anything but settled, though the teosinte hypothesis currently reigns in popularity. Study of the origin of maize is interdisciplinary, including geographical, archeological, botanical, historical, and genetic evidences (Brown, 1978; Goodman, 1988; Wilkes, 2004). To exclude evidence from any one of these disciplines may limit one's ability to understand the origin of maize.

Races of Maize

There is great genetic diversity found within maize (Wright et al., 2005). In the past century there have been numerous monographs and surveys on the races of maize. Sturtevant (1899) divided maize varieties into six "species groups" based on kernel morphology. Anderson and Cutler (1942) recognized the artificial nature of these groupings and called for a more comprehensive study of the races of maize. Thereafter, the Rockefeller Foundation and the National Academy of Sciences published a series of monographs that identified over 300 races of maize in the Americas (Brieger et al., 1958; Brown, 1960; Grant et al., 1963; Grobman et al., 1961; Hatheway, 1957; Paterniani and Goodman, 1977; Ramirez et al., 1960; Roberts et al., 1957; Timothy et al., 1961, 1963; Wellhausen et al., 1952, 1957). Goodman and Bird (1977) and Goodman and Brown (1988) provide the most comprehensive summaries to date of the aforementioned monographs. A series of publications by Goodman, Stuber, and associates represent the most complete molecular surveys on the genetic diversity among the races of maize based on isozyme markers (Bretting et al., 1987, 1990; Goodman and Stuber, 1983; Goodman et al., 1980; Sanchez and Goodman, 1992a, 1992b; Sanchez et al., 2000a, 2000b, 2006).

Maize Diversity in the U.S.

The U.S. is the world leader in maize production (USDA, 2005a) with over 80 million acres of maize grown in 2005 (USDA, 2005b). However, very little of the diversity that is found among the races of maize is represented in U.S. production acreage. Goodman and Brown (1988) classified 10 broad racial complexes of maize that have, at some time, been used in the U.S. However, today U.S. maize production is composed of basically two races, the Northern Flints and Southern Dents. Corn Belt Dents, which are a product of

repeated hybridization of the Northern Flints and Southern Dents, are sometimes considered a third race (Brown, 1947).

Pre-hybrid Maize Diversity in the U.S.

Before the advent of hybrid maize, there were hundreds of open pollinated varieties of maize grown throughout the U.S. Pre-20th century farmers selected the best ears at harvest to use as seed the following season. Selection criteria varied among growers as did the niche environment in which selections were being made. This system of maize production and farmer-selection promoted diversity across the U.S. Corn Belt. This diversity probably peaked around 1900, the same time that corn shows were gaining popularity across the Corn Belt (Wallace and Bressman, 1937). The purpose of the corn shows was to recognize varieties that showed the greatest yield potential. Wallace and Bressman (1937) describe the ideal corn show ear as being "10 inches long, 7½ inches in circumference, with eighteen to twenty-two rows packed together on the cob and carried out over the tip and well-rounded butt" (p. 251). However, the corn shows were flawed because yield potential was judged by individual ear and kernel morphology, not agronomic yield. In fact, corn shows may have had an opposite affect on maize production than was originally intended. Often the prize-winning corn-show varieties did not yield as well as varieties that were judged inferior by corn-show standards (Wallace and Brown, 1988). Unfortunately, through the popularity of corn shows and prize-winning varieties, many growers abandoned their traditional varieties and adopted the sometimes inferior "prize corns".

In time, growers realized that the prize-winning varieties from the corn shows were not necessarily the highest yielding varieties (Wallace and Brown, 1988). By 1910, variety yield trials began replacing corn shows and a few noted varieties were gaining popularity throughout the Corn Belt, varieties such as Reid Yellow Dent, Krug, Lancaster, and Leaming (Goodman and Brown, 1988). These superior, higher yielding varieties, replaced many of the traditional varieties. Subsequently, much of the genetic diversity that had accumulated through centuries varietal differentiation across the Corn Belt was lost (Wallace and Brown, 1988).

It is interesting to note that U.S. maize yields reached a plateau around 1900 and subsequently began a downward trend during the first three decades of the 20th century.

Based on USDA data from 1866 – 2005 (USDA, 2006), maize yields in the U.S. were improving from 1866 – 1900 (Fig. 1.1). However, from 1900 – 1936 yields steadily decreased across the Corn Belt, a trend that was clearly established before the droughts of the early to mid 1930's. The exact cause of this trend is open to speculation. However, it is difficult to attribute a 30 year trend merely to weather conditions or "bad luck". Genetic variation for yield across the Corn Belt obviously was not exhausted as evidenced by the tremendous gains seen since the 1930's. However, genetic variation within open pollinated maize populations may have been limited, especially in light of the 20 year influence of the corn shows which promoted uniformity, the antithesis of the diversity that drives productivity in an open pollinated maize population. This, coupled with the superficial definition of yield that was praised by the corn shows, may have been a contributor to this temporary agronomic downslide in maize productivity.

The Advent of Hybrid Maize

Hybrid vigor in maize was first noted around the year 1871 by Charles Darwin who observed height differences between inbred parents and their cross-bred progeny (Darwin, 1877). W. J. Beal, a close follower of Darwin (Wallace and Brown, 1988), was intrigued by this finding and subsequently crossed two divergent dent corns, becoming the first individual to make controlled pollinations in maize with the expressed purpose of increasing yields through hybrid vigor (Beal, 1878). In 1908 George Harrison Shull noted the value of inbreeding in maize improvement, stating that "the object of the corn-breeder should not be to find the best pure-line, but to find and maintain the best hybrid combinations" through inbreeding (Shull, 1908). His "pure line" theory of maize breeding (Shull, 1909) was a highly significant contribution to maize improvement, although its agricultural significance was not immediately realized. Early inbreeding efforts with open pollinated maize varieties were plagued by severe inbreeding depression (Jones, 1918). This limited the practicality of hybrid maize production. Other maize scientists of the time were also actively inbreeding maize and observing the effects. E.M. East was one such prominent individual who was especially intrigued by Shull's work and had actually observed similar results in his own research (Crabb, 1947). One of East's students was D.F. Jones, another very influential individual in maize breeding in the 20th century.

It wasn't until D.F. Jones introduced the double cross in 1918 that large-scale hybrid maize production became possible (Jones, 1918). Some varieties survived the inbreeding process and others did not. A few outstanding varieties, including Reid Yellow Dent, Minnesota 13, Lancaster Sure Crop, and Leaming Corn, served as the genetic foundation for hybrid maize (Baker, 1984; Goodman and Brown, 1988). This had a bottlenecking effect on the genetic diversity of U.S. maize because many open pollinated varieties that did not survive inbreeding were left behind and lost forever.

Diversity within Modern U.S. Maize

In the period from 1956 to 1986, the American Seed Trade Association conducted six surveys on the breadth of the U.S. maize germplasm base (Darrah and Zuber, 1986; Sprague, 1971; Zuber, 1975; Zuber and Darrah, 1980). The most recent survey (Darrah and Zuber, 1986) found that 5 inbred lines, B73, A632, W117, Mo17, and CM174, were each used per se in more than 1% of the total U.S. seed requirement in 1984, the greatest being B73 which was used in 11% of the total U.S. seed requirement. Smith (1988) conducted an isozyme survey of the U.S. maize germplasm base. He concluded that inbred lines B73, A632, Oh43, and Mo17 were the major contributors to U.S. maize germplasm. Subsequent surveys of germplasm usage have been unsuccessful due to seed labels that prohibit genotyping and the increased reluctance of private companies to provide relevant information.

Baker (1984), of Pioneer Hi-Bred international, Inc., reported what he and Bill Ambrose (a long-time corn breeder at Pioneer Hi-Bred International, Inc.) believed to be the seven most widely used hybrid combinations in the U.S., they were:

1) B73 × Mo17
2) A632 × H99^{3}H95
3) Mo17 × A634
4) B73 × PA91
5) B73 × MS71
6) Mo17 × CM105
7) A632 × W117.

Baker also provides historical background on each of the lines involved in these hybrids. Goodman (Goodman, 1992) concluded that inbred lines B14A, B37, B68, B73, B84 (female

lines) and C103, Mo17, and Oh43 (male lines) have essentially served as the primary germplasm source for U.S. maize breeding programs for decades. Troyer (2004, 1999) provides background and historical information on the most prominent lines in use in the U.S.

Influential Central and Southern Corn Belt Inbred Lines

As noted, several inbred lines stand out in the literature as being highly influential in U.S. maize breeding and production. Brief histories of some of these lines are provided in the following:

B73

Inbred line B73 has been the most widely used inbred line in breeding and production since its release in 1972 (Baker, 1984; Darrah and Zuber, 1986). It was developed at Iowa State University out of cycle 5 of the Iowa Stiff Stalk Synthetic (Russell, 1972). It was actually discarded one year but was quickly retrieved after yield data were analyzed (Troyer, 1999). Despite problems with insect and disease susceptibility, it has excellent yield potential. It is most famous for its use in the very popular hybrid B73 × Mo17. Relative maturity of B73 hybrids ranges from 110 to 130 days (Baker, 1984).

B14/B14A

Inbred line B14 was developed at Iowa State University from the first cycle of recurrent selection of the Iowa Stiff Stalk Synthetic. It was developed by G.F. Sprague and released in 1953 (Troyer, 1999). It provides high yield, fast ear dry-down, resistance to root and stalk lodging, and resistance to northern corn leaf blight (*Helminthosporium turcicum* Pass.) (Russell et al., 1971). B14, however, is susceptible to corn leaf rust (*Puccinia sorghi* Schw.) which prompted the development and release of B14A in 1962, which is nearly identical to B14, but carries resistance to corn leaf rust. B14A was developed through backcrossing to Cuzco (Cuzco × B14 (8)) (Russell et al., 1971). B14 and derived-line hybrids are generally earlier than 110 days relative maturity (Baker, 1984). B14 is a parent of such influential inbred lines as A632 [(Mt42 × B14)$B14^3$], A634 [(Mt42 × B14) self $B14^2$], CM105 [V3 × $B14^2$], and CM174 [V3 × $B14^2$] (Coors et al., 1993). B68 is another

influential line that was derived through three backcrosses to B14 (Russell et al., 1971; Goodman, 1998).

Mo17

Inbred line Mo17 was developed under the direction of M. S. Zuber at the University of Missouri as part of C. O. Grogan's thesis project. It was released in 1964 (Troyer, 1999; Zuber, 1973). It is most famous for its use in hybrid combination with B73. Mo17 was developed out of CI187-2 × C103. Inbred line CI187-2 was selfed out of Krug Reid by L. Pfister and C103 was developed by D.F. Jones who selfed it out a Lancaster population that was obtained directly from Noah L. Hershey's farm near Parkesburg, Pennsylvania (Baker, 1984; Troyer, 1999). C103 was possibly the first widely used Lancaster line (Goodman, personal communication). Relative maturity of Mo17 hybrids is similar to that of C103, 95 to 125 days. (Baker, 1984; Zuber, 1973).

Oh43

Inbred line Oh43 was developed by Glenn H. Stringfield at the Ohio Experiment Station and released in 1949 (Troyer, 1999). It was selfed out of W8 × Oh40B. W8 is ½ Minnesota 13, ½ Funk Yellow Dent and Oh40B was developed from the Lancaster Synthetic (Coors et al., 1993). Though Oh43 is not included in Darrah and Zuber's 1986 survey, they do note that it has probably a made a significant contribution through private lines such as LH38 (Holden's Foundation Seed). Smith (1988) likewise recognized the contribution of Oh43 through the popular private lines LH38 and LH98.

B37

Like B14, inbred line B37 was developed at Iowa State University from the first cycle of recurrent selection on the Iowa Stiff Stalk Synthetic (Russell et al., 1971). It was developed by G.F. Sprague and released in 1958 (Troyer, 1999). B37 replaced the older B14 and it itself was eventually largely replaced by B73 (Baker, 1984; Goodman, personal communication). It is reported by Darrah and Zuber (1986) as being used in .3% of the total seed requirement in 1984. B37 hybrids range in maturity from 115 to 130 days (Baker, 1984).

Diversifying the U.S. Maize Germplasm Base

For years, maize breeders have advocated breeding with tropical germplasm as a means of diversifying the U.S. maize germplasm base. Melhus (1948) called for a critical study of Latin American maize, noting that such material could provide useful variants in disease, insect, drought, heat, and cold resistance. Brown (1953), in a review of germplasm sources for U.S. maize improvement, addressed the issue on a global basis. Wellhausen (1956) forecasted a yield plateau in U.S. maize improvement, stating that a "point of diminishing returns has now been reached ..., corn breeders will need to look elsewhere for a new source of yield genes." In 1965 Wellhausen reiterated the value of exotic sources of germplasm and presented data on race evaluations. Lonnquist (1974) called for the development of breeding pools from tropical and tropical × temperate germplasm, and noted the discouragement of breeders who had failed in their efforts to breed with tropical germplasm because their selection of tropical parents had essentially been "random". Brown (1975), in the wake of the 1970 southern corn leaf blight epidemic (Horsfall et al., 1972), reviewed the state of the U.S. maize germplasm base and listed some of the more promising sources of exotic germplasm—Coastal Tropical Flint, Tuxpeño, Tuson, Tiquisate Golden Yellow, Cuban Flint, Chandelle, Haitian Yellow, and the ETO synthetic. Stuber (1978) suggested that "every effort should be made to widen the corn germplasm base in U.S. breeding programs," and presented screening results of a wide range of exotic maize races from Latin America. In more recent years the charge has been led by Goodman (Goodman, 1990; Goodman, 1992; Goodman, 1998; Goodman, 1999; Goodman, 2004; Goodman and Carson, 2000; Goodman et al., 2000) and students out of his program at North Carolina State University (Castillo-Gonzalez and Goodman, 1989; Hawbaker et al., 1997; Holland, 1994; Holland and Goodman, 1995, 2003; Holland et al., 1996; Holley and Goodman, 1988; Lewis and Goodman, 2003; Nelson et al., 2006; Tallury and Goodman, 1999; Uhr and Goodman, 1995a, 1995b).

Despite the historical emphasis that has been placed on diversifying U.S. maize with exotic germplasm, there is currently very little tropical germplasm represented in private U.S. maize breeding programs (Goodman, 1999). Goodman (1998) surveyed private breeding programs in the U.S. and found that there was an increase in the use of exotic germplasm

from less than 1% in 1984 to 2.9 % in 1996. While the increase is notable, the underlying numbers are still quite low. Furthermore, only one tenth of the exotic germplasm referred to in that study was of tropical origin. According to Goodman (1998), most exotic germplasm used in the U.S. has two sources, B68 and the French lines F2 and F7. Inbred line B68 is an Iowa State inbred that was developed from backcrossing Maiz Amargo with B14. Maiz Amargo is an Argentine cultivar that was discovered in the 1930s and it and its derivatives are used in many breeding programs as a source of insect resistance. Inbred lines F2 and F7 were derived from the open-pollinated French cultivar Lacaune and provide improved emergence in cold, wet conditions (Goodman, 1998; 1999). Tropical germplasm is typically used only as a source of disease or insect resistance introduced through backcrossing.

While there is still very little exotic germplasm found in maize production acreage in the U.S. today, there are substantial efforts being made by some in the maize community to incorporate exotic maize germplasm. The maize breeding program at North Carolina State University has been working with tropical germplasm for nearly 25 years. NC State provides an ideal environment for a long-term breeding program with tropical maize given its southern location and its historical emphasis on maize breeding. Wellhausen (1956) noted that maize breeding programs in the South, with climate and growing conditions midway between those of Mexico and the Corn Belt, would provide a valuable service to the Corn Belt and local growers through the incorporation of tropical material. This is precisely what the NC State maize breeding program has attempted, producing tropical inbreds that are adapted to southern growing conditions and competitive with elite commercial inbreds. To date, over 45 NC lines have been released that are of partial or all-tropical origin (MBS Genetics, 2005).

Further efforts in diversifying the U.S. maize germplasm base are being carried out through the Germplasm Enhancement of Maize (GEM) project, a private/public collaborative breeding project sponsored by the USDA (Salhuana, 1994). The program was proposed as a follow-up to the Latin American Maize Project (LAMP) which evaluated over 12,000 accessions from 12 countries throughout North, Central, and South America (Pollak, 2003; Salhuana et al., 1991). Through GEM, exotic lines and accessions are crossed with elite proprietary U.S. inbreds for line-development purposes. GEM involves the cooperation of

approximately 20 private companies and so far 36 GEM-derived lines have been released (Balint-Kurti et al., 2006; Blanco et al., 2005; Carson et al., 2006).

While the breeding efforts through GEM and at NC State are major steps forward in maize germplasm enhancement, in many aspects the programs will not have succeeded until larger percentages of exotic germplasm are being grown in production acreage across the U.S. Achieving success in this light is a formidable task for two reasons. First, exotic materials are several decades behind elite U.S. materials in overall improvement. For example, in 1948 when maize breeding programs across the U.S. were in their second or third cycles of recurrent selection, and hybrid maize production across the U.S. was approaching 100%, the Rockefeller Foundation, the only institution of its kind in Mexico, was releasing its first hybrids (Fitzgerald, 1986). Second, even the most elite tropical maize lines must overcome photoperiod and other adaptation barriers if they are to be used in temperate breeding efforts. These obstacles certainly highlight the long-term nature of working with exotic germplasm. This was certainly realized by the early maize breeders like Melhus (1948), who called for young breeders to take on the work of developing tropical synthetics and populations.

Modern Statistical Methods and Experimental Design

The significant advancements in breeding methodology within maize and other crops in the early to mid part of the 20th century were paralleled by advancements in statistical analysis and experimental design. Agricultural experiments were the vehicle by which much of modern experimental design was established (Fisher, 1926). Uniformity trials were frequently used during the early part of the century to explain error variation in field experiments. This work illuminated the inherent variability that arises in the field from non-treatment effects. Considerable effort was subsequently devoted to experimental designs that would accommodate field variation (Fisher, 1926).

The same year that D.F. Jones (1918) introduced the double cross, R.A. Fisher introduced the word variance into the statistical language with implication to the analysis of variance components (Box, 1978; Fisher, 1918). In his first edition of "Statistical Methods for Research Workers", Fisher (1925) demonstrated the additive property of variance,

thereby providing for an estimate of error from its various causes (Anderson and Bancroft, 1952; Robinson, 1987). The analysis of variance quickly became one of the principal research tools in the biological sciences (Eisenhart, 1947).

The four primary experimental designs that emerged following the birth of the analysis of variance were (i) the completely randomized design, (ii) the randomized complete-blocks design, (iii) the latin-square designs, and (iv) the incomplete blocks-designs (Anderson and Bancroft, 1952). Eisenhart (1947) gives a comprehensive overview of the uses for the analysis of variance and the assumptions associated with its use.

One class of experimental analysis that emerged at this time was the spatial or "nearest-neighbor" analyses, which adjust observed values for variation within the field. Besag and Kempton (1986) give four distinct applications of neighboring plots analysis, many of which date back to the early to mid part of the 20th century. (1) Adjustment for fertility trends through systematic arrangements of check plots. This is perhaps the oldest application of nearest-neighbor analysis (Wiancko, 1914), and is particularly useful when treatment replication is not possible. (2) Adjustments for fertility trends using a Papadakis or related analyses that does not require additional checks, but relies on the treatment replication and neighboring plots to establish trends. (3) Adjustments for competition between plots. (4) Adjustments for interference between neighboring treatments. Federer and Schlottfeldt (1954) used covariance to detect row and column gradients in a field trial, a technique sometimes referred to as a trend analysis. Zimmerman and Harville (1991) introduced an analysis that models spatial heterogeneity directly, based on the assumption that neighboring plots will have correlated errors. Brownie et al. (1993) did a comprehensive comparison among three of these spatial analyses, trend analysis, Papadakis method, and the correlated errors analysis. Jines et al. (2006) developed software that compares various spatial analyses and outputs results from the "preferred" analysis, based on various criteria.

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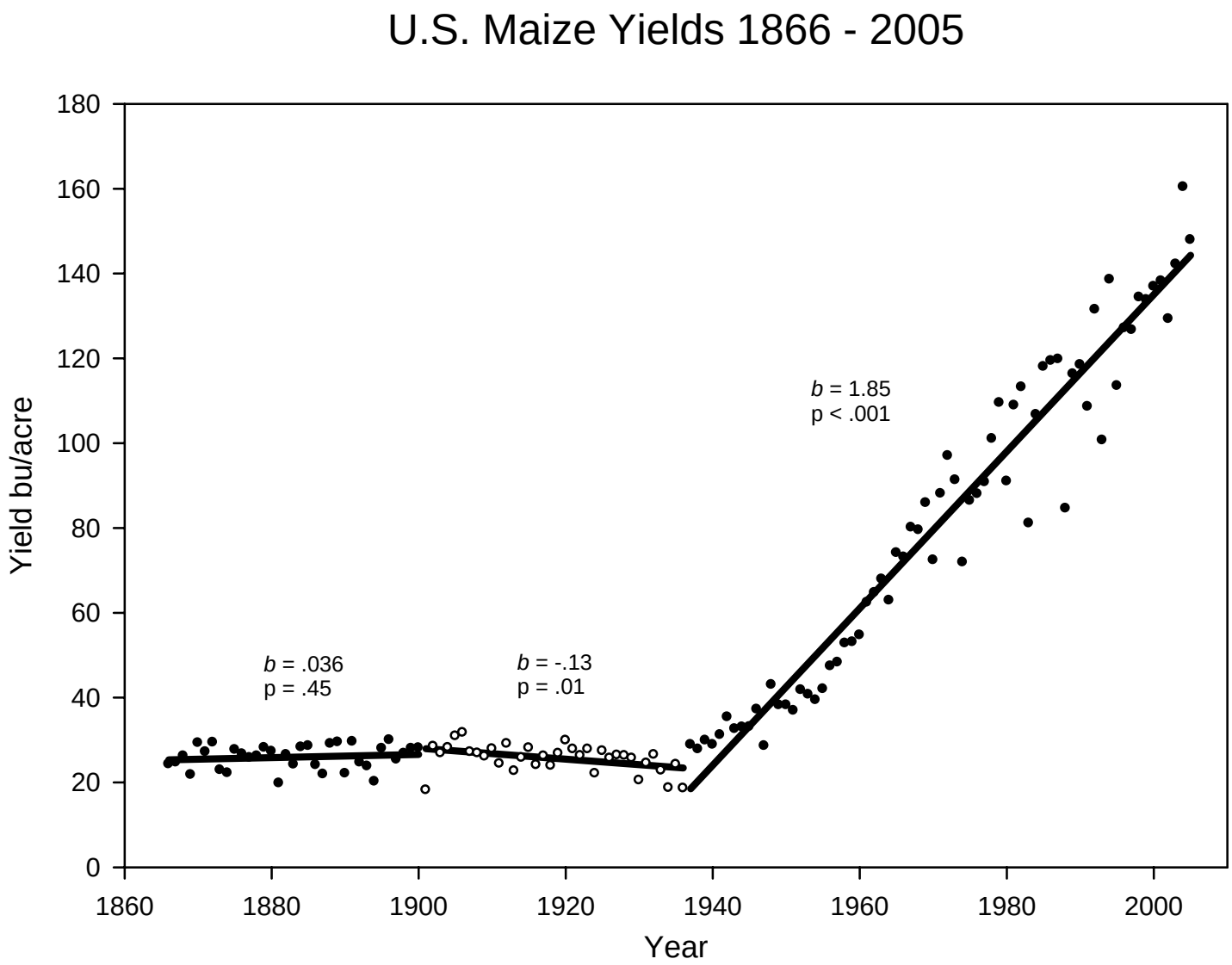

Figure 1.1 U.S. maize yields from 1866 – 2006 (USDA. 2006. National Agricultural Statistics Service [Online] http://www.nass.usda.gov/Data_and_Statistics/index.asp (verified 3/8/06)

– CHAPTER II –

Selecting Among Available, Elite Tropical Maize Inbreds for Use in Long-Term Temperate Breeding

by

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Selecting Among Available, Elite Tropical Maize Inbreds For Use in Long-Term Temperate Breeding[1]

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ABSTRACT – The narrowness of the temperate maize (Zea mays L.) germplasm base has long been recognized, and there are many available, elite tropical lines that might be used to profitably broaden it. However, there are few comparative yield-trial data by which to choose which line(s) might be most useful. As the investment required for using a tropical line in a temperate breeding program is large, line-choice is critical. Here we report the results of testing a group of potentially useful tropical lines in topcrosses grown in North Carolina. Results for 50%-exotic topcrosses and for 25%-exotic topcrosses are compared, and the 50%-exotic topcrosses with a broad-based tester (here, LH132.LH51) appear to be most efficient for initial screening. In addition, virtually all crosses suggested that any superior tropical line could be used equally well with either Stiff Stalk or non Stiff Stalk germplasm. Of the 22 lines tested, CML258 and Tzi9 appear to be the most promising, if yield improvement is a major criterion. None of the lines appeared to have serious lodging, maturity, or moisture problems in either 25% or 50%-tropical crosses.

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[1] This paper is dedicated to Dr. Donald N. Duvick who has served as an inspiration to the third author for over 45 years and whose leadership in the maize breeding and germplasm communities has been unmatched. The first and second authors are Pioneer Research Fellows whose stipends are a direct result of decisions made by Dr. Duvick while he was Vice-President of Research at Pioneer Hi-Bred International Inc.

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Introduction

Use of public tropical lines for U.S. commercial maize (Zea mays L.) breeding is either undocumented or non-existent. A possible exception is the old Cuban line A6, which was still being used in tropical hybrids over 40 years after its development by del Valle (1952). A major reason for the under-utilization of this valuable germplasm source is the sparse amount of yield-trial data available for most tropical lines. Effective evaluation of tropical, unadapted maize is costly and time-consuming in the U.S. corn-belt, where most temperate maize breeding is done. Thus, temperate maize breeding programs have shown minimal interest in such lines.

Many tropical lines have been available for over 15 years from the International Maize and Wheat Improvement Center (CIMMYT), the North Central Regional Plant Introduction Station (NCRPIS), or Jim Brewbaker in Hawaii. Potentially useful tropical lines have also been released from IITA (International Institute of Tropical Agriculture; Kim et al., 1987), the Suwan station in Thailand (Chutkaew, 1997), and South Africa, among others. Although substantial amounts of disease and insect resistance data exist (Brewbaker et al., 1989), very little comparative yield-trial data from either temperate or tropical areas have been published with which to make among-line choices, with the exception of work by Han et al. (1991) and Vasal et al. (1992). CIMMYT alone has released hundreds of lines (Srinivasan, 2001), almost all of which are described as having "good general combining ability," but many have little readily available data. Other sources of tropical lines and hybrids often have even less data. Much of the useful information on tropical hybrids and inbred lines is "word of mouth" or presented on slides or posters, often in meetings held in remote locations, rather than published in readily-available journals.

The maize breeding program at North Carolina State University has dealt extensively with tropical germplasm for nearly 25 years. NC State provides an ideal environment for a long-term breeding program with tropical maize given its southern location and its historical emphasis on maize breeding. We identified 22 all-tropical, public inbreds for screening and evaluation for use in our own breeding program and for potential use in GEM (Germplasm Enhancement of Maize), a public/private collaborative program designed to broaden the germplasm base of U.S. maize (Salhuana et al., 1994; Pollak and Salhuana, 1998, 2001;

Pollak, 2003). Our primary objective in conducting this study was to determine, in a yield-trial setting, which of these all-tropical lines might be most useful in a temperate breeding program. Additionally, we wanted to address three questions relative to testing procedures.
(1) Can tropical lines be directly topcrossed to a U.S. source, be tested in North Carolina, and yield useful comparative data?
(2) Do tropical lines need to be tested initially with both Stiff-Stalk (SS) and non-Stiff-Stalk (NSS) testers?
(3) Is testing topcrosses at the 25%-tropical level more informative than testing at the 50%-tropical level?

Data already exist that suggests (1) was correct (Stuber, 1978; Goodman et al., 2000), but the materials involved in those studies had little past history of selection. There are varying results regarding question (2). Mungoma and Pollak (1988), Pollak et al. (1991), and Geadelmann (1984) reported population × tester interaction among some tropical maize populations. Holland and Goodman (1995) found the opposite in evaluation of tropical accessions. Holley and Goodman (1988) also reported little heterotic interaction in evaluation of first generation, all-tropical, temperate-adapted lines. Note, however, that the aforementioned studies involved tropical populations, accessions, or temperate-adapted lines. Our study deals exclusively with all-tropical, unadapted inbred lines. Point (3) has not been addressed directly before.

Our reasons for conducting this study were the scarcity of usable, comparative yield-trial data from the tropics and the increasing reluctance of the private sector to share germplasm or information. Effective line selection is crucial for success in any breeding program, especially one that deals with unadapted, exotic germplasm. Until the available tropical material is screened, and the more promising lines identified, there is little chance of its effective use in a public breeding program.

Materials and Methods

The 22 lines used and their sources are listed in Table 2.1. Most were included in the genetic diversity studies of Liu et al. (2003). These lines represent a sample of what were believed to be the best of the available public, tropical inbred lines when the study started in

2000. They were chosen based on data presented at meetings such as the annual ASA-CSSA meetings, meetings and discussions at CIMMYT, a preliminary draft of a booklet by Srinivasan (2001), and conversations with maize breeders such as Hugo Cordova and S.K. Vasal at CIMMYT, Dave Smith and Glenn Robison at DeKalb, S.K. Kim at IITA, Takumi Izuno and Rick Ward at Pioneer, and Randy Holley at Syngenta. Each tropical line entered into 25% and 50%-tropical topcrosses in the following two ways. First, we crossed each tropical line to LH132.LH51 (basically, an improved B73.Mo17, developed and supplied to us by Holdens Foundation Seeds, now a part of Monsanto). This was formerly a widely-used hybrid, and one still in production. Such a hybrid represents a broad cross-section of U.S. maize (Smith 1988). Second, we crossed each tropical line to two U.S. inbreds, one representing SS germplasm (NC328) and one representing NSS germplasm (B97). After making the tropical inbred × U.S. inbred cross, we crossed the F_1 onto an appropriate tester; tropical × NC328 F_1s were crossed to FR615.FR697, a C103 sister-line cross representing non-Stiff Stalk germplasm, and tropical × B97 F_1s were crossed to FR992.FR1064, a B73 sister-line cross representing Stiff Stalk germplasm (FR testers were supplied to us by Illinois Foundation Seeds). Thus, each of the 22 lines was represented in three topcrosses, a 50%-tropical topcross and two 25%-tropical topcrosses.

The tropical × temperate line crosses began in the summer of 2000 at Clayton, NC. Topcross seed was produced in the winter nursery in Homestead, Fl, in 2000 - 2001. Tester seed in the winter nursery was delay planted (3 to 12 days) to match line maturity.

A total of 66 crosses was grown at 4 North Carolina locations over three years (2001, 2002, and 2003). Plots were grown at Clayton, Lewiston, and Sandhills, NC, each year. Plots were grown at Plymouth, NC, in 2001 and 2002, but were lost to a hurricane in 2003. Thus, a total of 11 North Carolina environments were represented in the study. All crosses were grown together in lattice designs with three replications per location along with six commercial hybrid checks, Dekalb 687, Dekalb 697, Pioneer 3165, Pioneer 3223, Pioneer 32K61, and Pioneer 31G98. These commercial checks represent a broad range of maturities grown in North Carolina at the time the study was conducted. All crosses and checks were represented in 2002 and 2003. Experiments grown in 2001 included only three checks, DeKalb 687, Pioneer P3165 and P32K61, and (due to a vandalism incident in our nursery)

did not include seven of the 66 topcrosses evaluated in 2002 and 2003: A6, CML254, CML264, and CML281 in topcrosses with FR992.FR1064 and CML264 and Ki44 in topcrosses with FR615.FR697. All plots were two-rows, 4.88 m in length measured from the center of the alley, with 1 m alleys between plots, and row spacing of 96.5 cm at all locations except Lewiston, NC, where row spacing was 91.4 cm. Plots were planted with 44 seeds/plot with a target plant density of 43,000 plants/ha at Clayton, Plymouth, and Sandhills, NC, and 45,000 plants/ha at Lewiston, NC. Data reported here are limited to yield, moisture percentage, ear height, plant height, percent erect plants at harvest, and days to anthesis (Table 2.2). Days to anthesis were recorded at Clayton, NC, only; all other data were collected at all locations.

Statistical analysis was done using PROC GLM in SAS version 8.0 (SAS Institute Inc., 1999). Years and environments were considered random and entries were considered fixed. Mean square error, degrees of freedom for error, and corresponding LSDs were calculated independently for 50%-tropical and 25%-tropical topcrosses. LSDs were calculated using a Satterthwaite approximation for degrees of freedom where necessary. Correlation analysis was done using Spearman's coefficient of rank correlation for comparison between broad-based, SS, and NSS testers and between years within and among testers. Four different selection truncation points were used for yield comparison among lines: lowest check, 90% of check mean, check mean – LSD, and tester mean + LSD.

Results and Discussion

As expected, few of these experimental crosses performed well enough per se to merit much, if any, further attention, if yield is the primary objective. Typically, any experimental hybrid with a mean yield more than one LSD below the mean of the checks would be unlikely to lead to competitive lines unless the number of lines developed and tested was very large (>> 100), and the breeder very fortunate. However, because we were dealing with widely varied, unadapted, tropical lines, no single selection criterion seemed to provide adequate information about line performance. Therefore we used four different truncation points for yield comparisons; (1) lowest check, (2) 90% of check mean, (3) check mean - LSD, and (4) tester mean + LSD (Table 2.3). Using these selection criteria, several lines

stood out across years and testers. CML258 and Tzi9 were consistently the two highest yielding lines, followed by Tzi8. Two other lines, CML277 and CML264, showed potential worth consideration, CML264 performing best in NSS topcrosses. The remaining 17 lines have little to offer as far as yield is concerned.

Only two of the 66 line × tester combinations lodged significantly more than the mean of the commercial checks (Table 2.2). About 42% of the line × tester combinations failed to differ significantly from the checks for ear and plant height. In the topcrosses involving B97, KUI2007 flowered 3 days earlier than the earliest check, Pioneer 32K61. None of the experimental crosses had grain moisture as low as Pioneer 31G98, which was also the highest-yielding entry.

For the purpose of initially screening 100%-tropical inbred lines, our results suggest that it is not necessary to topcross to both SS and NSS testers. Correlation analysis of topcross performance (averaged across three years and ranked by yield) gave rank correlation coefficients $r = 0.46$ and $r = 0.44$ for broad-based topcrosses vs. SS and NSS topcrosses, respectively (Table 2.4). However, correlation analysis of topcross performance from year to year on the same tester gave correlation rank coefficients ranging from $r = 0.05$ to $r = 0.72$, with the LH132.LH51 topcrosses being very much the most consistent across years (with $r \approx 0.68$). The r-values for the FR992.1064 topcrosses were very low, making results obtained with this tester rather uninformative, although Tzi9 consistently made the selection cut-off on this tester. The r-values for FR615.FR697 topcrosses were higher, although one correlation was below 0.3. Correlation coefficients for line rank from year to year, averaged across all three testers, were slightly higher. In all cases correlation among years was highest between 2002 and 2003. This is somewhat surprising because 2002 was a drought year and 2003 was very wet. However, all locations were irrigated, which lessened the effects of drought in 2002.

Our results suggest that screening with a broad-based tester provides as good an indication of relative line performance as any single-tester method. Testing at the 50%-tropical level requires less time and fewer resources than testing at the 25%-tropical level. Given the large number of potential lines to be tested and the limited resources available, this screening procedure seems a reasonable one to pursue, while it might logically be followed

by SS and NSS screening of the most promising lines. Our screening procedures for 100%-tropical unadapted inbred lines will undoubtedly be done at the 50%-tropical level in the future, as there appears to be no need to have only 25%-tropical germplasm in topcross yield trials in North Carolina. These conclusions are consistent with results from other studies with all-tropical lines at NC State (Holley and Goodman, 1988; Holland and Goodman, 1995). Considerations other than yield, most likely disease or insect resistance, seed quality, or pollen production, will most likely determine where a temperate breeder might employ better tropical lines.

In topcrosses to a single broad-based tester (50%-tropical), many of the problems (photoperiod related or otherwise) typically associated with growing unadapted tropical material in a temperate environment were lessened enough to allow effective line-evaluation. In order to run effective yield trials in North Carolina, flowering dates should be within a few days of the checks and grain moisture at harvest cannot be much higher than 28%. Lines evaluated on a single broad-based tester certainly met these criteria. Among 50%-tropical topcrosses, days to flowering ranged from 69 to 78 with a mean of 72.8, about a day and a half later than the mean of the commercial checks. Mean grain moisture at harvest was 19.3%, the wettest (CML254) being 21.2%. Lodging resistance was quite good with only one line (KUI2021) lodging significantly more than the mean of the commercial checks. Mean ear and plant heights were 107 cm and 271 cm respectively, significantly higher than the corresponding mean of the checks.

Differences in mean yield, averaged over all years, were significant ($p < .001$) between the three types of topcrosses: LH132.LH51 at 6.9 Mg ha, FR992.FR1064 at 7.1 Mg ha, and FR615.FR697 at 7.4 Mg ha. The lower yields observed in LH132.LH51 topcrosses come as no surprise, simply because of the higher percentage of unadapted tropical background in these crosses. Our previous experience with NSS vs. SS crosses with tropical material has been that the latter almost always yield better. The contradiction seen here is most likely attributed to the NC328 vs. B97 contribution in these crosses. NC328 is more adapted to North Carolina growing conditions and, therefore, it probably boosts yield in the NSS topcrosses, although further investigation would be necessary to draw any substantial conclusions.

Conclusion

Broadening the U.S. maize germplasm base is dependent on the incorporation of tropical germplasm. The pool of widely available public, tropical hybrids and inbred lines is the most logical source of germplasm, but the lack of available comparative yield trial data on such lines has made effective line-choice difficult. Use of tropical germplasm in a temperate breeding program is costly and time-consuming; therefore, line-choice is critical. The task of evaluation and incorporation of such lines has fallen largely on the shoulders of public maize breeding programs. Given the large number of potentially useful lines to be screened and the limited (and rapidly depleting) resources available to public breeding programs, efficiency is key in effective evaluation.

Results presented here suggest that in North Carolina, initial screening of all-tropical materials can be done effectively at the 50%-tropical level from topcrosses to a single broad-based U.S. tester. Furthermore, many of the problems commonly encountered when testing all-tropical material (namely photoperiod and disease issues) are lessened enough to allow effective evaluation when testing at the 50%-tropical level. In light of the large number of publicly available tropical lines, and the finite resources available to public breeding programs, this screening method is likely the most efficient.

The relative success of all-tropical, temperate-adapted lines like NC296 and NC346 (Goodman, 1999; Tallury and Goodman, 1999) has demonstrated the yield potential in elite exotic sources, but such events are rare. However, these and other temperate-adapted, all-tropical lines, like NC298 and NC300, offer resistance against diseases that could affect today's narrowing U.S. germplasm base. Further progress will require continued commitment and long-term funding, as progress is slow. The release of NC296 required 15 years of development (Goodman, 1993), which is not atypical of line development using predominantly exotic germplasm. The data presented here suggest that five of the 22 lines tested probably merit inclusion in such efforts: CML258, CML264, and CML277, and Tzi8 and Tzi9. Two lines, CML258 and Tzi9, appear to be the most promising.

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Table 2.1 Lines used, germplasm sources, and seed sources.

LINE	GERMPLASM SOURCE	SEED SOURCE
A6	Cuban Flint	Pioneer
CML247	Pool 24 (Tuxpeño)	CIMMYT
CML254	Tuxpeño Sequia	CIMMYT
CML258	Pop. 21 (Tuxpeño)	CIMMYT
CML264	Pop. 21 (Tuxpeño)	CIMMYT
CML277	Pop. 43 (La Posta, Tuxpeño)	CIMMYT
CML281	Pop. 43 (La Posta, Tuxpeño)	CIMMYT
CML287	Pop. 24 (Antigua-Venezuela; Tuśon/Tuxpeño)	CIMMYT
Ki3	Suwan 1 (Thailand)	Pioneer
Ki21	Suwan 1 (Thailand)	DeKalb
Ki11	Suwan 1 (Thailand)	Pioneer
Ki14	Suwan 1 (Thailand)	Brewbaker
Ki43	Suwan 3 (Thailand)	DeKalb
Ki44	KS 6 (Suwan, Thailand)	DeKalb
KUI2007	Suwan 1; DeKalb version of Ki3	DeKalb
KUI2021	Suwan 1; DeKalb version of Ki9	Dekalb
Tzi8	TZB × TZSR	IITA
Tzi9	SIDS7734 × TZSR	IITA
Tzi10	Pop. 44 × TZSR	IITA
Tzi11	Mo17 × RPPSR	IITA
Tzi16	N28 × RPPTZSR-Y	IITA
Tzi25	B732 × (B73 × RPPSR-TZ)	IITA

The lines originally acquired from Dekalb, Pioneer, and IITA have been deposited with NCRPIS at Ames.

Table 2.2 Means of tropical lines × U.S. testers; 50% and 25%-tropical topcrosses.

Year 2003: Clayton, Lewiston, and Sandhills, N.C.
Year 2002: Clayton, Lewiston, Plymouth, and Sandhills, N.C.
Year 2001: Clayton, Lewiston, Plymouth, and Sandhills N.C.

Pedigree	Yield	Mois	Ear	Plant	EP[1]	Anth
	Mg ha^{-1}	%	Ht (cm)	Ht (cm)	%	Days
A6 × LH132.LH51	6.6	18.9	116	276	92	73
A6.B97 × FR992.FR1064	6.9	17.3	97	265	93	69
A6.NC328 × FR615.FR697	7.3	17.8	103	271	87	71
CML247 × LH132.LH51	6.9	19.8	100	256	92	72
CML247.B97 × FR992.FR1064	7.3	17.7	94	251	94	69
CML247.NC328 × FR615.FR697	7.2	18.2	95	260	95	71
CML254 × LH132.LH51	5.3	21.2	124	288	98	78
CML254.B97 × FR992.FR1064	6.9	17.7	95	258	96	70
CML254.NC328 × FR615.FR697	7.4	18.4	111	280	94	74
CML258 × LH132.LH51	7.9	19.0	114	281	95	75
CML258.B97 × FR992.FR1064	7.2	17.6	99	265	96	70
CML258.NC328 × FR615.FR697	7.9	17.5	101	273	94	72
CML264 × LH132.LH51	6.6	21.0	101	274	98	75
CML264.B97 × FR992.FR1064	7.3	17.6	89	253	98	70
CML264.NC328 × FR615.FR697	7.8	18.2	97	271	97	71
CML277 × LH132.LH51	7.5	19.9	104	272	95	74
CML277.B97 × FR992.FR1064	7.1	17.8	93	253	95	69
CML277.NC328 × FR615.FR697	7.7	18.3	97	267	92	70
CML281 × LH132.LH51	6.7	19.1	116	287	97	77
CML281.B97 × FR992.FR1064	7.2	17.3	97	264	97	69
CML281.NC328 × FR615.FR697	7.3	17.5	103	268	95	71
CML287 × LH132.LH51	6.9	20.3	121	295	93	75
CML287.B97 × FR992.FR1064	7.3	17.9	104	276	95	70
CML287.NC328 × FR615.FR697	7.4	18.2	107	278	94	71
Ki3 × LH132.LH51	6.7	19.5	87	243	97	69
Ki3.B97 × FR992.FR1064	6.7	17.6	82	243	93	68
Ki3.NC328 × FR615.FR697	6.8	18.4	88	255	95	69
Ki11 × LH132.LH51	6.7	18.9	103	270	95	72
Ki11.B97 × FR992.FR1064	7.2	17.2	95	256	95	68
Ki11.NC328 × FR615.FR697	7.4	17.5	100	267	94	70
Ki14 × LH132.LH51	6.5	18.7	104	262	97	73
Ki14.B97 × FR992.FR1064	7.0	17.2	92	253	93	69
Ki14.NC328 × FR615.FR697	7.1	18.3	101	267	93	70
Ki21 × LH132.LH51	7.2	18.2	107	265	89	72
Ki21.B97 × FR992.FR1064	7.2	17.3	95	251	92	69
Ki21.NC328 × FR615.FR697	6.9	17.1	94	257	91	68
Ki43 × LH132.LH51	7.3	19.7	99	261	96	71
Ki43.B97 × FR992.FR1064	7.1	17.6	91	255	95	69
Ki43.NC328 × FR615.FR697	7.4	17.9	96	265	95	70
Ki44 × LH132.LH51	6.6	19.0	98	256	98	71
Ki44.B97 × FR992.FR1064	6.9	17.5	90	252	95	69
Ki44.NC328 × FR615.FR697	7.2	17.8	99	267	94	71
KUI2007 × LH132.LH51	6.9	19.5	88	250	93	69
KUI2007.B97 × FR992.FR1064	7.0	17.3	86	248	93	66
KUI2007.NC328 × FR615.FR697	7.4	17.8	90	258	92	70
KUI2021 × LH132.LH51	7.2	19.0	111	275	88	72
KUI2021.B97 × FR992.FR1064	6.9	17.7	98	269	91	68
KUI2021.NC328 × FR615.FR697	7.2	17.9	102	271	89	70

Table 2.2 Continued

Pedigree	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
Tzi8 × LH132.LH51	7.5	20.1	104	271	96	72
Tzi8.B97 × FR992.FR1064	7.2	18.3	96	259	95	69
Tzi8.NC328 × FR615.FR697	7.7	18.6	99	268	95	70
Tzi9 × LH132.LH51	7.5	18.5	112	283	92	72
Tzi9.B97 × FR992.FR1064	7.6	17.1	100	264	92	70
Tzi9.NC328 × FR615.FR697	7.9	17.5	107	282	92	70
Tzi10 × LH132.LH51	6.0	18.9	117	286	98	75
Tzi10.B97 × FR992.FR1064	6.9	17.2	98	271	97	70
Tzi10.NC328 × FR615.FR697	7.4	18.1	100	275	95	71
Tzi11 × LH132.LH51	6.9	19.4	104	269	96	71
Tzi11.B97 × FR992.FR1064	7.1	17.6	94	261	96	69
Tzi11.NC328 × FR615.FR697	7.3	18.7	100	271	93	70
Tzi16 × LH132.LH51	7.3	17.6	104	276	94	71
Tzi16.B97 × FR992.FR1064	7.1	17.0	95	263	95	69
Tzi16.NC328 × FR615.FR697	7.6	17.0	101	272	92	71
Tzi25 × LH132.LH51	7.0	19.0	109	270	90	71
Tzi25.B97 × FR992.FR1064	7.1	17.5	93	255	95	69
Tzi25.NC328 × FR615.FR697	7.4	17.8	102	271	94	70
Means: Experiment	7.1	18.3	100	266	94	71
50%-Tropical	6.9	19.3	107	271	95	73
25%-Tropical (SS)	7.1	17.5	94	258	95	69
25%-Tropical (NSS)	7.4	17.9	100	269	93	70
DeKalb 687	8.4	17.4	95	256	95	71
DeKalb 697	8.9	17.8	97	264	90	70
Pioneer P3165	7.8	19.1	91	254	89	74
Pioneer P31G98	9.0	16.7	98	267	95	71
Pioneer P3223	8.9	17.4	103	260	89	73
Pioneer P32K61	8.0	17.0	82	258	96	69
Check Means	8.5	17.6	94	260	92	71
LSD*	0.3	0.6	3.9	5.1	3.8	0.9

[1] EP = Erect Plants (at harvest).

*Appropriate for comparison of experimental cross to mean of the commercial checks at $\alpha = .05$

Table 2.3 Lines selected using four selection truncation points for yield.

Year	Truncation Point*	Tester		
		LH132.LH51	FR992.FR1064	FR615.FR697
2001	1	CML258	----------	CML258, Tzi8, Tzi9
2001	2	>6	>6	>6
2001	3	>6	>6	>6
2001	4	CML258	----------	CML258, Tzi9
2002	1	----------	----------	Tzi9
2002	2	CML258	----------	CML258, CML28, Tzi9
2002	3	----------	----------	----------
2002	4	CML258, CML277, Ki43, Tzi8	----------	CML258, CML264, CML281, KUI2007, Ki43, Tzi9
2003	1	CML258, Tzi16, Tzi8, Tzi9	CML247, Tzi9	CML258, CML264, CML277, CML287, Tzi8
2003	2	CML258, Tzi8, Tzi9	CML247, Tzi9	CML258, CML264, CML277, CML287, Tzi9
2003	3	Tzi9	----------	----------
2003	4	CML258, Tzi16, Tzi8, Tzi9	Tzi9	CML258, CML264, Tzi8
3 Year	1	CML258	----------	CML258, CML264, Tzi9
3 Year	2	CML258	----------	CML258, CML264, CML277, Tzi8, Tzi9
3 Year	3	----------	----------	----------
3 Year	4	CML258, CML277, Ki43, Tzi16, Tzi8, Tzi9	Tzi9	CML258, CML264, CML277, Tzi16, Tzi8, Tzi9

*Truncation Points: (1) Lowest check, (2) 90% of check mean (3) check mean – LSD, (4) tester mean + LSD. LSD calculations at $\alpha = .05$

Table 2.4 Spearman's coefficients of correlation for entries ranked by yield across testers and years.

	LH132.LH51 vs FR992.FR1064	LH132.LH51 vs FR615.FR697	FR992.FR1064 vs FR615.FR697
Avg. Across Years	0.46	0.44	0.40
	2001 vs 2002	2001 vs 2003	2002 vs 2003
LH132.LH51	0.65	0.66	0.72
FR992.FR1064*	0.05	0.12	0.52
FR615.FR697**	0.28	0.61	0.60
Avg. Across Testers	0.59	0.67	0.80

For each comparison n = 22 except where noted.

* For comparisons involving FR992.FR1064 in 2001, n=18.

** For comparisons involving FR615.FR697 in 2001, n=20.

– CHAPTER III –

Selecting Among Available, Elite Exotic Maize Inbreds for Use in Long-Term Temperate Breeding II

Introduction

The U.S. maize (*Zea mays L.*) germplasm base is narrow. Thus, ability to adapt to emerging biotic and abiotic stresses is impaired and there is increased potential for widespread crop failure as exemplified by the 1970 southern corn leaf blight epidemic (Horsfall et al., 1972). For years, maize breeders have advocated breeding with tropical germplasm (Brown, 1953; Brown, 1975; Goodman, 1992, 2004; Lonnquist, 1974; Melhus, 1948; Stuber, 1978; Wellhausen, 1956, 1965), which is the most logical source of added diversity. However, currently there is very little tropical germplasm represented in U.S. maize breeding programs (Goodman, 1999).

There are many elite tropical lines which are publicly available from maize breeding programs in the tropics (Nelson et al., 2006). One reason for the underutilization of this germplasm resource is the lack of available data on relative line performance. Breeders have little information on which to base their parental choices. Breeding with exotic germplasm is difficult and various temperate breeding programs have largly failed in their efforts to use tropical germplasm because their choice of an exotic collection has been more or less random (Lonnquist, 1974; Stuber, 1978). Having available information on relative line performance will likely increase the chances of success with its use.

Various studies have been conducted which provide useful information about tropical germplasm. Melhus (1948) crossed multiple native Guatemalan collections with U.S. inbreds and evaluated in them Guatemala. Wellhausen (1956) made exotic intra- and inter-racial crosses and evaluated them in Mexico. Stuber (1978) screened exotic maize races from Latin America in North Carolina. The Latin American Maize Project (LAMP) evaluated over 12,000 tropical exotic accessions in a 5 year cooperative public/private effort (Salhuana et al., 1991). These screening trials were carried out in the tropics and led to the identification of many potentially useful tropical accessions (Salhuana et al., 1998). Han et

al. (1991), Vasal et al. (1992a; 1992b), and Hede et al. (1999) evaluated tropical inbred maize lines for combining ability and agronomic performance in tropical environments. Castillo-Gonzalez and Goodman (1989), Holland and Goodman (1995), and Mickelson et al. (2001) carried out screening trials of accessions and improved populations in temperate environments. However, aside from work done by Nelson et al. (2006) there have not been any published studies that have screened elite tropical inbreds in a temperate environment.

Here we report the results of a screening study, similar to that by done by Nelson et al. (2006), in which elite tropical inbreds were evaluated in North Carolina and assessed for use in a temperate breeding program. The objective of this study was to identify elite exotic maize inbreds that can be used in broadening the U.S. maize germplasm base. The yield data generated in this study will provide temperate maize breeders with a comprehensive resource for selecting exotic germplasm. Breeding with exotic germplasm is a costly and time-consuming endeavor (Goodman, 1992), the success of which is largely determined by choice of germplasm (Hallauer and Miranda, 1986).

Materials and Methods

Germplasm Selection

Eighty-eight inbred lines, mostly tropical in origin, were chosen for screening. Many of these lines were identified through unpublished sources, i.e. conference talks, poster sessions, or word-of-mouth. Each line and its country and breeding program of origin is listed in Table 3.1. Sixty five of the lines were developed by the International Maize and Wheat Improvement Center (CIMMYT) in Mexico (Srinivasan, 2001). Eight lines are of temperate exotic origin, developed at the University of Novi Sad in Serbia. Seven were developed in Cameroon through joint cooperation of the International Institute of Tropical Agriculture (IITA) and the Cameroon Institute of Agronomic Research (IRA) (Everett et al., 1994a, 1994b). Four were developed by Hans Gevers at the Agricultural Research Council's Grain Crop Institute in South Africa. Three were developed by IITA in Nigeria. One line included in the study, an NC296A derivative, is an all-tropical line that was developed at North Carolina State University but underwent a gametophyte factor conversion attempt at

Novi Sad University, Serbia. All lines, except the eight from Serbia, are tropical in origin; however, for this study all lines will be referred to as 'exotic'.

The exotic inbreds included in the study were chosen for evaluation for a number of reasons. First, these lines are exotic from a U.S. perspective, containing many alleles that are not found in the U.S. maize germplasm base. Second, unlike accessions and unimproved land races which have been the focus of many studies with exotic germplasm (Castillo-Gonzalez and Goodman, 1989; Holland and Goodman, 1995; Melhus, 1948; Salhuana et al., 1998; Stuber, 1978; Wellhausen, 1965), these lines have already seen multiple cycles of inbreeding and selection. Third, these lines are considered elite in their countries of origin, showing good yield potential, disease resistance, and overall favorable agronomic performance. Fourth, they are all publicly available and the seed for most can be obtained with relative ease.

Yield Trial Evaluation

Yield trial evaluations were carried out from 2001 – 2005. Each exotic line was initially crossed to a broad-based U.S. tester, LH132 × LH51 (Holden's Foundation Seeds), an improved B73 × Mo17 hybrid of Stiff Stalk (SS) × non-Stiff Stalk (NSS) origin. The resulting 50%-exotic testcrosses were then evaluated in replicated yield trials. Following each year of testing, the poorest performing lines were eliminated. In general, experimental entries that were not within one LSD of the check mean were eliminated from the study. Lines that remained after their first two years of screening then entered two modified three-way testcrosses, each resulting in a 25%-exotic testcross. In the first of these testcrosses, the exotic line was crossed to a line of SS origin and then crossed to a NSS × NSS sister-line hybrid. The SS line used was NC374 and the NSS × NSS sister-line hybrid was FR615 × FR697 (Illinois Foundation Seed). In the second of these modified three-way testcrosses, each exotic line was crossed to a line of NSS origin and then crossed to a SS × SS sister-line hybrid. The NSS line used was either NC414, NC418, or NC382 and the SS × SS sister-line hybrid used was FR992 × FR1064 (Illinois Foundation Seed). Therefore, by its third year of testing, an exotic line was represented in yield trials by three testcrosses, one 50%-exotic testcross and two 25%-exotic testcrosses. These three testcrosses were then tested together for the remainder of the study. Because inbreds 326172w, 326633A, and 327609A are of

known SS origin, these lines were crossed to FR615 × FR697 for initial screening. Thirteen commercial hybrid checks were used in the study. These commercial checks represent a range of maturities grown in North Carolina at the time the study was conducted. All 126 line × tester combinations, the 13 hybrid checks, and the years that they were grown are listed in Table B.1.

The number of entries included in any single year of testing varied. This is because newly acquired exotic lines were continually being added to the study and poorly performing experimental entries were continually being eliminated. Thus, the design was unbalanced between years because better performing experimental entries were tested for multiple years while poor performing experimental entries were often eliminated after only one year of testing. The design was balanced across environments within any given year.

Yield trial evaluations were conducted over five years at five North Carolina locations, the Central Crops Research Station in Clayton, NC, the Peanut Belt Research Station in Lewiston / Woodville, NC, the Tidewater Research Station in Plymouth, NC, the Sandhills Research Station in Jackson Springs, NC, and the Caswell Research Station in Kinston, NC (Figures B.5 and B.6). These locations were chosen because they represent the primary maize production regions in North Carolina. Yield trial data were collected at Clayton and Lewiston all five years. Plots were grown at Plymouth all five years, but yield trial data from this location was not used in 2003 or 2004 because of hurricane damage. Plots were grown at Sandhills for four of the five years, 2003 being the exception. Yield trial data were collected at Kinston in 2004 only. Thus, 18 North Carolina environments were represented in the study.

Two replications were planted in a double lattice design at all 2001 and 2002 environments and at Clayton, 2004. All other environments had three replications planted in a triple lattice design. All plots were two rows, 4.88 m in length measured from the center of the alley, with 1 m alleys, and row spacing of 96.5 cm at all locations except Lewiston where row spacing was 91.4 cm. Plots were planted with 44 seeds/plot with a target plant density of 43,000 plants/ha^{-1} at all locations except Lewiston where target plant density was 45,000 plants/ha^{-1}. Data reported here are limited to yield, moisture percentage at harvest, ear

height, plant height, percent erect plants at harvest, and days to anthesis. Days to anthesis was recorded at Clayton only; all other data were collected at all locations.

Data Analysis

Statistical analysis was done using SAS version 9.1.3 (SAS Institute Inc., 2003). Data from individual environments was screened for outliers by observing coefficients of variation and plot residuals. Stand was fitted as a covariate ($p < .001$) in the analysis of yield data from Lewiston, 2003, and Sandhills, 2005. Stands at these environments were poor due to non-genotypic effects, wet cool weather after planting at Lewiston and bird-damage at Sandhills. Environment means were obtained using each of five statistical models: the randomized complete block (RCB), lattice, trend, correlated errors (CE), and trend + correlated errors (T+CE). At four environments, spatial analysis was not an option due to field constraints or planting errors. As suggested by Brownie et al. (1993), reps were not included in the trend analysis and only trend effects with $p < .01$ were included in the trend or T+CE analysis. Reps were included in the T+CE analysis. Environment means obtained with each model were compared and a 'preferred' analysis was chosen. Comparisons among analyses were based on F-values for treatment effects, the square root of the average variance of an entry mean (SAV), spearman rank correlations of treatment means with the RCB, and the model mean square error (MSE) where applicable (Brownie et al., 1993; Jines et al., 2006). The RCB served as the default analysis if other analyses failed to be at least 105% as effective in reducing SAV or if improvements in the other criteria were not present. A single analysis was chosen for the analysis of each trait across all environments within each year. This was done to simplify tests for genotype by environment interaction (G×E). Using these criteria, a preferred analysis was chosen for generating individual entry means within each environment (Table 3.2).

Entry means across environments were obtained in two ways. First, entry means from all 18 environments were included in a mixed model analysis using PROC MIXED in SAS; entries were considered fixed and all other effects were considered random. Through this mixed analysis, entry means for all 126 experimental entries and 13 checks were obtained through a single analysis, despite the unbalanced nature of the experiment between years. However, because of the unequal representation of entries across environments, entry

means are calculated with varying levels of precision. This prevents pairwise comparisons between entries with a means separation statistic like the least significant difference (LSD).

Second, entry means from individual environments were used to perform across environment analysis for balanced subsets of entries. These subsets included all entries grown within any given year, and subsets of entries that were grown together across years. By splitting the data into balanced subsets, entry means were estimated with equal precision, thus allowing more appropriate comparisons between entries. For these subsets, a protected LSD was generated for pair-wise comparisons between experimental entries, comparisons between an experimental entry and the mean of experimental entries, and comparisons between an experimental entry and the mean of the commercial checks.

Line × tester interaction for line performance on each of the three testers was evaluated using the SLICE option with the LSMEANS statement with PROC GLM in SAS. The SLICE option partitions interaction LSMEANS effects and produces tests of simple effects (SAS Institute Inc., 2003).

Correlation analysis was done using Spearman's coefficient of rank correlation for comparison of line rank on the broad-based, SS, and NSS testers and for comparison of entry rank across environments.

A "Consistency of Performance" analysis (Ketata et al., 1989) was done by plotting genotype mean rank against the standard deviation of entry rank across environments. Within each environment, entries were ranked using PROC RANK in SAS with a TIES = MEAN statement to assign mean ranking to tied values. Mean entry ranks were obtained with PROC GLM using an LSMEANS statement. The standard deviations (SE) of entry ranks were calculated as follows, using residuals outputted from PROC GLM:

$$\mathrm{SE} = \sqrt{\frac{\sum_{i=1}^{n} r_i^{\,2}}{n-1}},$$

where n is the number of environments and r is the i^{th} residual value (Steel et al., 1997).

Results and Discussion

Entry Performance

In all analyses except one, F-values for the null hypothesis of no differences between entries for the given trait were highly significant ($p < .01$). There were no significant differences in % erect plants for entries in 2001. This is because there were not any late season storms in 2001 and all locations had a very high % erect plants.

Entry means are given in Table 3.3 for a subset of the better performing entries. This subset includes data from 10 environments from 2003 – 2005. Experimental entry values that did not differ significantly from the mean of the checks are emboldened. Of the 50%-exotic entries, the CML343 testcross was the highest yielding, followed by the CML274, CML157Q, CML373, and CML108 testcrosses. These entries also exhibited lodging resistance, each being within one LSD of the check mean for % erect plants. The CML108 testcross was within one LSD of the check mean for all traits except yield and moisture, although it was drier than the wettest check, Garst 8288.

Among the 25%-exotic entries, the two CML341and the two CML10 testcrosses were the four highest yielding. The CML10.NC414 testcross was within one LSD of the check mean for all traits except moisture.

Data on additional subsets of entries, including individual year means, are given in Tables B.2 – B.8. Discussion on each of these subsets is also provided in Appendix B.

Line × Tester Interaction

Some lines exhibited significant line × tester interaction. For example, in 2005 CML10 testcrosses with the SS and NSS testers ranked 9th and 10th respectively, yet the CML10 testcross with the broad-based tester ranked 64th overall. Table 3.4 gives F-values and significance levels of line × tester interactions. Tests are based on yields expressed as deviations from the mean yield of all lines on the respective tester. By doing so line × tester interaction effects due to absolute yield differences between testers are minimized. (Line × tester interactions based on actual testcross yields are given in Table B.9.) Based on Table 3.4, only three lines showed significant line × tester interactions, CML10, CML269, and CML274. Inbred lines CML374, CML103, CML333, CML343, and CML216 showed the least line × tester interaction.

Genotype × Environment Interaction

There was significant G×E for many of the traits in the within-year analysis (Table B.10). Such interactions may be noteworthy when conducting screening experiments in a breeding program, particularly when correlations across environments are low. When the correlation for a single trait is low between two environments, this may suggest that the trait is being controlled by different genes in different environments (Falconer and Mackay, 1996).

To further address G×E, spearman coefficients of rank correlation between environments were calculated for experimental entries ranked by trait (Table B.11). These correlations were higher for highly heritable traits, such as moisture, ear height, and plant height (Hallauer and Miranda, 1986). Correlations between environments for percent erect plants were low because this trait is highly affected by environment-specific weather conditions. Correlations between environments for yield were variable but generally low, ranging from r = -.02 to r = .67 with a median value of .42.

Stability analysis was performed to further address G×E for yield. Two approaches were used toward stability analysis, a consistency of performance analysis as described by Ketata et al. (1989) and an environmental index as proposed by Finlay and Wilkinson (1963). Neither analysis was performed for 2003 data because there were only two environments in 2003.

Ketata's consistency of performance analysis establishes a relative measure of stability by plotting the standard deviation of entry rank across environments against genotype mean rank. Entries with low standard deviations are considered stable. The "ideal" genotype will be found near the origin, indicating that it is consistently high-ranking.

Consistency of performance analysis was done on an individual year basis and only 50%-tropical testcrosses (for which data were most complete) were used. Consistency of performance plots for 2001, 2002, 2004, and 2005 are shown in Figures B.1 – B.4 respectively. By this measure of stability, the CML341 and CML108 testcrosses generally showed the greatest stability. In all cases, the commercial checks exhibited greater stability than most of the experimental entries.

Methods, results, and discussion on Finlay and Wilkerson's environmental index are given in Appendix B.

Tester Correlation

In previous screening trials done at NC State (Nelson et al., 2006), correlation analysis of line rank on different testers was used to assess the effectiveness of the various testers in evaluating line performance. For example, if line ranks were highly correlated across testers, it was concluded that a single tester would have been sufficient for yield trial screening. However, in the present study, correlation analysis could not be used in this manner. This is because poorly performing lines were dropped from the experiment in the early stages of testing. By truncating the distribution in this way, the correlation coefficients became constrained and unreliable (Levin, 1999). This is especially evident when considering correlations for testcross yield. Because culling levels in the early stages of screening were based on yield performance, the distribution for yield was more severely truncated than the distributions for other traits. This is exemplified in Table B.12 where the coefficient of correlation for yield ranges from -0.40 to 0.69.

Conclusion

Most of today's elite U.S. hybrids are derived from a small pool of inbreds that were developed almost a half-century ago (Goodman, 1992; Smith, 1988; Troyer, 1999). While maize yields in the U.S. continue to improve (USDA, 2006) and the long-foretold yield plateau (Wellhausen, 1956) has not yet been reached, there is little evidence that there is a monopoly on yield genes in the U.S. (Goodman, 1992). The results presented here certainly indicate that there is yield potential outside the Corn Belt. Within any given year of testing, a handful of 50%-exotic testcrosses rivaled or beat the check mean in yield performance. Seven lines stand out across analyses as the better performing lines in the experiment as far as yield is concerned: CML10, CML108, CML157Q, CML274, CML341, CML343, and CML373. CML341 testcrosses were the most consistently high-yielding entries. CML108 testcrosses, while not always the highest yielding entries, consistently exhibited superior performance across all the traits measured.

Breeders who are working with tropical-exotic germplasm are faced with a number of challenges, namely photoperiod sensitivity, disease susceptibility, and weak roots and stocks (Holland and Goodman, 1995). The magnitude of these challenges can be minimized by selecting tropical-exotic parents that are more easily adapted. The maize breeding program at NC State has already begun breeding with many of the lines presented in this study. They are being used in both exotic × temperate and exotic × exotic breeding crosses and populations. The lines screened here, in conjunction with lines screened by Nelson et al. (2006), provide temperate breeders with information on a sizable pool of potentially useful exotic maize inbred lines. These lines certainly deserve further attention in temperate breeding efforts.

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Table 3.1 Experimental Lines and Origin.

Line	Breeder / Program	Country	Line	Breeder / Program	Country
A214N	Hans Gevers	South Africa	CML270	CIMMYT	Mexico
BO46W	Hans Gevers	South Africa	CML273	CIMMYT	Mexico
C70	IITA / IRA	Cameroon	CML274	CIMMYT	Mexico
CML5	CIMMYT	Mexico	CML285	CIMMYT	Mexico
CML9	CIMMYT	Mexico	CML288	CIMMYT	Mexico
CML10	CIMMYT	Mexico	CML295	CIMMYT	Mexico
CML14	CIMMYT	Mexico	CML304	CIMMYT	Mexico
CML16	CIMMYT	Mexico	CML311	CIMMYT	Mexico
CML38	CIMMYT	Mexico	CML314	CIMMYT	Mexico
CML40	CIMMYT	Mexico	CML319	CIMMYT	Mexico
CML45	CIMMYT	Mexico	CML321	CIMMYT	Mexico
CML48	CIMMYT	Mexico	CML322	CIMMYT	Mexico
CML52	CIMMYT	Mexico	CML323	CIMMYT	Mexico
CML56	CIMMYT	Mexico	CML325	CIMMYT	Mexico
CML61	CIMMYT	Mexico	CML327	CIMMYT	Mexico
CML69	CIMMYT	Mexico	CML329	CIMMYT	Mexico
CML91	CIMMYT	Mexico	CML331	CIMMYT	Mexico
CML92	CIMMYT	Mexico	CML332	CIMMYT	Mexico
CML103	CIMMYT	Mexico	CML333	CIMMYT	Mexico
CML108	CIMMYT	Mexico	CML341	CIMMYT	Mexico
CML116	CIMMYT	Mexico	CML343	CIMMYT	Mexico
CML142	CIMMYT	Mexico	CML373	CIMMYT	Mexico
CML144	CIMMYT	Mexico	CML374	CIMMYT	Mexico
CML145	CIMMYT	Mexico	CML384	CIMMYT	Mexico
CML150	CIMMYT	Mexico	DO940Y	Hans Gevers	South Africa
CML154Q	CIMMYT	Mexico	NC296A-NS	NCSU/ Univ. of Novi Sad	U.S. / Serbia
CML157Q	CIMMYT	Mexico	Tzi3	IITA	Nigeria
CML158Q	CIMMYT	Mexico	Tzi17	IITA	Nigeria
CML159	CIMMYT	Mexico	Tzi18	IITA	Nigeria
CML161	CIMMYT	Mexico	VO613Y	Hans Gevers	South Africa
CML173	CIMMYT	Mexico	314190w	Univ. of Novi Sad	Serbia
CML176	CIMMYT	Mexico	316096A	Univ. of Novi Sad	Serbia
CML184	CIMMYT	Mexico	317027A	Univ. of Novi Sad	Serbia
CML186	CIMMYT	Mexico	318056A	Univ. of Novi Sad	Serbia
CML193	CIMMYT	Mexico	326172w	Univ. of Novi Sad	Serbia
CML216	CIMMYT	Mexico	326633A	Univ. of Novi Sad	Serbia
CML218	CIMMYT	Mexico	327609A	Univ. of Novi Sad	Serbia
CML220	CIMMYT	Mexico	796 NS	Univ. of Novi Sad	Serbia
CML223	CIMMYT	Mexico	87036	IITA / IRA	Cameroon
CML228	CIMMYT	Mexico	89199	IITA / IRA	Cameroon
CML238	CIMMYT	Mexico	89291	IITA / IRA	Cameroon
CML255	CIMMYT	Mexico	89302	IITA / IRA	Cameroon
CML261	CIMMYT	Mexico	90156	IITA / IRA	Cameroon
CML269	CIMMYT	Mexico	90301	IITA / IRA	Cameroon

Table 3.2 Preferred analysis used for each trait across all locations within years.

Year	Yield Mg ha^{-1}	Mois %	Ear Ht(cm)	Plant Ht(cm)	EP[1] %	Anth Days
2001	RCB	RCB	RCB	RCB	RCB	RCB
2002	Lattice	Lattice	Lattice	Lattice	Lattice	RCB
2003	T+CE	Trend	RCB	RCB	Trend	RCB
2004	Lattice	Trend	RCB	Lattice	Lattice	RCB
2005	Trend	Lattice	Lattice	Trend	RCB	RCB

RCB = Randomized Complete Block, T+CE = Trend + Correlated Errors.
[1] Percent erect plants at harvest.

Table 3.3 25% and 50%-exotic entry means from 10 environments 2003 – 2005.

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
BO46W × LH132.LH51	7.1	18.7	113	289	**79**	70
CML10 × LH132.LH51	6.8	19.1	124	299	**68**	71
CML10.NC414 × FR992.FR1064	**7.5**	17.6	**105**	**280**	**74**	**68**
CML10.NC374 × FR615.FR697	**7.5**	17.6	113	298	**71**	69
CML16 × LH132.LH51	7.0	18.9	128	308	**73**	69
CML38 × LH132.LH51	6.9	19.2	120	**283**	**69**	71
CML69 × LH132.LH51	6.7	19.1	115	**281**	62	**67**
CML69.NC414 × FR992.FR1064	6.7	17.7	**103**	**275**	**70**	**66**
CML69.NC374 × FR615.FR697	6.7	17.6	109	287	63	68
CML91 × LH132.LH51	6.8	17.2	**107**	**273**	**76**	68
CML91.NC414 × FR992.FR1064	6.8	**16.9**	**94**	**266**	**78**	**66**
CML91.NC374 × FR615.FR697	7.3	**16.2**	**105**	**283**	**71**	**68**
CML92 × LH132.LH51	6.8	17.7	110	286	64	68
CML92.NC414 × FR992.FR1064	6.8	17.1	**104**	**274**	**70**	**66**
CML92.NC374 × FR615.FR697	6.9	**16.4**	114	297	64	**68**
CML103 × LH132.LH51	7.0	**16.8**	115	**276**	53	68
CML103.NC414 × FR992.FR1064	7.0	**16.9**	**103**	**269**	**68**	**66**
CML103.NC374 × FR615.FR697	7.2	**16.6**	112	287	63	**67**
CML108 × LH132.LH51	7.2	17.1	**100**	**275**	**71**	**67**
CML108.NC414 × FR992.FR1064	6.8	**16.8**	**95**	**265**	**71**	**65**
CML108.NC374 × FR615.FR697	7.2	22.0	**102**	**281**	**71**	**67**
CML154Q × LH132.LH51	7.0	18.5	**106**	**271**	53	**67**
CML154Q.NC414 × FR992.FR1064	6.7	17.6	**101**	**273**	**72**	**66**
CML154Q.NC374 × FR615.FR697	7.2	**16.6**	111	293	65	**67**
CML157Q × LH132.LH51	7.3	17.9	121	292	**74**	68
CML157Q.NC414 × FR992.FR1064	7.0	17.4	**106**	**277**	**71**	**66**
CML157Q.NC374 × FR615.FR697	7.2	**16.9**	110	290	**71**	68
CML176 × LH132.LH51	7.0	19.1	124	304	57	70
CML216 × LH132.LH51	7.0	18.9	128	309	56	71
CML269 × LH132.LH51	7.0	19.2	117	292	**71**	70
CML274 × LH132.LH51	**7.4**	17.7	124	301	**73**	71
CML327 × LH132.LH51	6.9	17.6	120	296	**76**	69
CML333 × LH132.LH51	6.8	18.6	115	**284**	62	68
CML333.NC414 × FR992.FR1064	6.9	17.7	**107**	**278**	**67**	**67**
CML333.NC374 × FR615.FR697	7.3	**16.9**	115	294	**69**	68
CML341 × LH132.LH51	7.1	18.9	123	295	**69**	71
CML341.NC414 × FR992.FR1064	**7.5**	17.2	109	**280**	**75**	**68**
CML341.NC374 × FR615.FR697	**7.7**	**16.7**	111	289	**72**	69
CML343 × LH132.LH51	**7.7**	18.7	110	285	**76**	70
CML373 × LH132.LH51	7.2	19.1	110	**280**	**78**	69
CML374 × LH132.LH51	7.1	18.5	122	300	**71**	69
DO940Y × LH132.LH51	6.7	18.1	113	**277**	**73**	69
VO613Y × LH132.LH51	6.6	18.8	117	**275**	**70**	70
Entry Mean	7.0	17.9	112	285	69	68
DeKalb 697	8.3	17.0	105	275	72	68
Garst 8288	7.9	17.2	97	281	82	66
LH132 × LH51	6.7	15.9	98	269	70	66
LH200 × LH262	7.6	16.6	111	282	70	68
Pioneer P31G98	8.3	15.9	107	283	75	68
Check Mean	7.7	16.5	103	278	74	67

Table 3.3 (continued)

	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
Entry v. Entry LSD	0.5	0.7	6	8	8	1
Entry v. Entry Mean LSD	0.3	0.5	4	5	6	0
Entry v. Check Mean LSD	0.4	0.5	4	6	7	1

[1] Percent erect plants at harvest.

Table 3.4 Line × tester interactions for yield given as deviations from the mean

Line	F-Value	Prob. F	Testcross Yield Mg ha^{-1}			# Env
			SS × NSS 50%-Exotic	SS × SS 25%-Exotic	NSS × NSS 25%-Exotic	
CML10	7.78	0.001*	-0.2	0.5	0.3	10
CML69	1.53	0.219	-0.3	-0.2	-0.5	10
CML91	1.93	0.148	-0.2	-0.2	0.1	10
CML92	0.50	0.606	-0.1	-0.2	-0.3	10
CML103	0.12	0.887	0.1	0.1	0.0	10
CML108	2.58	0.079	0.2	-0.2	0.0	10
CML154Q	1.98	0.141	0.1	-0.3	0.0	10
CML157Q	2.34	0.100	0.3	0.0	-0.1	10
CML333	0.46	0.630	-0.1	-0.1	0.0	10
CML341	2.79	0.065	0.1	0.5	0.4	10
Mean			6.9	7.0	7.2	
CML16	1.94	0.163	0.1	0.0	0.4	8
CML38	0.92	0.411	-0.1	-0.3	-0.1	8
CML269	4.66	0.018*	0.0	0.3	-0.3	8
Mean			6.6	6.7	6.9	
CML176	2.63	0.089	-0.6	0.1	-0.4	4
CML216	0.68	0.513	-0.4	-0.2	-0.5	4
CML274	4.35	0.022*	0.8	-0.1	0.4	4
CML343	0.68	0.514	0.7	0.3	0.5	4
CML373	1.17	0.324	-0.4	-0.1	0.1	4
CML374	0.08	0.924	-0.1	0.0	-0.1	4
Mean			6.9	7.0	6.9	

F-values and significance levels of line × tester interactions expressed as deviations from the mean as given. Tests are based on data from the number of environments given.

– CHAPTER IV –

Gray Leaf Spot Evaluation of Elite Exotic Maize Inbreds

Introduction

Gray leaf spot (GLS) of maize (*Zea mays*) was first reported by Tehon and Daniels (1925). It is caused by the fungus *Cercospora zeae-maydis* and is characterized by long narrow tan to gray lesions with borders that typically run parallel to the leaf vein (Beckman and Payne, 1982). Within *C. zeae-maydis* there are two sibling species and many isolates of varying levels of aggressiveness (Bair and Ayers, 1986; Carson and Goodman, 2006; Carson et al., 2002; Dunkle and Carson, 1999).

Gray leaf spot thrives in humid environments that favor slow drying dews and late-season fogs (Beckman and Payne, 1982). The disease is the most prevalent in the mountainous regions of Kentucky, Tennessee, Virginia, North Carolina, and South Carolina (Beckman and Payne, 1983). For many years GLS was found predominantly in these mountainous regions of the eastern United States and was relatively unimportant in terms of maize production (Ward et al., 1999). However, since the 1970's the occurrence of GLS infection has increased substantially and spread throughout the U.S. corn-belt (Bair and Ayers, 1986; Beckman and Payne, 1982, 1983; Bubeck et al., 1993; Carson et al., 2002; Ward et al., 1999). Today GLS is found in maize growing regions from eastern Colorado to the coasts of North Carolina and Virginia (Carson et al., 2002).

The increased occurrence of GLS is attributed to the coinciding increase in reduced-tillage and continuous maize cropping systems. Such management practices are conducive to GLS infestation because *C. zeae-maydis* overwinters in maize residue that remains on the soil surface and is easily transmitted to the maize crop the following year. Yield loss caused by GLS is attributed to decreased photosynthetic leaf area, lodging due to weakened stocks, and premature plant death in the most serious incidents (Ward et al., 1999). Today GLS is considered by some to be the most important foliar disease of maize in the U.S. (Carson and Goodman, 2006; Carson et al., 2002; Gordon et al., 2004).

The most efficient means of controlling GLS is through genetic resistance (Carson and Goodman, 2006; Carson et al., 2002; Graham et al., 1993; Thompson et al., 1987; Ward et al., 1999). Most of today's commercial hybrids contain some level of genetic GLS resistance, but few are highly resistant (Graham et al., 1993; Goodman, unpublished data). Though resistance can be found in a variety of genetic backgrounds, it most commonly comes through non-Stiff Stalk (NSS) and tropical sources (Carson and Goodman, 2006; Carson et al., 2002; Graham et al., 1993; Thompson et al., 1987). Thus, breeders are often limited in their choice of a Stiff-Stalk (SS) parent in hybrid development if GLS resistance is of importance. Furthermore, experience at NC State has shown that much of the GLS-resistant germplasm performs rather poorly with regards to yield and other agronomic characteristics (Bubeck et al., 1993; Goodman, unpublished data). Thus, there is a need for additional sources of GLS-resistant germplasm that not only exhibit high yield potential, but that combine well with NSS germplasm.

Previously, Nelson et al. (2006) and Nelson (Chapter 3 of this thesis) reported on the agronomic performance of 110 tropical and temperate-exotic inbred lines in testcrosses. The objective of those studies was to identify exotic sources of maize germplasm that carry favorable yield and agronomic and traits and can be used in broadening the U.S. maize germplasm base. Here we report GLS screening results for a similar set of inbred lines, most of which were included in the aforementioned studies. The primary objective in conducting this study was to identify tropical sources of GLS resistance. The results of this study, in conjunction with the results of Nelson et al. (2006) and Nelson (Chapter 3 of this thesis), will provide temperate maize breeders with a comprehensive resource for selecting tropical germplasm that is GLS-resistant and exhibits favorable agronomic characteristics.

Materials and Methods

Germplasm Selection

The 102 exotic inbreds screened for GLS resistance were chosen because they are likely candidates for use in broadening the U.S. maize germplasm base. They have potential for contributing not only GLS resistance, but favorable yield and other agronomic characteristics to U.S. maize. Most of the lines were developed by the International Maize

and Wheat Improvement Center (CIMMYT) in Mexico (Srinivasan, 2001). Eight were developed by the International Institute of Tropical Agriculture (IITA) in Nigeria. Seven were developed in Cameroon through joint cooperation of IITA and the Cameroon Institute of Agronomic Research (IRA) (Everett et al., 1994a, 1994b). Six were developed at Kasetsart University in Thailand (Chutkaew et al.). Four are of temperate exotic origin, developed at the University of Novi Sad in Serbia. Four were developed by Hans Gevers at the Agricultural Research Council's Grain Crop Institute in South Africa. One, A6, is a Cuban flint developed in Cuba by C. G. del Valle (1952). One line, an NC296A derivative, is an all-tropical line that was developed at North Carolina State University but underwent a gametophyte factor conversion attempt at Novi Sad University, Serbia. Table 4.1 lists the breeding institutions and their relative line prefix.

The exotic lines were screened for GLS as inbreds per se and in testcross combinations using remnant seed from previous yield trial experiments (Nelson et al., 2006, Chapter 3 of this thesis). Only 53 of the lines were tested in testcrosses because seed from some of the poorly performing testcroses (from yield trials) had been discarded. Three lines, Ki44, NC296A-NS, and Tzi11 were not screened as inbreds per se, but were screened in testcrosses. Testcrosses were made as follows. The exotic line entered a three-way testcross with a broad based U.S. tester, LH132 × LH51 (Holden's Foundation Seeds), an improved B73 × Mo17 hybrid of SS × NSS origin. Because inbreds 326172w, 326633A, and 327609A are of known SS origin, these lines were crossed to FR615 × FR697 (Illinois Foundation Seed). Some of the exotic lines were also represented in two modified three-way testcrosses, each resulting in a 25%-exotic testcross. In the first of these testcrosses, the exotic line was crossed to a line of SS origin and then crossed to a NSS × NSS sister-line hybrid. The SS line used was NC374 and the NSS × NSS sister-line hybrid was FR615 × FR697. In the second of these modified three-way testcrosses, each exotic line was crossed to a line of NSS origin and then crossed to a SS × SS sister-line hybrid. The NSS line used was either NC414, NC418, or NC382 and the SS × SS sister-line hybrid used was FR992 × FR1064 (Illinois Foundation Seed).

Inbred and hybrid checks with varying degrees of GLS susceptibility were included in the study. The GLS susceptible inbred check was B73. Inbred lines NC250, NC258, and

NC304 served as the GLS-resistant checks. The GLS susceptible hybrid checks were Pioneer 3394 and Pioneer 3223. The GLS-resistant hybrid checks used were DeKalb 687, Pioneer 32W86, and Pioneer 32K61.

Experimental Design

GLS screening trials were grown in the mountain and western piedmont regions of North Carolina at three locations: Andrews, NC, Laurel Springs, NC, and Salisbury, NC (Figures B.5 and B.6). These locations are in areas that are prone to GLS development and the fields used have a history of severe GLS infection. Plots at Salisbury and Andrews were planted no-till in fields that had GLS-infected residue from the previous season. Plots at Laurel Springs were planted into conventional tillage all years except one and were inoculated with *C. zeae-maydis* infested sorghum seeds each year when plants were at the V6 growth stage.

Inbred per se screening trials were grown at Andrews from 2000-2005, at Laurel Springs in 2000, 2001, and 2003-2005, and at Salisbury in 2003. Thus, 12 environments were represented in inbred per se screening. One replication was planted at nine of the environments, two replications were planted at the other three environments in a randomized complete block design. Replication between environments was not equal; for example, some lines were grown in all 12 environments while some were grown in only one. This is partially because initial GLS screening efforts among these exotic inbreds were focused only on lines that performed well in yield trials. However, beginning in 2003, GLS screening among exotic inbreds was expanded and 100 of the 102 exotic inbreds were screened in 2005. The number of environments in which each line was grown is given in Table 4.2.

Testcross screening trials were grown in two environments only, Andrews and Laurel Springs in 2005. Plots were arranged in a randomized complete block design with two replications in each environment.

Plots at Laurel Springs and Salisbury were 4.88 m in length measured from the center of the alley with 1m alleys and 25 seeds planted per plot. Plots at Andrews were 3.05 m in length measured from the center of the alley with .80 m alleys and ~15 seeds planted per plot. Row spacing was .91 m at Laurel Springs and .76 m at Salisbury and Andrews. Target

plant density, in plant/ha^{-1}, was 56,000 at Laurel Springs, 67,000 at Salisbury, and 65,000 at Andrews.

Visual GLS ratings were given on a 1 – 9 scale as described by Bubeck et al. (1993), 1 being fully susceptible and 9 being fully resistant. The first GLS rating at Laurel Springs was taken when the majority of the plants in the environment were at anthesis. Initial ratings at Andrews were taken shortly after anthesis. Subsequent GLS ratings at both locations were taken at about 10 day intervals until the majority of the plants reached senescence. Three to four ratings were taken at each environment.

Data Analysis

An average GLS rating was obtained for each plot using the area under the disease progress curve (AUDPC) as initially described by Shaner and Finney (1977) and as given by Campbell and Madden (1990):

$$\text{AUDPC} = \sum_{i}^{n-1}\left(\frac{y_i + y_{i+1}}{2}\right)\left(t_{i+1} - t_i\right)$$

where n is the number of ratings, y_i is the i^{th} rating, and t_i is the time (days) of the i^{th} rating. The AUDPC value was standardized to the original 1 – 9 scale by dividing by the total area of the graph, $(t_n - t_1)$ (Campbell and Madden, 1990; Fry, 1978).

Statistical analysis was done using SAS version 9.1.3 (SAS Institute Inc., 2003). Mean GLS ratings within environments (that had multiple replications) and across environments were obtained using a mixed model; genotypes were considered fixed and all other effects were considered random. Because the data for inbred per se GLS trials was unbalanced across environments, mean GLS ratings are estimated with varying levels of precision as indicated by the standard errors given in Table 4.2. In the analysis of testcross data from Laurel Springs in 2005, days to anthesis had a significant effect (p = .003) when included in the model as a covariate. However, because the coefficient of correlation between means obtained with and without the covariate was very high, r = .98, the covariate was dropped from the model for the final analysis. A protected LSD was used to assess differences between testcross entries using Saxton's (1998) pdmix800 means separation SAS macro.

Correlations between inbred per se and testcross GLS ratings were obtained using Spearman's coefficient of rank correlation.

Results and Discussion

Entry Performance

In all analyses, F-values for the null hypothesis of no differences in mean GLS rating between genotypes were highly significant for both inbred per se and testcross trials either with or without the checks included in the analysis.

Mean GLS ratings for inbreds per se and testcrosses are given in Tables 4.2 and 4.3, respectively. Experimental entries that performed within the top 10% are emboldened. Among the inbred lines, CML5, CML14, CML108, and CML145 showed the greatest GLS resistance. The 12 most resistant inbreds had GLS resistance at or greater than the most resistant check, NC250, which had a mean GLS rating of 7.3. Among the testcrosses, the entries with the greatest GLS resistance were the 50%-exotic CML258, CML254, and CML281 testcrosses and the 25%-exotic CML373.NC374 testcross. There were 30 testcross entries that were as resistant as or more resistant than the most resistant hybrid check, Pioneer 32W86, which had a mean GLS rating of 6.9.

Because 50 of the lines were screened both as inbreds per se and as testcrosses, a correlation analysis was used to address the relationship of GLS resistance in the inbreds per se and their respective testcrosses. Because inbred per se and testcross GLS screening trials were done in separate experiments and in different environments, Spearman's coefficient of rank correlation, a nonparametric correlation statistic, was used. The correlation between GLS resistance in inbreds per se and their respective hybrids was relatively high, $r = .59$. This suggests that many of the inbreds retained much of their GLS resistance in hybrid combination.

Gray Leaf Spot and Yield Correlation

Because all of the exotic lines that were tested in GLS screening trials were also tested in yield trials in earlier studies (Nelson et al., 2006; Chapter 3 of this thesis), a comparison was done to assess GLS resistance and yield potential. Inbred per se GLS ratings for each line were plotted against testcross yield performance on the broad based tester,

LH132 × LH51. Because yield data are from two separate studies, two plots are given, one corresponding to yield data from Nelson et al. (2006) (Figure 4.1), and one corresponding to yield data from Chapter 3 of this thesis (Figure 4.2). Coefficients of correlation, though negative in both cases, were not significantly different from zero (r = -.08 and r = -.03). Similar results were seen when testcross GLS scores were plotted against testcross yield performance (Figures C.1 and C.2).

There are several lines that stand out as having both high GLS resistance and high yield potential. From Figure 4.1, CML258 was the highest ranked entry for both GLS resistance and testcross yield performance. CML277 and Tzi16 also had high GLS resistance and high testcross yield. From Figure 4.2, three lines stand out as having good GLS resistance and testcross yield, CML108, CML274, and CML343.

The relatively neutral correlation between GLS resistance and testcross yield performance indicates that GLS resistance among this group of exotic materials is relatively independent of yield potential. This is good news for breeders who must often sacrifice yield for disease resistance or vice versa.

Conclusion

Gray leaf spot has become one of the most economically important foliar diseases of maize. As incidence of GLS increases, so does the need for GLS-resistant germplasm, especially on the SS side of the pedigree. Here we have identified a group of exotic maize inbreds, mostly of tropical origin, that carry substantial GLS resistance. Various studies have shown that many tropical materials combine well with either SS or NSS germplasm (Holland and Goodman, 1995; Holley and Goodman, 1988; Nelson et al., 2006). Thus, tropical sources of GLS resistance may be utilized in backcrossing programs with elite SS or NSS materials without disrupting heterotic patterns. Many of the GLS-resistant lines presented here also exhibit high yield potential that merits attention beyond a mere backcrossing program. Such lines are CML108, CML258, CML274, CML277, CML343, and Tzi16. These lines are valuable to temperate breeders, not only for their high yield potential and GLS resistance, but also for their contribution of diverse germplasm to the narrowing U.S. maize germplasm base.

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Table 4.1 Breeding programs / breeders and line prefixes.

Breeding Program / Breeder	Line Prefix
International Maize and Wheat Improvement Center (CIMMYT)	CML
University of Novi Sad, Serbia	numeric*
International Institute of Tropical Agriculture (IITA)	Tzi
Cameroon Institute of Agronomic Research (IRA) / IITA	numeric, C
Kasetsart University, Thailand	KUI, Ki
Hans Gevers, South Africa	BO, DO, VO, A
Carlos González del Valle, Cuba	A6†
North Carolina State University	NC

* Alpha-numeric designation, ex. 314190w.

† A6 is the only Cuban line represented in this study.

Table 4.2 GLS ratings of 102 experimental inbreds and 5 checks with standard errors and # of environments.

Entry	GLS Rating	SE	Env #	Entry	GLS Rating	SE	Env #
A214N	6.2	0.39	4	CML274	7.1	0.34	6
A6	5.9	0.39	4	CML277	7.0	0.32	7
BO46W	7.1	0.52	2	CML281	7.3	0.31	8
C70	6.6	0.52	2	CML285	7.3	0.39	4
CML5	**8.2**	0.29	9	CML287	6.4	0.32	7
CML9	6.9	0.34	6	CML288	7.3	0.36	5
CML10	**7.5**	0.29	10	CML295	6.9	0.52	2
CML14	**7.7**	0.31	8	CML304	7.0	0.36	5
CML16	6.9	0.34	6	CML311	6.1	0.39	4
CML38	6.1	0.34	6	CML314	**7.5**	0.39	4
CML40	7.2	0.34	6	CML319	6.2	0.34	6
CML45	7.1	0.32	7	CML321	6.8	0.71	1
CML48	6.9	0.32	7	CML322	5.3	0.52	2
CML52	**7.4**	0.27	12	CML323	6.8	0.52	2
CML56	6.7	0.44	3	CML325	6.6	0.44	3
CML61	**7.4**	0.32	7	CML327	6.3	0.36	5
CML69	6.1	0.36	5	CML329	5.8	0.44	3
CML91	6.7	0.39	4	CML331	7.0	0.71	1
CML92	6.7	0.36	5	CML332	6.7	0.52	2
CML103	5.7	0.36	5	CML333	5.7	0.36	5
CML108	**7.7**	0.34	6	CML341	6.4	0.34	6
CML116	6.7	0.71	1	CML343	6.7	0.36	5
CML142	6.2	0.44	3	CML373	6.8	0.36	5
CML144	6.8	0.39	4	CML374	7.2	0.36	5
CML145	**7.6**	0.32	7	CML384	6.8	0.39	4
CML150	6.6	0.34	6	DO940Y	6.2	0.52	2
CML154Q	5.7	0.36	5	Ki3	6.4	0.71	1
CML157Q	6.4	0.39	4	Ki11	3.7	0.52	2
CML158Q	5.7	0.52	2	Ki21	6.9	0.39	4
CML159	7.2	0.34	6	Ki43	4.7	0.71	1
CML161	6.7	0.44	3	KUI2007	4.4	0.71	1
CML173	6.9	0.52	2	KUI2021	6.7	0.52	2
CML176	6.6	0.44	3	Tzi3	6.3	0.52	2
CML184	5.8	0.44	3	Tzi8	6.1	0.32	7
CML186	5.6	0.44	3	Tzi9	5.5	0.39	4
CML193	5.2	0.44	3	Tzi10	6.9	0.32	7
CML216	6.7	0.44	3	Tzi16	6.9	0.27	12
CML218	6.2	0.44	3	Tzi17	7.1	0.52	2
CML220	3.8	0.71	1	Tzi18	6.9	0.27	12
CML223	6.2	0.36	5	Tzi25	5.8	0.34	6
CML228	3.9	0.52	2	VO613Y	**7.5**	0.31	8
CML238	6.7	0.52	2	314190w	5.9	0.71	1
CML247	6.7	0.29	10	316096A	4.3	0.52	2
CML254	7.3	0.36	5	317027A	5.7	0.71	1
CML255	6.5	0.44	3	318056A	6.0	0.71	1
CML258	**7.5**	0.29	10	87036	5.7	0.52	2
CML261	7.1	0.29	10	89199	5.9	0.52	2
CML264	6.5	0.44	3	89291	5.9	0.52	2
CML269	6.9	0.34	6	89302	7.0	0.71	1
CML270	6.9	0.36	5	90156	7.2	0.52	2
CML273	7.1	0.34	6	90301	6.3	0.52	2
Susceptible Checks:				Resistant Checks:			
B73	4.4	0.28	10	NC250	7.3	0.29	9
Pioneer 3394	4.2	0.30	8	NC258	6.7	0.28	10
				NC304	7.2	0.31	8

Mean of Experimental Entries: 6.5
Mean of Susceptible Checks: 4.3
Mean of Resistant Checks: 7.1

GLS ratings on a 1-9 scale, 1 = susceptible 9 = resistant. Entries with ratings within the top 10% are emboldened.

Table 4.3 GLS ratings of testcrosses and 15 commercial checks.

Experimental Entry	GLS Rating	Experimental Entry	GLS Rating
A6 × LH132.LH51	6.8	CML274.NC382 × FR992.FR1064	6.7
A6.NC328 × FR615.FR697	6.4	CML274.NC374 × FR615.FR697	6.5
A6.B97 × FR992.FR1064	6.3	CML277 × LH132.LH51	7.2
BO46W × LH132.LH51	6.7	CML277.NC328 × FR615.FR697	6.9
C70 × LH132.LH51	**7.2**	CML277.B97 × FR992.FR1064	6.3
CML10 × LH132.LH51	**7.2**	CML281 × LH132.LH51	**7.5**
CML10.NC414 × FR992.FR1064	6.6	CML281.NC328 × FR615.FR697	7.0
CML10.NC374 × FR615.FR697	6.8	CML281.B97 × FR992.FR1064	7.0
CML16 × LH132.LH51	6.7	CML287 × LH132.LH51	6.5
CML16.NC418 × FR992.FR1064	6.6	CML287.NC328 × FR615.FR697	6.6
CML16.NC374 × FR615.FR697	6.9	CML287.B97 × FR992.FR1064	6.2
CML38 × LH132.LH51	6.8	CML327 × LH132.LH51	6.8
CML38.NC418 × FR992.FR1064	6.9	CML333 × LH132.LH51	6.6
CML38.NC374 × FR615.FR697	6.9	CML333.NC414 × FR992.FR1064	6.4
CML69 × LH132.LH51	6.5	CML333.NC374 × FR615.FR697	6.4
CML69.NC414 × FR992.FR1064	6.2	CML341 × LH132.LH51	6.1
CML69.NC374 × FR615.FR697	6.4	CML341.NC414 × FR992.FR1064	6.5
CML91 × LH132.LH51	6.7	CML341.NC374 × FR615.FR697	**7.3**
CML91.NC414 × FR992.FR1064	6.6	CML343 × LH132.LH51	7.2
CML91.NC374 × FR615.FR697	6.9	CML343.NC382 × FR992.FR1064	6.6
CML92 × LH132.LH51	6.4	CML343.NC374 × FR615.FR697	7.0
CML92.NC414 × FR992.FR1064	5.6	CML373 × LH132.LH51	**7.2**
CML92.NC374 × FR615.FR697	6.4	CML373.NC382 × FR992.FR1064	7.0
CML103 × LH132.LH51	6.4	CML373.NC374 × FR615.FR697	**7.5**
CML103.NC414 × FR992.FR1064	5.9	CML374 × LH132.LH51	7.1
CML103.NC374 × FR615.FR697	6.6	CML374.NC382 × FR992.FR1064	6.5
CML108 × LH132.LH51	6.9	CML374.NC374 × FR615.FR697	6.9
CML108.NC414 × FR992.FR1064	6.0	DO940Y × LH132.LH51	6.4
CML108.NC374 × FR615.FR697	6.7	Ki3 × LH132.LH51	6.6
CML116 × LH132.LH51	6.6	Ki3.NC328 × FR615.FR697	6.4
CML154Q × LH132.LH51	6.2	Ki3.B97 × FR992.FR1064	5.9
CML154Q.NC414 × FR992.FR1064	6.4	Ki11 × LH132.LH51	5.9
CML154Q.NC374 × FR615.FR697	6.5	Ki11.NC328 × FR615.FR697	5.8
CML157Q × LH132.LH51	7.1	Ki11.B97 × FR992.FR1064	6.3
CML157Q.NC414 × FR992.FR1064	6.0	Ki21 × LH132.LH51	6.5
CML157Q.NC374 × FR615.FR697	6.7	Ki21.NC328 × FR615.FR697	6.6
CML176 × LH132.LH51	6.9	Ki21.B97 × FR992.FR1064	6.4
CML176.NC382 × FR992.FR1064	6.9	Ki43 × LH132.LH51	6.8
CML176.NC374 × FR615.FR697	**7.2**	Ki43.NC328 × FR615.FR697	6.5
CML216 × LH132.LH51	6.8	Ki43.B97 × FR992.FR1064	6.1
CML216.NC382 × FR992.FR1064	6.4	Ki44 × LH132.LH51	6.5
CML216.NC374 × FR615.FR697	6.4	Ki44.NC328 × FR615.FR697	6.4
CML247 × LH132.LH51	6.5	Ki44.B97 × FR992.FR1064	6.0
CML247.NC328 × FR615.FR697	6.9	KUI2007 × LH132.LH51	6.6
CML247.B97 × FR992.FR1064	6.5	KUI2007.NC328 × FR615.FR697	6.2
CML254 × LH132.LH51	**7.5**	KUI2007.B97 × FR992.FR1064	5.8
CML254.NC328 × FR615.FR697	6.9	KUI2021 × LH132.LH51	6.6
CML254.B97 × FR992.FR1064	6.8	KUI2021.NC328 × FR615.FR697	6.3
CML258 × LH132.LH51	**7.9**	KUI2021.B97 × FR992.FR1064	6.1
CML258.NC328 × FR615.FR697	6.5	NC296A × LH132.LH51	7.1
CML258.B97 × FR992.FR1064	6.8	Tzi3 × LH132.LH51	6.8
CML264 × LH132.LH51	6.9	Tzi8 × LH132.LH51	**7.2**
CML264.NC328 × FR615.FR697	6.3	Tzi8.NC328 × FR615.FR697	6.4
CML264.B97 × FR992.FR1064	6.3	Tzi8.B97 × FR992.FR1064	6.0
CML269 × LH132.LH51	6.8	Tzi9 × LH132.LH51	6.5
CML269.NC418 × FR992.FR1064	6.5	Tzi9.NC328 × FR615.FR697	6.4
CML269.NC374 × FR615.FR697	7.0	Tzi9.B97 × FR992.FR1064	6.2
CML274 × LH132.LH51	6.7	Tzi10 × LH132.LH51	**7.2**

Table 4.3 (continued)

Experimental Entry	GLS Rating	Experimental Entry	GLS Rating
Tzi10.NC328 × FR615.FR697	6.7	Tzi25 × LH132.LH51	6.1
Tzi10.B97 × FR992.FR1064	6.6	Tzi25.NC328 × FR615.FR697	6.1
Tzi11 × LH132.LH51	6.9	Tzi25.B97 × FR992.FR1064	6.0
Tzi11.NC328 × FR615.FR697	6.5	VO613Y × LH132.LH51	6.8
Tzi11.B97 × FR992.FR1064	6.8	89291 × LH132.LH51	6.3
Tzi16 × LH132.LH51	7.1	89302 × LH132.LH51	**7.2**
Tzi16.NC328 × FR615.FR697	6.4	90156 × LH132.LH51	6.7
Tzi16.B97 × FR992.FR1064	6.5	90301 × LH132.LH51	5.3
Tzi17 × LH132.LH51	7.1		

Commercial Check	GLS Rating	Commercial Check	GLS Rating
DeKalb 687	6.6	Pioneer 3165	6.4
DeKalb 697	6.4	Pioneer 3223	4.5
Garst 8288	5.6	Pioneer 32D99	6.6
HC33 × TR7322	6.5	Pioneer 32K61	6.6
LH132 × LH51	5.8	Pioneer 32R25	4.7
LH195 × LH256	6.2	Pioneer 32W86	6.9
LH200 × LH262	6.1	Pioneer 3394	4.4
NK91-R9	5.9		

Experimental Entries:	Mean = 6.6		
Commercial Checks:	Mean = 5.9	Max = 6.9	Min = 4.4

GLS ratings on a 1-9 scale, 1 = susceptible 9 = resistant. Experimental entries with ratings within the top 10% are emboldened.

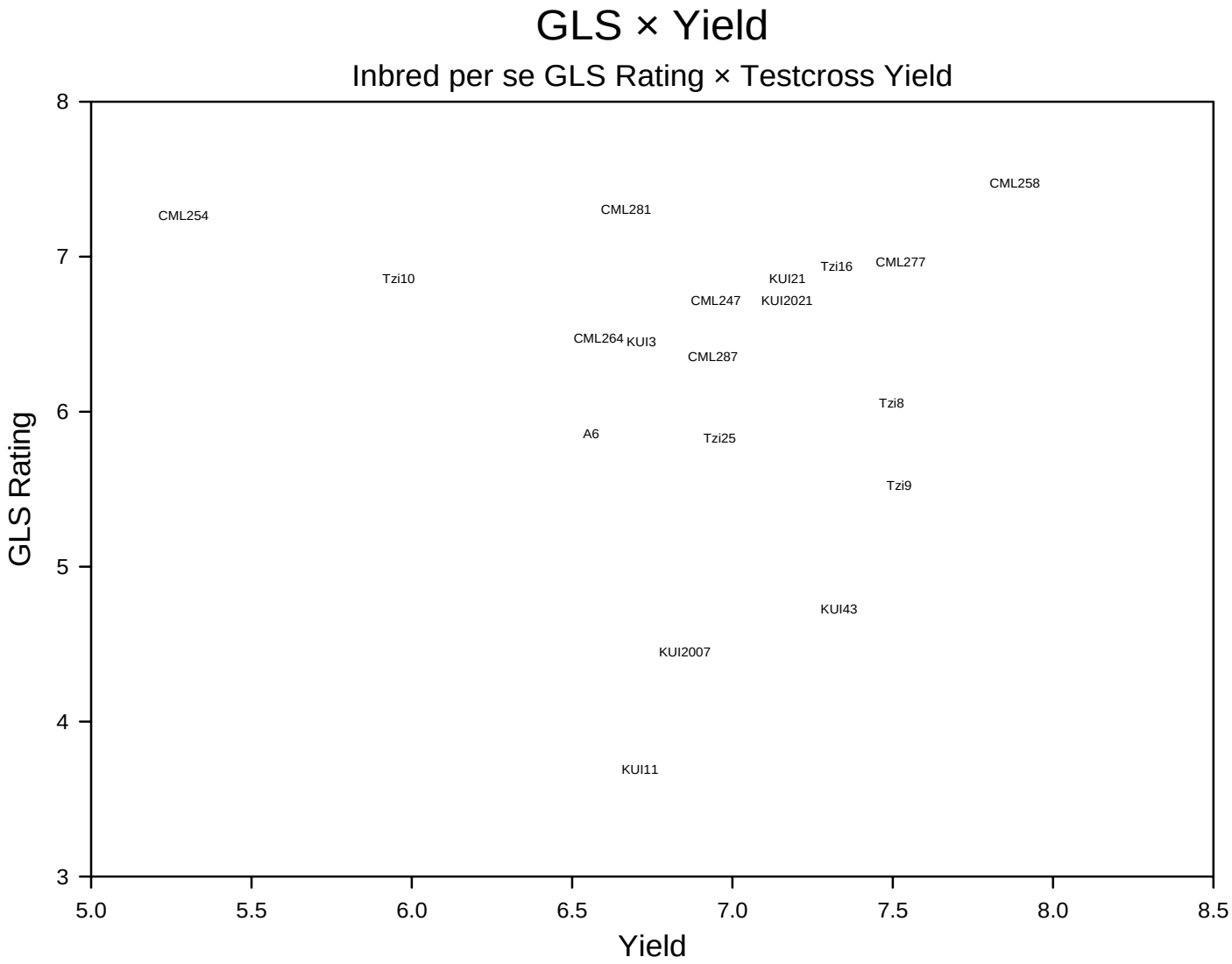

Figure 4.1 Inbred per se GLS ratings × testcross yield, entries from Nelson et al. (2006). Tester = LH132 × LH51. Coefficient of correlation, r = -0.08.

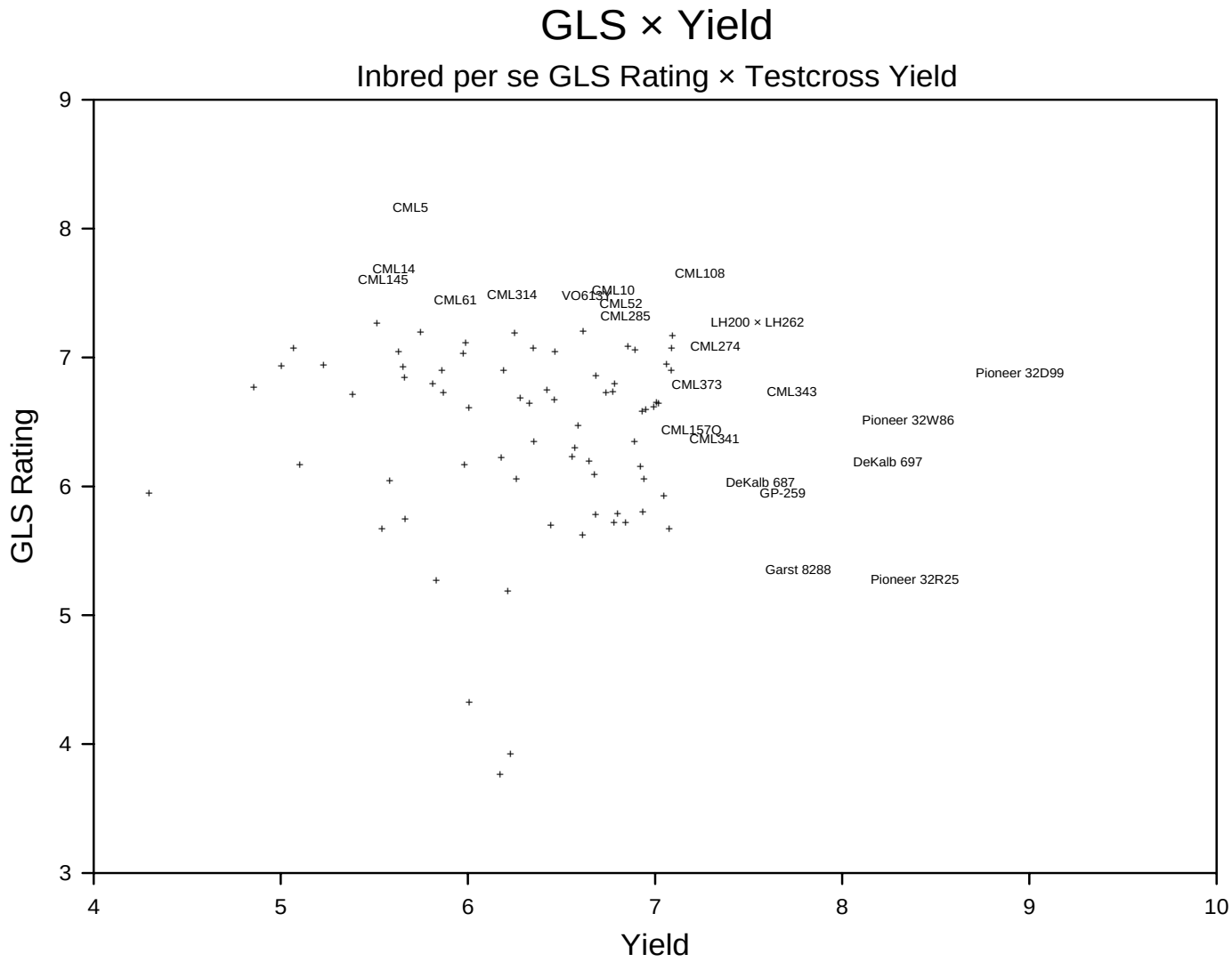

Figure 4.2 Inbred per se GLS ratings × testcross yield, entries from Chapter 3 of this thesis. Tester = LH132 × LH51. Coefficient of correlation, r = -0.03. For ease of viewing, only the higher-yielding / more resistant line names are shown, all other lines are represented by (+).

Appendices

– APPENDIX A –

Supporting Material for Chapter II

Line × Tester Interaction

There were significant line × tester interactions for yield among some of the tropical lines tested. Table A.1 gives mean testcross yield on the three testers used and significance values for line × tester interaction. Table A.2 expresses testcross yield as a deviation from the mean yield on the given tester, thereby minimizing line × tester interaction effects due to differences between testers.

Table A.1 Line × tester interactions for yield

Line	F-Value	Prob. F	Testcross Yield Mg ha^{-1}		
			SS × NSS 50%-Exotic	SS × SS 25%-Exotic	NSS × NSS 25%-Exotic
A6	7.52	0.001*	6.6	7.1	7.3
CML247	1.86	0.156	6.9	7.3	7.2
CML254	63.88	<.001*	5.3	6.8	7.4
CML258	8.46	<.001*	7.9	7.2	7.9
CML264	13.29	<.001*	6.6	7.3	7.8
CML277	5.17	0.006*	7.5	7.1	7.7
CML281	5.61	0.004*	6.7	7.2	7.3
CML287	3.18	0.043*	6.9	7.3	7.4
Ki3	0.25	0.777	6.7	6.7	6.8
Ki11	6.19	0.002*	6.7	7.2	7.4
Ki14	6.18	0.002*	6.5	7.0	7.1
Ki21	2.22	0.109	7.2	7.2	6.9
Ki43	1.38	0.252	7.3	7.1	7.4
Ki44	4.92	0.008*	6.6	6.9	7.3
KUI2007	4.93	0.008*	6.9	7.0	7.4
KUI2021	1.02	0.361	7.2	6.9	7.2
Tzi8	3.20	0.042*	7.5	7.2	7.7
Tzi9	1.97	0.141	7.5	7.6	7.9
Tzi10	29.79	<.001*	6.0	6.9	7.4
Tzi11	1.86	0.158	6.9	7.1	7.3
Tzi16	2.77	0.064	7.3	7.1	7.6
Tzi25	2.94	0.054*	7.0	7.1	7.4

F-values and significance levels of line × tester interactions. Mean line yield on each tester is given.

Table A.2 Line × tester interactions for yield given as deviations from the mean

Line	F-Value	Prob. F	Testcross Yield Mg ha^{-1}		
			SS × NSS 50%-Exotic	SS × SS 25%-Exotic	NSS × NSS 25%-Exotic
A6	1.10	0.334	-0.3	0.0	-0.1
CML247	1.88	0.154	0.1	0.2	-0.2
CML254	39.09	<.001*	-1.6	-0.3	0.0
CML258	11.25	<.001*	1.0	0.1	0.5
CML264	5.04	0.007*	-0.3	0.2	0.4
CML277	6.18	0.002*	0.6	0.0	0.3
CML281	0.90	0.408	-0.2	0.1	-0.1
CML287	0.57	0.566	0.0	0.2	0.0
Ki3	1.85	0.159	-0.2	-0.4	-0.5
Ki11	0.77	0.464	-0.2	0.1	0.0
Ki14	1.26	0.285	-0.4	-0.1	-0.2
Ki21	10.19	<.001*	0.3	0.1	-0.5
Ki43	3.63	0.027*	0.4	0.0	0.0
Ki44	0.49	0.611	-0.3	-0.2	-0.1
KUI2007	0.42	0.659	0.0	-0.1	0.0
KUI2021	3.89	0.021*	0.3	-0.2	-0.2
Tzi8	3.58	0.029*	0.6	0.1	0.3
Tzi9	0.47	0.627	0.6	0.5	0.5
Tzi10	13.95	<.001*	-0.9	-0.2	0.0
Tzi11	0.23	0.794	0.0	0.0	-0.1
Tzi16	2.50	0.084	0.4	0.0	0.2
Tzi25	0.02	0.976	0.1	0.0	0.0
Mean			6.9	7.1	7.4

F-values and significance levels of line × tester interactions expressed as deviations from the mean as given.

– APPENDIX B –

Supporting Material for Chapter III

Results and Discussion

Subsets of Exotic Entries

In 2001 (Table B.2), the CML341 testcross was the highest yielding experimental entry, followed by the CML103 and CML108 testcrosses. Of the six highest yielding experimental entries, five were not significantly different from the check mean for moisture, and all six flowered within two days of the check mean. The CML108 testcross was better than or equal to the check mean for all traits except plant height.

In 2002 (Table B.3), the CML341 testcross was again the highest yielding experimental entry, followed by the CML38, CML269, and CML157Q testcrosses. The CML16 and CML274 testcrosses, which were new additions to the experiment in 2002, were also among the highest yielding experimental entries. The CML108 testcross again performed well overall, being within one LSD of the check mean for all traits.

In 2003 (Table B.4) and thereafter, 25%-exotic testcrosses were included in the study. Entry means among 25%-exotic entries tend to be superior to those among 50%-exotic testcrosses because they contain a larger percentage of adapted germplasm. For this reason, experimental entry performance will be addressed separately for 50%-and 25%-exotic crosses. Among the 50%-exotic entries, the CML154Q testcross was the highest yielding, followed by the CML103 and CML373 testcrosses. The CML373 testcross was new to the study in 2003 and had a higher percentage of erect plants than all other experimental entries, including the checks. The CML343 testcross, also new in 2003, also had high percentage erect plants and relatively good yield. The CML108 testcross was again among the top yielding experimental entries and was within one LSD of the checks for all traits except moisture. Among the 25%-exotic entries, the CML10.NC374 testcross was the highest yielding, followed by the CML92.NC374 and CML10.NC414 testcrosses. The CML341.NC414 and CML154Q.NC414 testcrosses were also among the top yielding experimental entries.

In 2003, plots were planted at three locations, all of which incurred heavy hurricane damage at the end of the season. Plots at one location were abandoned entirely and the remaining two locations were harvested despite severe lodging. Because there were fewer replications and there was substantial plot damage, standard errors and LSDs in 2003 were larger than in other years. Percent erect plants at harvest for the experimental entries and checks were low, 45% and 41% respectively. Moistures were also low due to weather-related harvest delays.

Among the 50%-exotic entries in 2004 (Table B.5), the CML343 testcross was the highest yielding, followed by the CML373 and CML157Q testcrosses. The CML108 testcross was again among the highest yielding experimental entries and was within one LSD of the check mean for all traits. Among 25%-exotic entries, the two CML341 testcrosses were the highest yielding experimental entries, followed by the CML10.NC414 testcross. The CML341.NC374 testcross was also drier than the check mean.

Among the 50%-exotic entries in 2005 (Table B.6), the CML274 testcross was the highest yielding followed by the CML343 and 89291 testcrosses. Inbred 89291 was new to the experiment in 2005. Among the 25%-exotic entries, the CML16.NC374 testcross was the highest yielding, followed by the CML341.NC374 and CML343.NC374 testcrosses. The CML274.NC374, CML343.NC382, and both CML10 testcrosses were also among the highest yielding experimental entries.

Table B.7 gives means for a subset of entries that were tested together from 2002 through 2005, representing data from 14 environments. All experimental entries in this analysis failed to be within one LSD of the check mean for yield. The CML274 testcross was the highest yielding experimental entry, followed by the CML341 and CML157Q testcrosses. The CML108 testcross was also among the highest yielding experimental entry and was within one LSD of the check mean for all traits except yield. The driest experimental entry was the CML103 testcross and four experimental entries flowered as early as the check mean.

Table B.8 gives mean value for all 136 experimental entries and 13 checks taken across all 18 environments. Because of the unbalanced design across all environments, mean values are estimated with varying levels of precision as indicated by the standard errors given

in the table. Experimental entry mean values that were within the best 10% are emboldened. Among the 50%-exotic entries, the CML343, 89291, and NC296A testcrosses were the highest yielding. Among the 25%-exotic entries, the CML343.NC374 and CML341.NC374 testcrosses were the highest yielding.

Stability Analysis Using an Environmental Index

In Finlay and Wilkinson's (1963) environmental index, entry performance at each environment is regressed on overall environment mean. The regression coefficient is viewed as a measure of stability. A regression coefficient of $b = 0$ indicates that an entry's performance does not change over environments, i.e. it is stable. However, this may also indicate that an entry does not perform to the potential allowed by the environment. A regression coefficient greater than $b = 1$ is an indication of instability because such entries may perform well in optimum conditions only. According to Finlay and Wilkerson, an ideal genotype will have maximum yield potential in the most favorable environments and also show stability across environments. Entries with a regression coefficient around $b = 1$ fit into this category; they are considered relatively stable across environments and yet adaptable to changes in the yield potential established by the environment. Environmental index regression coefficients for each entry are given by year in Tables B.13 – B.16.

References

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Table B.1 Entries and years tested.

Experimental Entries	Years Tested				
A214N × LH132.LH51	2001				
BO46W × LH132.LH51			2003	2004	2005
C70 × LH132.LH51					2005
CML5 × LH132.LH51	2001				
CML9 × LH132.LH51	2001				
CML10 × LH132.LH51	2001	2002	2003	2004	2005
CML10.NC414 × FR992.FR1064			2003	2004	2005
CML10.NC374 × FR615.FR697			2003	2004	2005
CML14 × LH132.LH51	2001				
CML16 × LH132.LH51		2002	2003	2004	2005
CML16.NC418 × FR992.FR1064				2004	2005
CML16.NC374 × FR615.FR697				2004	2005
CML38 × LH132.LH51	2001	2002	2003	2004	2005
CML38.NC418 × FR992.FR1064				2004	2005
CML38.NC374 × FR615.FR697				2004	2005
CML40 × LH132.LH51		2002			
CML45 × LH132.LH51	2001				
CML48 × LH132.LH51		2002			
CML52 × LH132.LH51	2001	2002			
CML56 × LH132.LH51		2002			
CML61 × LH132.LH51	2001				
CML69 × LH132.LH51	2001	2002	2003	2004	2005
CML69.NC414 × FR992.FR1064			2003	2004	2005
CML69.NC374 × FR615.FR697			2003	2004	2005
CML91 × LH132.LH51	2001	2002	2003	2004	2005
CML91.NC414 × FR992.FR1064			2003	2004	2005
CML91.NC374 × FR615.FR697			2003	2004	2005
CML92 × LH132.LH51	2001	2002	2003	2004	2005
CML92.NC414 × FR992.FR1064			2003	2004	2005
CML92.NC374 × FR615.FR697			2003	2004	2005
CML103 × LH132.LH51	2001	2002	2003	2004	2005
CML103.NC414 × FR992.FR1064			2003	2004	2005
CML103.NC374 × FR615.FR697			2003	2004	2005
CML108 × LH132.LH51	2001	2002	2003	2004	2005
CML108.NC414 × FR992.FR1064			2003	2004	2005
CML108.NC374 × FR615.FR697			2003	2004	2005
CML116 × LH132.LH51				2004	2005
CML142 × LH132.LH51		2002			
CML144 × LH132.LH51		2002			
CML145 × LH132.LH51		2002			
CML150 × LH132.LH51		2002			
CML154Q × LH132.LH51	2001	2002	2003	2004	2005
CML154Q.NC414 × FR992.FR1064			2003	2004	2005
CML154Q.NC374 × FR615.FR697			2003	2004	2005
CML157Q × LH132.LH51	2001	2002	2003	2004	2005
CML157Q.NC414 × FR992.FR1064			2003	2004	2005
CML157Q.NC374 × FR615.FR697			2003	2004	2005
CML158Q × LH132.LH51	2001				
CML159 × LH132.LH51		2002			
CML161 × LH132.LH51		2002			
CML173 × LH132.LH51		2002			
CML176 × LH132.LH51		2002	2003	2004	2005

Table B.1 (continued)

Experimental Entries	Years Tested				
CML176.NC382 × FR992.FR1064					2005
CML176.NC374 × FR615.FR697					2005
CML184 × LH132.LH51		2002			
CML186 × LH132.LH51		2002			
CML193 × LH132.LH51		2002			
CML216 × LH132.LH51		2002	2003	2004	2005
CML216.NC382 × FR992.FR1064					2005
CML216.NC374 × FR615.FR697					2005
CML218 × LH132.LH51	2001				
CML220 × LH132.LH51	2001				
CML223 × LH132.LH51		2002			
CML228 × LH132.LH51	2001				
CML238 × LH132.LH51	2001				
CML255 × LH132.LH51		2002			
CML261 × LH132.LH51	2001				
CML269 × LH132.LH51		2002	2003	2004	2005
CML269.NC418 × FR992.FR1064				2004	2005
CML269.NC374 × FR615.FR697				2004	2005
CML270 × LH132.LH51			2003		
CML273 × LH132.LH51		2002			
CML274 × LH132.LH51		2002	2003	2004	2005
CML274.NC382 × FR992.FR1064					2005
CML274.NC374 × FR615.FR697					2005
CML285 × LH132.LH51		2002			
CML288 × LH132.LH51			2003		
CML295 × LH132.LH51		2002			
CML304 × LH132.LH51			2003		
CML311 × LH132.LH51	2001				
CML314 × LH132.LH51	2001				
CML319 × LH132.LH51		2002			
CML321 × LH132.LH51	2001				
CML322 × LH132.LH51	2001				
CML323 × LH132.LH51	2001				
CML325 × LH132.LH51			2003		
CML327 × LH132.LH51			2003	2004	2005
CML329 × LH132.LH51		2002			
CML331 × LH132.LH51	2001				
CML332 × LH132.LH51	2001				
CML333 × LH132.LH51	2001	2002	2003	2004	2005
CML333.NC414 × FR992.FR1064			2003	2004	2005
CML333.NC374 × FR615.FR697			2003	2004	2005
CML341 × LH132.LH51	2001	2002	2003	2004	2005
CML341.NC414 × FR992.FR1064			2003	2004	2005
CML341.NC374 × FR615.FR697			2003	2004	2005
CML343 × LH132.LH51			2003	2004	2005
CML343.NC382 × FR992.FR1064					2005
CML343.NC374 × FR615.FR697					2005
CML373 × LH132.LH51			2003	2004	2005
CML373.NC382 × FR992.FR1064					2005
CML373.NC374 × FR615.FR697					2005
CML374 × LH132.LH51			2003	2004	2005
CML374.NC382 × FR992.FR1064					2005

Table B.1 (continued)

Experimental Entries	Years Tested				
CML374.NC374 × FR615.FR697					2005
CML384 × LH132.LH51			2003		
DO940Y × LH132.LH51			2003	2004	2005
NC296A-NS × LH132.LH51				2004	2005
Tzi3 × LH132.LH51					2005
Tzi17 × LH132.LH51					2005
Tzi18 × LH132.LH51	2001				
VO613Y × LH132.LH51			2003	2004	2005
314190w × LH132.LH51			2003		
316096A × LH132.LH51			2003		
317027A × LH132.LH51			2003		
318056A × LH132.LH51			2003		
326172w. × FR615.FR697			2003	2004	
326633A. × FR615.FR697			2003		
327609A. × FR615.FR697			2003		
796 NS × LH132.LH51			2003		
87036 × LH132.LH51					2005
89199 × LH132.LH51					2005
89291 × LH132.LH51					2005
89302 × LH132.LH51					2005
90156 × LH132.LH51					2005
90301 × LH132.LH51					2005
Checks					
DeKalb 687	2001				
DeKalb 697		2002	2003	2004	2005
Garst 8288		2002	2003		2005
HC33 × TR7322					2005
LH132 × LH51	2001		2003	2004	2005
LH195 × LH256			2003		2005
LH200 × LH262		2002	2003	2004	2005
Pioneer 3165	2001				
Pioneer 32D99					2005
Pioneer 32K61	2001	2002	2003		
Pioneer 32R25			2003		2005
Pioneer 32W86					2005
Pioneer 31G98		2002	2003	2004	2005

Table B.2 2001 entry means. Data from Clayton, Lewiston, Plymouth, and Sandhills, NC.

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1]* %	Anth Days
A214N × LH132.LH51	6.0	**17.9**	**106**	**269**	99	**73**
CML5 × LH132.LH51	6.6	**21.1**	117	314	98	79
CML9 × LH132.LH51	6.5	25.7	**109**	288	100	80
CML10 × LH132.LH51	**7.7**	22.5	117	298	99	**78**
CML14 × LH132.LH51	6.5	25.9	123	292	99	79
CML38 × LH132.LH51	**7.5**	25.0	124	**285**	98	**78**
CML45 × LH132.LH51	5.9	22.3	121	304	99	84
CML52 × LH132.LH51	**7.4**	22.3	121	305	99	79
CML61 × LH132.LH51	6.8	22.1	126	311	99	83
CML69 × LH132.LH51	**7.6**	21.9	114	290	97	**75**
CML91 × LH132.LH51	**7.8**	**19.7**	111	289	100	**76**
CML92 × LH132.LH51	**8.0**	**19.7**	**109**	288	99	**75**
CML103 × LH132.LH51	**8.3**	**20.8**	121	291	98	**75**
CML108 × LH132.LH51	**8.3**	**19.6**	**101**	**286**	99	**74**
CML154Q × LH132.LH51	**7.6**	22.5	**99**	**272**	96	**76**
CML157Q × LH132.LH51	**7.8**	**20.9**	120	291	100	**76**
CML158Q × LH132.LH51	**7.3**	23.2	122	296	96	**77**
CML218 × LH132.LH51	6.9	**20.2**	**110**	**285**	99	**74**
CML220 × LH132.LH51	7.0	**19.3**	**101**	**272**	98	**73**
CML228 × LH132.LH51	7.1	**21.6**	**108**	**276**	99	79
CML238 × LH132.LH51	6.7	22.0	**101**	**265**	99	**75**
CML261 × LH132.LH51	6.9	23.4	133	315	98	79
CML311 × LH132.LH51	7.1	23.4	117	298	99	80
CML314 × LH132.LH51	7.1	**20.6**	116	288	100	**76**
CML321 × LH132.LH51	6.5	**21.3**	111	298	100	78
CML322 × LH132.LH51	6.7	**21.6**	**110**	**283**	99	**74**
CML323 × LH132.LH51	6.7	**19.3**	**103**	**271**	94	**73**
CML331 × LH132.LH51	6.5	25.0	**108**	293	99	78
CML332 × LH132.LH51	**7.3**	23.8	**108**	**284**	99	**75**
CML333 × LH132.LH51	**7.5**	**21.7**	119	293	98	**78**
CML341 × LH132.LH51	**8.4**	22.6	119	305	98	**78**
Tzi18 × LH132.LH51	7.1	22.0	**110**	**284**	96	**78**
Entry Means	7.2	21.9	114	290	98	77
DeKalb 687	8.4	19.1	104	277	100	76
LH132 × LH51	7.5	18.4	97	271	99	73
Pioneer 3165	7.8	22.6	106	283	97	79
Pioneer 32K61	7.8	18.3	97	282	99	74
Check Mean	7.9	19.6	101	278	98	75
Entry v. Entry LSD	0.9	2.9		1211	3	2
Entry v. Entry Mean LSD	0.6	2.1		88	2	2
Entry v. Check Mean LSD	0.7	2.3		99	3	2

* Non significant effect at $\alpha = .05$

[1] Percent erect plants at harvest.

Table B.3 2002 entry means. Data from Clayton, Lewiston, Plymouth, and Sandhills, NC.

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
CML10 × LH132.LH51	5.9	17.5	96	254	91	72
CML16 × LH132.LH51	**6.4**	17.4	111	271	**93**	72
CML38 × LH132.LH51	**6.6**	17.7	106	**240**	**92**	72
CML40 × LH132.LH51	5.4	16.7	109	263	**96**	72
CML48 × LH132.LH51	4.1	16.7	114	274	**98**	73
CML52 × LH132.LH51	**6.2**	17.9	100	258	**92**	72
CML56 × LH132.LH51	4.5	17.9	106	266	**95**	73
CML69 × LH132.LH51	5.8	17.5	**95**	**234**	**95**	**70**
CML91 × LH132.LH51	5.8	**16.0**	**93**	**245**	**97**	**72**
CML92 × LH132.LH51	5.2	16.4	**89**	**241**	**95**	**69**
CML103 × LH132.LH51	6.1	**15.7**	102	**233**	79	**70**
CML108 × LH132.LH51	**6.3**	**15.7**	**84**	**237**	**96**	**69**
CML142 × LH132.LH51	6.1	17.5	117	271	**98**	76
CML144 × LH132.LH51	5.9	17.3	109	254	88	76
CML145 × LH132.LH51	4.7	16.4	100	261	**95**	72
CML150 × LH132.LH51	5.5	16.5	**94**	**240**	**99**	**70**
CML154Q × LH132.LH51	5.4	16.9	**89**	**233**	80	**70**
CML157Q × LH132.LH51	**6.4**	17.0	104	**248**	**98**	**70**
CML159 × LH132.LH51	5.7	17.6	98	261	**93**	73
CML161 × LH132.LH51	5.4	18.3	104	252	**98**	74
CML173 × LH132.LH51	5.8	22.0	**78**	**228**	**96**	**69**
CML176 × LH132.LH51	**6.2**	17.0	108	262	83	74
CML184 × LH132.LH51	6.1	16.7	**90**	**231**	**95**	**69**
CML186 × LH132.LH51	5.7	16.6	**86**	**232**	**99**	**70**
CML193 × LH132.LH51	5.3	**16.1**	**92**	**238**	**96**	**70**
CML216 × LH132.LH51	**6.2**	17.9	110	271	89	73
CML223 × LH132.LH51	5.7	18.5	**92**	**243**	**96**	73
CML255 × LH132.LH51	5.7	17.9	108	265	**99**	74
CML269 × LH132.LH51	**6.4**	17.7	102	258	**98**	73
CML273 × LH132.LH51	6.0	16.8	101	257	**99**	75
CML274 × LH132.LH51	**6.3**	17.0	101	258	**98**	75
CML285 × LH132.LH51	6.0	17.9	106	263	**95**	73
CML295 × LH132.LH51	5.0	17.2	108	260	**93**	72
CML319 × LH132.LH51	5.3	16.8	106	268	**97**	74
CML329 × LH132.LH51	5.9	**16.0**	**85**	**246**	**97**	**68**
CML333 × LH132.LH51	**6.2**	18.3	105	**249**	89	**70**
CML341 × LH132.LH51	**6.9**	17.7	104	254	**94**	74
Entry Mean	5.8	17.3	100	252	94	72
DeKalb 697	7.2	15.8	91	243	95	69
Garst 8288	6.7	15.8	86	242	98	69
LH200 × LH262	6.7	15.9	95	248	98	72
Pioneer 32K61	6.2	15.6	78	233	99	70
Pioneer P31G98	7.4	14.8	91	240	98	70
Check Mean	6.8	15.6	88	241	98	70
Entry v. Entry LSD	0.9	1.0	9	12	8	2
Entry v. Entry Mean LSD	0.6	0.7	6	9	6	2
Entry v. Check Mean LSD	0.7	0.8	7	10	6	2

[1] Percent erect plants at harvest.

Table B.4 2003 entry means. Data from Clayton and Lewiston, NC. 50% and 25%-exotic testcrosses.

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
BO46W × LH132.LH51	**8.3**	14.7	121	310	**58**	68
CML10 × LH132.LH51	**8.3**	14.8	128	304	**59**	70
CML10.NC414 × FR992.FR1064	**8.8**	**13.9**	**106**	**301**	**59**	**67**
CML10.NC374 × FR615.FR697	**9.4**	**14.1**	**113**	**300**	**62**	68
CML16 × LH132.LH51	**8.4**	14.8	136	319	**61**	68
CML38 × LH132.LH51	**8.4**	15.2	122	**294**	**51**	69
CML69 × LH132.LH51	**7.8**	15.3	117	**282**	23	**65**
CML69.NC414 × FR992.FR1064	**7.9**	**14.3**	**114**	**290**	**37**	**65**
CML69.NC374 × FR615.FR697	**8.4**	**14.0**	**107**	**295**	**30**	**67**
CML91 × LH132.LH51	7.4	**13.5**	**113**	**291**	**45**	**67**
CML91.NC414 × FR992.FR1064	**8.1**	**13.5**	**95**	**286**	**58**	**64**
CML91.NC374 × FR615.FR697	**8.3**	**13.3**	**93**	**293**	**45**	**66**
CML92 × LH132.LH51	**8.6**	**14.1**	**110**	**293**	19	**66**
CML92.NC414 × FR992.FR1064	**8.2**	**14.2**	**108**	**290**	**43**	**65**
CML92.NC374 × FR615.FR697	**8.9**	**13.6**	117	307	**36**	**67**
CML103 × LH132.LH51	**8.9**	**13.7**	**113**	**293**	24	**67**
CML103.NC414 × FR992.FR1064	**8.5**	**13.9**	**109**	**288**	**39**	**65**
CML103.NC374 × FR615.FR697	**8.6**	**13.6**	**114**	**295**	**38**	**66**
CML108 × LH132.LH51	**8.8**	14.5	**103**	**288**	**53**	**65**
CML108.NC414 × FR992.FR1064	**7.7**	22.0	**96**	**287**	**48**	**64**
CML108.NC374 × FR615.FR697	**8.3**	**13.4**	**103**	**285**	**46**	**65**
CML154Q × LH132.LH51	**9.2**	15.1	**104**	**288**	**29**	**66**
CML154Q.NC414 × FR992.FR1064	**8.6**	**14.3**	**105**	**287**	**48**	**65**
CML154Q.NC374 × FR615.FR697	**8.6**	**14.1**	**109**	**296**	**38**	**66**
CML157Q × LH132.LH51	**8.2**	**14.4**	127	306	**59**	**66**
CML157Q.NC414 × FR992.FR1064	**8.4**	14.5	**116**	**295**	**47**	**64**
CML157Q.NC374 × FR615.FR697	**8.3**	**13.7**	**106**	**300**	**46**	**66**
CML176 × LH132.LH51	**8.3**	14.7	127	308	**36**	69
CML216 × LH132.LH51	**8.6**	15.2	123	310	**38**	69
CML269 × LH132.LH51	**8.6**	15.0	121	305	**43**	69
CML270 × LH132.LH51	6.5	**14.2**	**113**	**292**	**58**	68
CML274 × LH132.LH51	**8.2**	**14.0**	129	309	**60**	69
CML288 × LH132.LH51	6.8	14.6	**114**	**290**	**70**	70
CML304 × LH132.LH51	7.3	14.9	117	**299**	**37**	**66**
CML325 × LH132.LH51	7.3	**13.7**	**98**	**273**	**38**	**64**
CML327 × LH132.LH51	7.1	**14.1**	122	305	**68**	68
CML333 × LH132.LH51	**8.1**	15.0	118	**293**	**36**	**67**
CML333.NC414 × FR992.FR1064	**8.0**	**14.5**	**113**	**299**	**45**	**64**
CML333.NC374 × FR615.FR697	**8.6**	**14.2**	**113**	**301**	**42**	**67**
CML341 × LH132.LH51	**8.6**	14.9	122	**302**	**52**	69
CML341.NC414 × FR992.FR1064	**8.7**	**13.9**	**110**	**298**	**53**	66
CML341.NC374 × FR615.FR697	**8.5**	**13.7**	**110**	**297**	**52**	68
CML343 × LH132.LH51	**8.2**	14.8	**112**	**299**	**69**	70
CML373 × LH132.LH51	**8.9**	15.0	**106**	**285**	**74**	68
CML374 × LH132.LH51	**8.2**	15.0	124	310	**61**	69
CML384 × LH132.LH51	6.2	14.9	128	308	**69**	72
DO940Y × LH132.LH51	**7.9**	14.7	**116**	**286**	**53**	68
VO613Y × LH132.LH51	**8.0**	**14.5**	**113**	**285**	**47**	68
314190w × LH132.LH51	5.6	14.6	**105**	**275**	1	**64**
316096A × LH132.LH51	7.3	**14.1**	**97**	**291**	**27**	**63**

Table B.4 (continued)

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
317027A × LH132.LH51	7.0	**13.6**	**103**	**288**	**27**	**64**
318056A × LH132.LH51	6.9	**13.7**	**108**	**287**	**28**	**63**
326172w × FR615.FR697	**8.3**	**13.3**	**103**	**287**	24	**65**
326633A × FR615.FR697	**7.7**	**13.4**	**92**	**282**	**29**	**63**
327609A × FR615.FR697	**7.7**	**13.3**	**107**	**297**	**31**	**65**
796 NS × LH132.LH51	6.2	**13.8**	**90**	**257**	**36**	**62**
Entry Mean	8.0	14.4	112	294	45	67
DeKalb 697	9.5	13.9	112	287	20	67
Garst 8288	8.8	13.7	93	293	73	64
LH132 × LH51	7.6	14.0	96	285	19	65
LH195 × LH256	8.0	14.3	104	283	65	67
LH200 × LH262	8.6	14.3	108	295	38	67
Pioneer 32K61	8.3	14.0	97	289	51	65
Pioneer 32R25	9.4	13.9	120	299	16	68
Pioneer P31G98	9.8	13.5	113	297	45	66
Check Mean	8.7	14.0	105	291	41	66
Entry v. Entry LSD	1.1	0.7	12	14	19	1
Entry v. Entry Mean LSD	0.8	0.5	8	10	14	1
Entry v. Check Mean LSD	1.0	0.5	11	13	17	1

[1] Percent erect plants at harvest.

Table B.5 2004 entry means. Data from Clayton, Lewiston, Kinston, and Sandhills, NC. 50% and 25%-exotic testcrosses.

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
BO46W × LH132.LH51	6.4	17.6	**110**	**292**	**73**	64
CML10 × LH132.LH51	6.6	18.0	120	294	47	65
CML10.NC414 × FR992.FR1064	**7.1**	16.9	**104**	**279**	**59**	**60**
CML10.NC374 × FR615.FR697	**7.0**	**16.6**	**115**	306	52	**62**
CML16 × LH132.LH51	**6.9**	18.0	129	322	**59**	63
CML16.NC418 × FR992.FR1064	6.8	16.6	**113**	**278**	**67**	**59**
CML16.NC374 × FR615.FR697	**6.9**	**16.0**	119	315	**57**	**61**
CML38 × LH132.LH51	6.6	18.1	122	**286**	53	64
CML38.NC418 × FR992.FR1064	6.4	**16.5**	**105**	**266**	**68**	**62**
CML38.NC374 × FR615.FR697	6.5	16.8	119	**290**	**59**	63
CML69 × LH132.LH51	6.5	18.0	119	**287**	**59**	**61**
CML69.NC414 × FR992.FR1064	6.3	16.8	**99**	**270**	**67**	**59**
CML69.NC374 × FR615.FR697	5.8	**16.4**	**110**	**293**	50	**61**
CML91 × LH132.LH51	6.6	**16.1**	**111**	**272**	**80**	**61**
CML91.NC414 × FR992.FR1064	6.3	**16.1**	**95**	**266**	**69**	**59**
CML91.NC374 × FR615.FR697	**6.9**	**15.3**	**113**	**291**	**60**	**61**
CML92 × LH132.LH51	6.3	17.1	**112**	**292**	**58**	**61**
CML92.NC414 × FR992.FR1064	6.3	**16.4**	**103**	**273**	**62**	**58**
CML92.NC374 × FR615.FR697	6.1	**15.7**	**117**	302	49	**60**
CML103 × LH132.LH51	6.5	22.0	118	**279**	42	**61**
CML103.NC414 × FR992.FR1064	6.4	**16.2**	**102**	**272**	**58**	**59**
CML103.NC374 × FR615.FR697	6.7	**15.7**	**116**	296	51	**60**
CML108 × LH132.LH51	**7.1**	**16.5**	**104**	**278**	**63**	**61**
CML108.NC414 × FR992.FR1064	6.6	**16.1**	**99**	**262**	**61**	**57**
CML108.NC374 × FR615.FR697	6.8	**15.5**	**105**	**285**	**62**	**61**
CML116 × LH132.LH51	6.0	**16.1**	**109**	**280**	**57**	**59**
CML154Q × LH132.LH51	6.2	17.8	**107**	**269**	44	**59**
CML154Q.NC414 × FR992.FR1064	6.1	16.9	**102**	**275**	**62**	**59**
CML154Q.NC374 × FR615.FR697	6.6	**16.3**	**113**	303	**58**	**60**
CML157Q × LH132.LH51	**7.1**	17.0	120	**292**	**63**	**61**
CML157Q.NC414 × FR992.FR1064	6.8	16.8	**103**	**272**	**59**	**59**
CML157Q.NC374 × FR615.FR697	6.5	**15.6**	**114**	297	**59**	**62**
CML176 × LH132.LH51	**7.0**	18.3	123	310	36	64
CML216 × LH132.LH51	6.7	18.1	135	318	35	65
CML269 × LH132.LH51	6.4	18.2	**113**	**294**	**62**	**62**
CML269.NC418 × FR992.FR1064	**7.1**	17.0	**103**	**274**	**64**	**60**
CML269.NC374 × FR615.FR697	6.5	17.0	**114**	299	52	**62**
CML274 × LH132.LH51	6.7	17.1	127	304	56	65
CML327 × LH132.LH51	**7.0**	17.0	119	**293**	**60**	**61**
CML333 × LH132.LH51	6.4	18.0	**114**	**285**	52	**61**
CML333.NC414 × FR992.FR1064	6.8	17.1	**107**	**273**	56	**60**
CML333.NC374 × FR615.FR697	6.8	**15.9**	**116**	294	**57**	**61**
CML341 × LH132.LH51	6.7	17.3	123	300	**61**	63
CML341.NC414 × FR992.FR1064	**7.2**	**16.4**	**110**	**282**	**67**	**60**
CML341.NC374 × FR615.FR697	**7.4**	**15.8**	**113**	296	**62**	**61**
CML343 × LH132.LH51	**7.7**	17.7	**108**	**285**	**61**	**62**
CML373 × LH132.LH51	**7.2**	18.4	**110**	**280**	**61**	**61**
CML374 × LH132.LH51	**6.9**	17.2	125	297	52	**61**
DO940Y × LH132.LH51	6.4	17.1	**112**	**281**	**64**	**62**
NC296A × LH132.LH51	**7.6**	**16.3**	118	297	**60**	**61**

Table B.5 (continued)

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP_1 %	Anth Days
VO613Y × LH132.LH51	6.6	17.2	121	**282**	**57**	63
326172w × LH132.LH51	6.1	14.4	110	279	66	60
Entry Mean	6.7	16.9	113	287	58	61
DeKalb 697	8.6	16.5	102	274	72	61
LH132 × LH51	6.6	15.5	102	270	78	60
LH200 × LH262	7.3	16.0	115	285	58	61
Pioneer P31G98	7.7	15.4	108	287	69	62
Check Mean	7.6	15.9	107	279	69	61
Entry v. Entry LSD	0.7	0.8	10	14	13	2
Entry v. Entry Mean LSD	0.5	0.6	7	10	10	1
Entry v. Check Mean LSD	0.7	0.7	8	11	11	2

[1] Percent erect plants at harvest.

Table B.6 2005 entry means. Data from Clayton, Lewiston, Plymouth, and Sandhills, NC. 50% and 25%-exotic testcrosses.

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
BO46W × LH132.LH51	**7.1**	21.7	112	**276**	**96**	78
C70 × LH132.LH51	6.7	20.2	121	294	**91**	79
CML10 × LH132.LH51	6.2	22.3	125	300	**94**	79
CML10.NC414 × FR992.FR1064	**7.3**	20.2	**107**	**271**	**97**	**76**
CML10.NC374 × FR615.FR697	**7.2**	20.3	112	290	**94**	**77**
CML16 × LH132.LH51	6.5	22.0	122	289	**93**	**76**
CML16.NC418 × FR992.FR1064	6.5	**18.5**	112	**275**	**96**	77
CML16.NC374 × FR615.FR697	**7.6**	**19.1**	119	296	**94**	**76**
CML38 × LH132.LH51	6.4	22.2	117	**275**	**95**	79
CML38.NC418 × FR992.FR1064	6.4	**18.5**	**105**	**252**	**96**	79
CML38.NC374 × FR615.FR697	**7.1**	20.3	111	281	**94**	**77**
CML69 × LH132.LH51	6.3	22.2	110	**274**	85	**76**
CML69.NC414 × FR992.FR1064	6.6	20.2	**101**	**272**	**91**	**76**
CML69.NC374 × FR615.FR697	6.7	20.7	**108**	**278**	**91**	**77**
CML91 × LH132.LH51	6.7	20.1	**101**	**263**	**95**	**77**
CML91.NC414 × FR992.FR1064	6.5	19.4	**93**	**256**	**97**	**76**
CML91.NC374 × FR615.FR697	**7.2**	**18.4**	**104**	**269**	**95**	**76**
CML92 × LH132.LH51	6.5	20.1	**108**	**277**	**93**	**77**
CML92.NC414 × FR992.FR1064	6.7	19.3	**103**	**267**	**91**	**74**
CML92.NC374 × FR615.FR697	6.8	**18.5**	109	286	**93**	**76**
CML103 × LH132.LH51	6.6	**19.0**	114	**265**	78	**77**
CML103.NC414 × FR992.FR1064	7.0	22.0	**100**	**257**	**93**	**75**
CML103.NC374 × FR615.FR697	7.0	**19.1**	**108**	**274**	87	**76**
CML108 × LH132.LH51	6.5	**19.1**	**96**	**266**	**89**	**77**
CML108.NC414 × FR992.FR1064	6.6	**18.8**	**92**	**256**	**94**	**75**
CML108.NC374 × FR615.FR697	**7.1**	**18.5**	**100**	**276**	**94**	**76**
CML116 × LH132.LH51	6.2	**18.4**	**106**	**274**	**91**	**75**
CML154Q × LH132.LH51	6.8	20.8	**105**	**264**	74	**76**
CML154Q.NC414 × FR992.FR1064	6.4	20.0	**97**	**264**	**93**	**75**
CML154Q.NC374 × FR615.FR697	**7.1**	**18.3**	111	280	86	**76**
CML157Q × LH132.LH51	6.9	20.6	120	286	**93**	**77**
CML157Q.NC414 × FR992.FR1064	6.6	19.5	**104**	**273**	**95**	**75**
CML157Q.NC374 × FR615.FR697	**7.2**	19.6	**109**	**279**	**94**	**76**
CML176 × LH132.LH51	6.3	22.0	123	296	**89**	78
CML176.NC382 × FR992.FR1064	**7.1**	**19.2**	116	280	**96**	78
CML176.NC374 × FR615.FR697	6.5	21.0	116	288	**93**	**77**
CML216 × LH132.LH51	6.5	21.7	125	299	86	79
CML216.NC382 × FR992.FR1064	6.8	**19.2**	110	281	87	**77**
CML216.NC374 × FR615.FR697	6.4	20.4	109	291	**91**	78
CML269 × LH132.LH51	6.8	22.3	120	284	**94**	78
CML269.NC418 × FR992.FR1064	7.0	19.8	**101**	**260**	**95**	**77**
CML269.NC374 × FR615.FR697	6.8	20.0	**109**	283	**93**	**77**
CML274 × LH132.LH51	**7.7**	20.1	119	293	**96**	79
CML274.NC382 × FR992.FR1064	6.9	**18.1**	117	**279**	**96**	78
CML274.NC374 × FR615.FR697	**7.3**	20.0	113	286	**95**	78
CML327 × LH132.LH51	6.7	20.1	121	293	**95**	**77**
CML333 × LH132.LH51	6.6	21.0	115	**278**	85	**77**
CML333.NC414 × FR992.FR1064	6.5	19.9	**105**	**273**	**90**	**76**
CML333.NC374 × FR615.FR697	**7.1**	19.3	116	290	**94**	**77**
CML341 × LH132.LH51	6.7	22.5	123	287	87	80

Table B.6 (continued)

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
CML341.NC414 × FR992.FR1064	**7.2**	19.6	**109**	**270**	**95**	**77**
CML341.NC374 × FR615.FR697	**7.6**	**19.1**	**109**	**279**	**93**	**77**
CML343 × LH132.LH51	**7.6**	21.6	112	**276**	**95**	79
CML343.NC382 × FR992.FR1064	**7.3**	**18.9**	**108**	**272**	**93**	**77**
CML343.NC374 × FR615.FR697	**7.4**	19.2	107	288	**94**	78
CML373 × LH132.LH51	6.5	21.8	112	**278**	**97**	**77**
CML373.NC382 × FR992.FR1064	6.9	19.3	108	**271**	**95**	**76**
CML373.NC374 × FR615.FR697	7.0	19.6	110	283	**95**	78
CML374 × LH132.LH51	6.7	21.6	119	297	**95**	78
CML374.NC382 × FR992.FR1064	7.0	**18.3**	115	**279**	**97**	78
CML374.NC374 × FR615.FR697	6.8	19.7	109	283	**97**	**77**
DO940Y × LH132.LH51	6.3	20.9	114	**267**	**92**	78
NC296A × LH132.LH51	6.6	**18.5**	112	**280**	**92**	**77**
Tzi3 × LH132.LH51	6.1	21.0	119	294	**96**	78
Tzi17 × LH132.LH51	6.1	**17.7**	112	**280**	**88**	78
VO613Y × LH132.LH51	6.1	22.6	114	**263**	**93**	79
87036 × LH132.LH51	5.3	20.3	146	324	88	78
89199 × LH132.LH51	6.8	21.5	123	295	**90**	78
89291 × LH132.LH51	**7.4**	20.7	119	287	**90**	**76**
89302 × LH132.LH51	6.2	20.4	111	**266**	87	**76**
90156 × LH132.LH51	5.5	22.7	**107**	**277**	**95**	78
90301 × LH132.LH51	6.3	20.0	114	290	79	78
Entry Mean	6.7	20.1	111	279	92	77
DeKalb 697	7.5	19.0	104	269	97	76
Garst 8288	7.9	19.4	94	271	98	74
HC33.TR7322	6.6	17.2	104	263	96	78
LH132 × LH51	6.3	17.2	96	260	88	74
LH200 × LH262	7.3	18.4	108	274	97	77
Pioneer 32D99	8.7	19.5	101	278	95	77
Pioneer 32R25	8.3	17.8	112	280	94	77
Pioneer 32W86	8.1	18.1	101	284	96	74
Pioneer P31G98	8.2	17.6	103	271	96	76
Check Mean	7.6	18.2	103	272	95	76
Entry v. Entry LSD	0.7	1.3	7	9	8	1
Entry v. Entry Mean LSD	0.5	0.9	5	7	6	1
Entry v. Check Mean LSD	0.6	1.0	5	7	6	1

[1] Percent erect plants at harvest.

Table B.7 Means for the subset of 50%-exotic entries from 14 environments 2002 – 2005.

Entry	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth Days
CML10 × LH132.LH51	6.5	18.7	116	286	75	71
CML16 × LH132.LH51	6.8	18.5	123	297	**79**	70
CML38 × LH132.LH51	6.8	18.7	116	**271**	**76**	71
CML69 × LH132.LH51	6.4	18.7	109	**268**	71	**68**
CML91 × LH132.LH51	6.5	16.9	**103**	**265**	**81**	69
CML92 × LH132.LH51	6.4	17.3	**104**	**273**	73	**68**
CML103 × LH132.LH51	6.7	**16.5**	112	**264**	60	**69**
CML108 × LH132.LH51	6.9	**16.7**	**96**	**264**	**78**	**68**
CML154Q × LH132.LH51	6.6	18.0	**101**	**260**	61	**68**
CML157Q × LH132.LH51	7.0	17.7	116	280	**81**	**68**
CML176 × LH132.LH51	6.8	18.5	119	292	64	71
CML216 × LH132.LH51	6.8	18.6	123	298	66	71
CML269 × LH132.LH51	6.8	18.8	113	282	**79**	70
CML274 × LH132.LH51	7.1	17.5	117	289	**80**	72
CML333 × LH132.LH51	6.7	18.5	112	274	70	**69**
CML341 × LH132.LH51	7.0	18.5	117	284	**76**	71
Entry Mean	6.7	18.0	112	278	73	70
DeKalb 697	8.0	16.6	101	266	78	68
Garst 8288	7.5	16.8	94	270	86	66
LH200 × LH262	7.3	16.4	106	273	78	69
Pioneer P31G98	8.0	15.6	102	271	82	69
Check Mean	7.7	16.4	101	270	81	68
Entry v. Entry LSD	0.4	0.6	5	6	7	1
Entry v. Entry Mean LSD	0.3	0.4	3	4	5	0
Entry v. Check Mean LSD	0.3	0.5	4	5	6	1

[1] Percent erect plants at harvest.

Table B.8 Entry means for 50% and 25%-exotic testcrosses.

Entry	Yield		Mois		Ear Ht		Plant Ht		EP[1]		Anth	
	Mg ha^{-1}	SE	%	SE	(cm)	SE	(cm)	SE	%	SE	Days	SE
A214N × LH132.LH51	5.1	0.44	**15.2**	1.0	102	5.3	**256**	7.99	80	7.0	**67**	3.0
BO46W × LH132.LH51	7.1	0.37	19.1	1.0	109	4.7	282	7.25	**92**	6.1	72	3.0
C70 × LH132.LH51	7.0	0.43	18.1	1.0	119	5.3	295	7.95	81	6.9	73	3.0
CML5 × LH132.LH51	5.7	0.44	18.3	1.0	113	5.3	300	7.99	79	7.0	73	3.0
CML9 × LH132.LH51	5.7	0.44	23.0	1.0	105	5.3	274	7.99	81	7.0	74	3.0
CML10 × LH132.LH51	6.8	0.35	19.5	0.9	116	4.4	288	7.01	80	5.8	73	2.9
CML10.NC414 × FR992.FR1064	7.5	0.37	18.0	1.0	102	4.7	273	7.25	87	6.1	69	3.0
CML10.NC374 × FR615.FR697	7.5	0.37	18.0	1.0	109	4.7	291	7.25	83	6.1	71	3.0
CML14 × LH132.LH51	5.6	0.44	23.2	1.0	119	5.3	278	7.99	80	7.0	73	3.0
CML16 × LH132.LH51	7.1	0.36	19.3	0.9	124	4.5	301	7.10	84	5.9	71	2.9
CML16.NC418 × FR992.FR1064	7.0	0.38	17.2	1.0	109	4.8	272	7.37	**88**	6.2	69	3.0
CML16.NC374 × FR615.FR697	7.6	0.38	17.2	1.0	116	4.8	301	7.37	82	6.2	69	3.0
CML38 × LH132.LH51	6.9	0.35	20.1	0.9	118	4.4	274	7.01	81	5.8	72	2.9
CML38.NC418 × FR992.FR1064	6.7	0.38	17.1	1.0	102	4.8	**255**	7.37	**88**	6.2	72	3.0
CML38.NC374 × FR615.FR697	7.1	0.38	18.2	1.0	112	4.8	281	7.37	83	6.2	71	3.0
CML40 × LH132.LH51	6.3	0.44	18.4	1.0	122	5.3	295	7.97	83	6.9	72	3.0
CML45 × LH132.LH51	5.1	0.44	19.6	1.0	117	5.3	291	7.99	80	7.0	78	3.0
CML48 × LH132.LH51	5.0	0.44	18.4	1.0	127	5.3	306	7.97	86	6.9	72	3.0
CML52 × LH132.LH51	6.8	0.38	19.6	1.0	116	4.8	291	7.37	80	6.3	73	3.0
CML56 × LH132.LH51	5.4	0.44	19.5	1.0	119	5.3	298	7.97	82	6.9	73	3.0
CML61 × LH132.LH51	5.9	0.44	19.4	1.0	122	5.3	297	7.99	80	7.0	77	3.0
CML69 × LH132.LH51	6.7	0.35	19.4	0.9	110	4.4	273	7.01	77	5.8	69	2.9
CML69.NC414 × FR992.FR1064	6.7	0.37	18.1	1.0	99	4.7	268	7.25	83	6.1	68	3.0
CML69.NC374 × FR615.FR697	6.7	0.37	18.0	1.0	105	4.7	280	7.25	75	6.1	70	3.0
CML91 × LH132.LH51	6.8	0.35	17.5	0.9	105	4.5	271	7.05	86	5.9	70	2.9
CML91.NC414 × FR992.FR1064	6.8	0.37	17.3	1.0	**91**	4.7	**259**	7.25	**91**	6.1	**68**	3.0
CML91.NC374 × FR615.FR697	7.3	0.37	**16.6**	1.0	101	4.7	275	7.25	84	6.1	70	3.0
CML92 × LH132.LH51	6.7	0.35	17.9	0.9	105	4.4	277	7.01	79	5.8	70	2.9
CML92.NC414 × FR992.FR1064	6.8	0.37	17.5	1.0	101	4.7	267	7.25	83	6.1	**68**	3.0
CML92.NC374 × FR615.FR697	6.9	0.37	16.8	1.0	110	4.7	290	7.25	77	6.1	70	3.0
CML103 × LH132.LH51	7.1	0.35	17.5	0.9	114	4.4	270	7.01	69	5.8	70	2.9
CML103.NC414 × FR992.FR1064	7.0	0.37	17.3	1.0	99	4.7	**262**	7.25	81	6.1	68	3.0
CML103.NC374 × FR615.FR697	7.2	0.37	17.1	1.0	109	4.7	279	7.25	75	6.1	69	3.0
CML108 × LH132.LH51	**7.2**	0.35	17.4	0.9	**97**	4.4	269	7.01	83	5.8	69	2.9
CML108.NC414 × FR992.FR1064	6.8	0.37	17.2	1.0	**92**	4.7	**257**	7.25	84	6.1	**67**	3.0

Table B.8 (continued).

Entry	Yield		Mois		Ear Ht		Plant Ht		EP[1]		Anth	
	Mg ha^{-1}	SE	%	SE	(cm)	SE	(cm)	SE	%	SE	Days	SE
CML108.NC374 × FR615.FR697	7.2	0.37	**16.7**	1.0	98	4.7	274	7.25	84	6.1	69	3.0
CML116 × LH132.LH51	6.4	0.38	**16.8**	1.0	104	4.8	272	7.37	80	6.2	68	3.0
CML142 × LH132.LH51	6.9	0.44	19.2	1.0	130	5.3	303	7.97	85	6.9	75	3.0
CML144 × LH132.LH51	6.8	0.44	19.0	1.0	122	5.3	286	7.97	76	6.9	75	3.0
CML145 × LH132.LH51	5.5	0.44	18.1	1.0	113	5.3	293	7.97	83	6.9	72	3.0
CML150 × LH132.LH51	6.3	0.44	18.1	1.0	107	5.3	272	7.97	86	6.9	70	3.0
CML154Q × LH132.LH51	6.8	0.35	19.0	0.9	101	4.4	263	7.01	68	5.8	69	2.9
CML154Q.NC414 × FR992.FR1064	6.7	0.37	18.0	1.0	**97**	4.7	266	7.25	84	6.1	68	3.0
CML154Q.NC374 × FR615.FR697	7.2	0.37	17.1	1.0	108	4.7	285	7.25	78	6.1	69	3.0
CML157Q × LH132.LH51	**7.2**	0.35	18.4	0.9	117	4.4	282	7.01	85	5.8	70	2.9
CML157Q.NC414 × FR992.FR1064	7.0	0.37	17.9	1.0	102	4.7	269	7.25	84	6.1	**68**	3.0
CML157Q.NC374 × FR615.FR697	7.2	0.37	17.3	1.0	107	4.7	283	7.25	83	6.1	70	3.0
CML158Q × LH132.LH51	6.4	0.44	20.5	1.0	118	5.3	283	7.99	77	7.0	71	3.0
CML159 × LH132.LH51	6.6	0.44	19.3	1.0	111	5.3	293	7.97	80	6.9	73	3.0
CML161 × LH132.LH51	6.3	0.44	20.0	1.0	117	5.3	284	7.97	86	6.9	74	3.0
CML173 × LH132.LH51	6.7	0.44	19.1	1.0	**91**	5.3	**260**	7.97	84	6.9	68	3.0
CML176 × LH132.LH51	7.0	0.36	19.3	0.9	120	4.5	296	7.10	70	5.9	73	2.9
CML176.NC382 × FR992.FR1064	7.4	0.43	17.1	1.0	114	5.3	281	7.95	86	6.9	72	3.0
CML176.NC374 × FR615.FR697	6.8	0.43	19.0	1.0	114	5.3	289	7.95	83	6.9	70	3.0
CML184 × LH132.LH51	6.9	0.44	18.3	1.0	103	5.3	263	7.97	83	6.9	68	3.0
CML186 × LH132.LH51	6.6	0.44	18.2	1.0	99	5.3	264	7.97	**87**	6.9	70	3.0
CML193 × LH132.LH51	6.2	0.44	17.8	1.0	105	5.3	270	7.97	84	6.9	70	3.0
CML216 × LH132.LH51	7.0	0.36	19.4	0.9	124	4.5	302	7.10	71	5.9	73	2.9
CML216.NC382 × FR992.FR1064	7.1	0.43	17.1	1.0	109	5.3	282	7.95	77	6.9	71	3.0
CML216.NC374 × FR615.FR697	6.6	0.43	18.4	1.0	107	5.3	292	7.95	81	6.9	72	3.0
CML218 × LH132.LH51	6.0	0.44	17.4	1.0	106	5.3	271	7.99	80	7.0	68	3.0
CML220 × LH132.LH51	6.2	0.44	**16.6**	1.0	**97**	5.3	**258**	7.99	79	7.0	**67**	3.0
CML223 × LH132.LH51	6.6	0.44	20.1	1.0	105	5.3	276	7.97	84	6.9	72	3.0
CML228 × LH132.LH51	6.2	0.44	18.9	1.0	104	5.3	**262**	7.99	80	7.0	73	3.0
CML238 × LH132.LH51	5.9	0.44	19.3	1.0	**97**	5.3	**251**	7.99	80	7.0	69	3.0
CML255 × LH132.LH51	6.6	0.44	19.6	1.0	121	5.3	297	7.97	**87**	6.9	74	3.0
CML261 × LH132.LH51	6.0	0.44	20.6	1.0	129	5.3	301	7.99	79	7.0	73	3.0
CML269 × LH132.LH51	7.1	0.36	19.6	0.9	114	4.5	286	7.10	84	5.9	72	2.9
CML269.NC418 × FR992.FR1064	7.4	0.38	18.0	1.0	**98**	4.8	262	7.37	86	6.2	69	3.0
CML269.NC374 × FR615.FR697	6.9	0.38	18.1	1.0	108	4.8	287	7.37	79	6.2	70	3.0

Table B.8 (continued).

Entry	Yield		Mois		Ear Ht		Plant Ht		EP[1]		Anth	
	Mg ha^{-1}	SE	%	SE	(cm)	SE	(cm)	SE	%	SE	Days	SE
CML270 × LH132.LH51	5.2	0.52	17.9	1.2	107	6.2	273	9.01	**95**	8.1	71	3.0
CML273 × LH132.LH51	6.9	0.44	18.4	1.0	114	5.3	289	7.97	86	6.9	75	3.0
CML274 × LH132.LH51	**7.3**	0.36	18.3	0.9	118	4.5	292	7.10	85	5.9	73	2.9
CML274.NC382 × FR992.FR1064	7.2	0.43	**16.1**	1.0	115	5.3	280	7.95	86	6.9	72	3.0
CML274.NC374 × FR615.FR697	**7.6**	0.43	18.0	1.0	111	5.3	287	7.95	85	6.9	72	3.0
CML285 × LH132.LH51	6.8	0.44	19.5	1.0	119	5.3	295	7.97	82	6.9	72	3.0
CML288 × LH132.LH51	5.5	0.52	18.3	1.2	109	6.2	271	9.01	**106***	8.1	73	3.0
CML295 × LH132.LH51	5.9	0.44	18.9	1.0	121	5.3	292	7.97	80	6.9	71	3.0
CML304 × LH132.LH51	6.0	0.52	18.6	1.2	112	6.2	280	9.01	73	8.1	69	3.0
CML311 × LH132.LH51	6.3	0.44	20.6	1.0	113	5.3	284	7.99	80	7.0	74	3.0
CML314 × LH132.LH51	6.2	0.44	17.9	1.0	112	5.3	274	7.99	81	7.0	70	3.0
CML319 × LH132.LH51	6.2	0.44	18.4	1.0	120	5.3	300	7.97	84	6.9	74	3.0
CML321 × LH132.LH51	5.7	0.44	18.5	1.0	107	5.3	284	7.99	81	7.0	72	3.0
CML322 × LH132.LH51	5.8	0.44	18.9	1.0	106	5.3	269	7.99	80	7.0	68	3.0
CML323 × LH132.LH51	5.8	0.44	**16.6**	1.0	99	5.3	**258**	7.99	75	7.0	**67**	3.0
CML325 × LH132.LH51	6.0	0.52	17.5	1.2	**93**	6.2	**254**	9.01	74	8.1	**67**	3.0
CML327 × LH132.LH51	6.9	0.37	18.1	1.0	117	4.7	288	7.25	**88**	6.1	70	3.0
CML329 × LH132.LH51	6.8	0.44	17.7	1.0	**98**	5.3	278	7.97	84	6.9	68	3.0
CML331 × LH132.LH51	5.6	0.44	22.3	1.0	104	5.3	279	7.99	80	7.0	72	3.0
CML332 × LH132.LH51	6.5	0.44	21.0	1.0	104	5.3	270	7.99	80	7.0	69	3.0
CML333 × LH132.LH51	6.8	0.35	19.2	0.9	114	4.4	278	7.01	76	5.8	70	2.9
CML333.NC414 × FR992.FR1064	6.9	0.37	18.1	1.0	103	4.7	271	7.25	80	6.1	69	3.0
CML333.NC374 × FR615.FR697	7.3	0.37	17.4	1.0	112	4.7	286	7.25	81	6.1	70	3.0
CML341 × LH132.LH51	**7.3**	0.35	19.5	0.9	118	4.4	288	7.01	81	5.8	72	2.9
CML341.NC414 × FR992.FR1064	7.5	0.37	17.6	1.0	106	4.7	273	7.25	**88**	6.1	70	3.0
CML341.NC374 × FR615.FR697	**7.7**	0.37	17.1	1.0	107	4.7	282	7.25	85	6.1	70	3.0
CML343 × LH132.LH51	**7.7**	0.37	19.1	1.0	106	4.7	277	7.25	**89**	6.1	72	3.0
CML343.NC382 × FR992.FR1064	**7.6**	0.43	16.9	1.0	106	5.3	273	7.95	82	6.9	71	3.0
CML343.NC374 × FR615.FR697	**7.7**	0.43	17.2	1.0	105	5.3	289	7.95	84	6.9	71	3.0
CML373 × LH132.LH51	**7.2**	0.37	19.5	1.0	107	4.7	273	7.25	**90**	6.1	71	3.0
CML373.NC382 × FR992.FR1064	7.1	0.43	17.3	1.0	106	5.3	272	7.95	85	6.9	70	3.0
CML373.NC374 × FR615.FR697	7.2	0.43	17.6	1.0	108	5.3	284	7.95	85	6.9	71	3.0
CML374 × LH132.LH51	**7.1**	0.37	19.0	1.0	119	4.7	292	7.25	83	6.1	71	3.0
CML374.NC382 × FR992.FR1064	7.2	0.43	**16.3**	1.0	113	5.3	280	7.95	87	6.9	71	3.0
CML374.NC374 × FR615.FR697	7.0	0.43	17.7	1.0	107	5.3	284	7.95	87	6.9	70	3.0

Table B.8 (continued).

Entry	Yield		Mois		Ear Ht		Plant Ht		EP[1]		Anth	
	Mg ha^{-1}	SE	%	SE	(cm)	SE	(cm)	SE	%	SE	Days	SE
CML384 × LH132.LH51	4.9	0.52	18.6	1.2	123	6.2	289	9.01	**106***	8.1	76	3.0
DO940Y × LH132.LH51	6.6	0.37	18.6	1.0	110	4.7	269	7.25	85	6.1	71	3.0
87036 × LH132.LH51	5.5	0.66	18.3	1.4	144	7.7	325	10.80	78	10.0	72	3.0
89199 × LH132.LH51	7.0	0.66	19.5	1.4	121	7.7	297	10.8	80	10.0	71	3.0
89291 × LH132.LH51	**7.7**	0.43	18.7	1.0	117	5.3	288	8.0	80	6.9	70	3.0
89302 × LH132.LH51	6.5	0.43	18.4	1.0	109	5.3	267	7.95	77	6.9	69	3.0
90156 × LH132.LH51	5.7	0.43	20.7	1.0	106	5.3	278	7.95	85	6.9	72	3.0
90301 × LH132.LH51	6.6	0.43	18.0	1.0	113	5.3	291	7.95	69	6.9	71	3.0
NC296A × LH132.LH51	**7.4**	0.38	**17.0**	1.0	112	4.8	284	7.37	83	6.2	70	3.0
Tzi3 × LH132.LH51	6.4	0.43	18.9	1.0	117	5.3	295	7.95	86	6.9	71	3.0
Tzi17 × LH132.LH51	6.4	0.43	**15.7**	1.0	110	5.3	281	7.95	78	6.9	71	3.0
Tzi18 × LH132.LH51	6.2	0.44	19.3	1.0	106	5.3	270	7.99	77	7.0	72	3.0
VO613Y × LH132.LH51	6.6	0.37	19.2	1.0	113	4.7	268	7.25	82	6.1	72	3.0
314190w × LH132.LH51	4.3	0.52	18.3	1.2	100	6.2	**256**	9.01	38	8.1	68	3.0
316096A × LH132.LH51	6.0	0.52	17.9	1.2	**92**	6.2	272	9.01	63	8.1	**66**	3.0
317027A × LH132.LH51	5.7	0.52	17.3	1.2	98	6.2	269	9.01	63	8.1	**68**	3.0
318056A × LH132.LH51	5.6	0.52	17.5	1.2	103	6.2	269	9.01	64	8.1	**67**	3.0
326172w. × FR615.FR697	6.6	0.40	**16.1**	1.0	103	4.9	269	7.57	80	6.5	68	3.0
326633A. × FR615.FR697	6.4	0.52	**17.1**	1.2	**87**	6.2	263	9.01	66	8.1	**66**	3.0
327609A. × FR615.FR697	6.4	0.52	**17.0**	1.2	102	6.2	278	9.01	67	8.1	68	3.0
796 NS × LH132.LH51	4.9	0.52	17.5	1.2	**85**	6.2	**238**	9.01	72	8.1	**66**	3.0
Mean of Exp. Entries	6.6		18.3		109.1		278.8		80.8		70.6	
DeKalb 687	7.6	0.44	16.4	1.0	100	5.3	263	7.99	81	7.0	70	3.0
DeKalb 697	8.2	0.36	17.4	0.9	102	4.5	270	7.10	84	5.9	69	2.9
Garst 8288	7.8	0.36	17.5	0.9	95	4.5	274	7.13	92	6.0	68	3.0
HC33.TR7322	6.9	0.43	15.1	1.0	103	5.3	264	7.95	85	6.9	71	3.0
LH132 × LH51	6.7	0.36	16.1	0.9	94	4.5	260	7.10	82	5.9	68	2.9
LH195 × LH256	6.7	0.52	18.0	1.2	99	6.2	264	9.01	102	8.1	70	3.0
LH200 × LH262	7.5	0.36	17.2	0.9	107	4.5	277	7.10	83	5.9	71	2.9
Pioneer 3165	6.9	0.44	19.8	1.0	102	5.3	269	7.99	78	7.0	73	3.0
Pioneer 32D99	9.0	0.43	17.5	1.0	99	5.3	279	7.95	85	6.9	70	3.0
Pioneer 32K61	7.0	0.37	16.7	1.0	92	4.7	267	7.24	84	6.1	68	3.0
Pioneer 32R25	8.4	0.40	16.4	1.0	112	4.9	281	7.57	73	6.5	70	3.0

Table B.8 (continued).

Entry	Yield		Mois		Ear Ht		Plant Ht		EP[1]		Anth	
	Mg ha^{-1}	SE	%	SE	(cm)	SE	(cm)	SE	%	SE	Days	SE
Pioneer 32W86	8.4	0.43	16.0	1.0	99	5.3	285	7.95	86	6.9	68	3.0
Pioneer P31G98	8.3	0.36	16.4	0.9	103	4.5	275	7.10	87	5.9	70	2.9
Mean of Checks	7.6		17.0		100.6		271.3		84.7		69.8	

Values that are within the best 10% are emboldened.
[1] % Erect plants, measured at harvest.
* Estimate inflated by adjustments for unbalance, values are assumed to be 100.

Table B.9 Line × tester interactions for yield

Line	F-Value	Prob. F	Testcross Yield Mg ha^{-1}			# Env
			SS × NSS 50%-Exotic	SS × SS 25%-Exotic	NSS × NSS 25%-Exotic	
CML10	11.05	<.001*	6.8	7.5	7.5	10
CML69	0.09	0.918	6.7	6.7	6.7	10
CML91	6.29	0.002*	6.8	6.8	7.3	10
CML92	0.24	0.785	6.8	6.8	6.9	10
CML103	0.67	0.516	7.0	7.0	7.2	10
CML108	3.04	0.051*	7.2	6.8	7.2	10
CML154Q	3.96	0.021*	7.0	6.7	7.2	10
CML157Q	1.15	0.319	7.3	7.0	7.2	10
CML333	3.38	0.037	6.8	6.9	7.3	10
CML341	5.89	0.003*	7.1	7.5	7.7	10
CML16	5.11	0.007*	6.7	6.7	7.2	8
CML38	2.13	0.122	6.5	6.4	6.8	8
CML269	2.96	0.055	6.6	7.0	6.6	8
CML176	4.64	0.012*	6.3	7.1	6.5	4
CML216	1.52	0.223	6.5	6.8	6.4	4
CML274	4.00	0.021*	7.7	6.9	7.3	4
CML343	0.37	0.690	7.6	7.3	7.4	4
CML373	1.71	0.186	6.5	6.9	7.0	4
CML374	0.43	0.649	6.7	7.0	6.8	4

F-values and significance levels of line × tester interactions. Mean line yield on each tester is given. Tests are based on data from the number of environments given.

Table B.10 Significance levels (α = .05) of genotype by environment interactions within years.

Entry Year	Yield Mg ha^{-1}	Mois %	Ear Ht (cm)	Plant Ht (cm)	EP[1] %	Anth* Days
2001	ns	<.001	.008	ns	ns	--
2002	.008	<.001	ns	ns	<.001	--
2003	.003†	.035	<.001	<.001	<.001	--
2004	<.001	<.001	<.001	<.001	ns	--
2005	<.001	<.001	ns	.041	<.001	--

*Flowering dates were only collected at Clayton, NC.
† p-value obtained using a Wald test.
[1] Percent erect plants at harvest.

Table B.11 Spearman's coefficient of rank correlation for traits* across environments.

Year	Cly v. Lew	Cly v. Ply/Kin‡	Cly v. Sdh	Lew v. Ply/Kin‡	Lew v. Sdh	Ply/Kin‡ v. Sdh
			Yield			
2001	0.57	0.47	0.63	0.27	0.67	0.36
2002	0.35	0.66	0.33	0.49	0.55	0.49
2003†	0.51	--	--	--	--	--
2004	0.37	0.49‡	0.16	0.26‡	0.30	-0.02‡
2005	0.50	0.41	0.50	0.37	0.30	0.42
			Moisture			
2001	0.68	0.77	0.76	0.74	0.73	0.77
2002	0.63	0.65	0.55	0.76	0.71	0.61
2003†	0.78	--	--	--	--	--
2004	0.68	0.68‡	0.84	0.50‡	0.66	0.64‡
2005	0.77	0.83	0.83	0.74	0.78	0.73
			Ear Height			
2001	0.51	0.49	0.39	0.58	0.67	0.45
2002	0.50	0.69	0.64	0.76	0.61	0.72
2003†	0.68	--	--	--	--	--
2004	0.45	0.60‡	0.55	0.71‡	0.28	0.53‡
2005	0.80	0.68	0.61	0.58	0.60	0.60
			Plant Height			
2001	0.74	0.70	0.62	0.78	0.65	0.55
2002	0.52	0.79	0.75	0.55	0.54	0.75
2003†	0.56	--	--	--	--	--
2004	0.61	0.69‡	0.59	0.82‡	0.49	0.49‡
2005	0.73	0.73	0.74	0.77	0.71	0.74
			% Erect Plants			
2001	0.11	0.34	-0.05	0.16	0.34	-0.05
2002	0.16	0.43	0.22	0.25	0.31	0.31
2003†	0.68	--	--	--	--	--
2004	0.40	0.44‡	0.23	0.38‡	0.36	0.06‡
2005	0.38	0.43	0.13	0.40	0.02	0.07

* Days to anthesis not included because data for this trait was collected at one environment only each year.
† Data collected from Cly and Lew only in 2003.
‡Kin substituted for Lew in 2004.

Table B.12 Spearman's coefficients of correlation for entries ranked across testers.

	LH132.LH51 vs FR992.FR1064	LH132.LH51 vs FR615.FR697	FR992.FR1064 vs FR615.FR697
2003 N = 10			
Yield Mg ha^{-1}	0.39	0.16	0.53
Moi %	0.55	0.75	0.62
Ear Ht (cm)	0.55	0.07	0.26
Plant Ht (cm)	0.66	0.53	0.79
Erect Plants %	0.72	0.92	0.78
Anthesis Days	0.52	0.56	0.80
2004 N = 13			
Yield Mg ha^{-1}	0.59	0.39	0.69
Moi %	0.83	0.93	0.73
Ear Ht (cm)	0.64	0.48	0.57
Plant Ht (cm)	0.55	0.54	0.79
Erect Plants %	0.48	0.57	0.25
Anthesis Days	0.50	0.66	0.28
2005 N = 19			
Yield Mg ha^{-1}	-0.40	0.39	0.12
Moi %	0.85	0.59	0.42
Ear Ht (cm)	0.86	0.46	0.71
Plant Ht (cm)	0.71	0.69	0.63
Erect Plants %	0.55	0.82	0.50
Anthesis Days	0.43	0.78	0.65
2003 – 2005 N = 10			
Yield Mg ha^{-1}	0.23	0.02	0.45
Moi %	0.88	0.85	0.76
Ear Ht (cm)	0.80	0.32	0.62
Plant Ht (cm)	0.82	0.58	0.66
Erect Plants %	0.33	0.77	0.36
Anthesis Days	0.52	0.59	0.68
2004 – 2005 N = 13			
Yield Mg ha^{-1}	0.27	0.50	0.46
Moi %	0.88	0.84	0.74
Ear Ht (cm)	0.81	0.45	0.63
Plant Ht (cm)	0.82	0.66	0.66
Erect Plants %	0.33	0.53	0.36
Anthesis Days	0.53	0.72	0.75

Table B.13 2001 Environmental Index

Entry	*b*	Yield Mg ha^{-1}	Entry	*b*	Yield Mg ha^{-1}
CML321 × LH132.LH51	1.56	6.5	CML157Q × LH132.LH51	0.99	7.8
CML61 × LH132.LH51	1.50	6.8	CML311 × LH132.LH51	0.99	7.1
CML5 × LH132.LH51	1.45	6.6	CML323 × LH132.LH51	0.95	6.7
CML92 × LH132.LH51	1.40	8.0	CML91 × LH132.LH51	0.92	7.8
CML341 × LH132.LH51	1.30	8.4	CML69 × LH132.LH51	0.91	7.6
CML331 × LH132.LH51	1.24	6.5	CML218 × LH132.LH51	0.91	6.9
CML108 × LH132.LH51	1.20	8.3	LH132 x LH51	0.87	7.5
A214N × LH132.LH51	1.20	6.0	CML238 × LH132.LH51	0.85	6.7
CML314 × LH132.LH51	1.18	7.1	CML103 × LH132.LH51	0.83	8.3
CML45 × LH132.LH51	1.18	5.9	CML154Q × LH132.LH51	0.81	7.6
CML10 × LH132.LH51	1.16	7.7	Pioneer 32K61	0.79	7.8
CML333 × LH132.LH51	1.15	7.5	CML261 × LH132.LH51	0.76	6.9
CML9 × LH132.LH51	1.13	6.5	Tzi18 × LH132.LH51	0.66	7.1
CML52 × LH132.LH51	1.12	7.4	CML220 × LH132.LH51	0.65	7.0
DeKalb 687	1.08	8.4	CML158Q × LH132.LH51	0.62	7.3
CML322 × LH132.LH51	1.04	6.7	Pioneer 3165	0.62	7.8
CML14 × LH132.LH51	1.04	6.5	CML332 × LH132.LH51	0.53	7.3
CML228 × LH132.LH51	1.00	7.1	CML38 × LH132.LH51	0.43	7.5

Coefficient of regression, *b*, for Finlay and Wilkerson's environmental index. Regression coefficients near *b* = 1 are an indication of stability across environments. Mean yield across environments is also given.

Table B.14 2002 Environmental Index

Entry	*b*	Yield Mg ha^{-1}	Entry	*b*	Yield Mg ha^{-1}
CML273 × LH132.LH51	2.60	6.0	CML150 × LH132.LH51	0.93	5.5
CML285 × LH132.LH51	2.17	6.0	DeKalb 697	0.89	7.2
CML145 × LH132.LH51	2.03	4.7	CML193 × LH132.LH51	0.83	5.3
CML333 × LH132.LH51	1.95	6.2	CML10 × LH132.LH51	0.80	5.9
CML52 × LH132.LH51	1.89	6.2	CML38 × LH132.LH51	0.78	6.6
CML255 × LH132.LH51	1.84	5.7	CML341 × LH132.LH51	0.75	6.9
CML48 × LH132.LH51	1.84	4.1	CML176 × LH132.LH51	0.68	6.2
CML144 × LH132.LH51	1.73	5.9	CML319 × LH132.LH51	0.63	5.3
CML142 × LH132.LH51	1.67	6.1	CML91 × LH132.LH51	0.60	5.8
CML269 × LH132.LH51	1.66	6.4	CML329 × LH132.LH51	0.56	5.9
CML184 × LH132.LH51	1.63	6.1	CML108 × LH132.LH51	0.46	6.3
CML16 × LH132.LH51	1.47	6.4	CML161 × LH132.LH51	0.34	5.4
CML40 × LH132.LH51	1.43	5.4	CML154Q × LH132.LH51	0.27	5.4
CML216 × LH132.LH51	1.43	6.2	Pioneer P31G98	0.26	7.4
CML56 × LH132.LH51	1.39	4.5	CML274 × LH132.LH51	0.24	6.3
CML223 × LH132.LH51	1.32	5.7	CML157Q × LH132.LH51	0.18	6.4
Pioneer 32K61	1.11	6.2	Garst 8288	0.08	6.7
CML173 × LH132.LH51	1.07	5.8	CML92 × LH132.LH51	0.00	5.2
CML295 × LH132.LH51	1.06	5.0	LH200 x LH262	-0.08	6.7
CML159 × LH132.LH51	1.01	5.7	CML103 × LH132.LH51	-0.19	6.1
CML69 × LH132.LH51	0.95	5.8	CML186 × LH132.LH51	-0.23	5.7

Coefficient of regression, *b*, for Finlay and Wilkerson's environmental index. Regression coefficients near *b* = 1 are an indication of stability across environments. Mean yield across environments is also given.

Table B.15 2004 Environmental Index

Entry	*b*	Yield Mg ha^{-1}	Entry	*b*	Yield Mg ha^{-1}
CML91 × LH132.LH51	2.15	6.6	CML176 × LH132.LH51	1.00	7.0
NK91-R9	1.42	6.7	CML108.NC374 × FR615.FR697	1.00	6.8
Pioneer P31G98	1.38	7.7	CML92 × LH132.LH51	1.00	6.3
CML16.NC374 × FR615.FR697	1.29	6.9	CML269 × LH132.LH51	0.99	6.4
CML91.NC374 × FR615.FR697	1.29	6.9	CML92.NC374 × FR615.FR697	0.99	6.1
CML38 × LH132.LH51	1.26	6.6	326172w. × FR615.FR697	0.99	6.1
VO613Y × LH132.LH51	1.21	6.6	CML10 × LH132.LH51	0.98	6.6
CML16 × LH132.LH51	1.19	6.9	CML108.NC414 × FR992.FR1064	0.98	6.6
LH200 x LH262	1.18	7.3	CML333.NC374 × FR615.FR697	0.96	6.8
Garst 8288	1.15	7.4	CML274 × LH132.LH51	0.95	6.7
BO46W × LH132.LH51	1.15	6.4	CML103.NC414 × FR992.FR1064	0.95	6.4
CML374 × LH132.LH51	1.11	6.9	CML333 × LH132.LH51	0.95	6.4
LH132 x LH51	1.10	6.6	DO940Y × LH132.LH51	0.95	6.4
CML216 × LH132.LH51	1.09	6.7	CML69.NC414 × FR992.FR1064	0.94	6.3
CML154Q.NC374 × FR615.FR697	1.08	6.6	CML103.NC374 × FR615.FR697	0.94	6.7
CML38.NC374 × FR615.FR697	1.06	6.5	CML108 × LH132.LH51	0.94	7.1
CML157Q × LH132.LH51	1.06	7.1	CML269.NC374 × FR615.FR697	0.92	6.5
CML10.NC414 × FR992.FR1064	1.05	7.1	CML38.NC418 × FR992.FR1064	0.92	6.4
CML154Q.NC414 × FR992.FR1064	1.05	6.1	CML157Q.NC374 × FR615.FR697	0.90	6.5
CML91.NC414 × FR992.FR1064	1.04	6.3	CML373 × LH132.LH51	0.85	7.2
CML69.NC374 × FR615.FR697	1.04	5.8	CML154Q × LH132.LH51	0.81	6.2
CML157Q.NC414 × FR992.FR1064	1.03	6.8	CML103 × LH132.LH51	0.80	6.5
CML341 × LH132.LH51	1.03	6.7	CML269.NC418 × FR992.FR1064	0.79	7.1
CML69 × LH132.LH51	1.02	6.5	NC296A × LH132.LH51	0.76	7.6
CML10.NC374 × FR615.FR697	1.02	7.0	CML116 × LH132.LH51	0.75	6.0
CML333.NC414 × FR992.FR1064	1.02	6.8	DeKalb 697	0.73	8.6
CML341.NC374 × FR615.FR697	1.02	7.4	CML16.NC418 × FR992.FR1064	0.70	6.8
CML327 × LH132.LH51	1.01	7.0	CML92.NC414 × FR992.FR1064	0.69	6.3
CML341.NC414 × FR992.FR1064	1.01	7.2	CML343 × LH132.LH51	0.66	7.7

Coefficient of regression, *b*, for Finlay and Wilkerson's environmental index. Regression coefficients near *b* = 1 are an indication of stability across environments. Mean yield across environments is also given.

Table B.16 2005 Environmental Index

Entry	*b*	Yield Mg ha^{-1}	Entry	*b*	Yield Mg ha^{-1}
LH132 x LH51	2.44	6.3	CML103.NC414 × FR992.FR1064	0.94	7.0
Pioneer 32W86	1.83	8.1	CML16 × LH132.LH51	0.94	6.5
CML157Q.NC414 × FR992.FR1064	1.81	6.6	CML176 × LH132.LH51	0.92	6.3
Pioneer 32D99	1.71	8.7	CML333 × LH132.LH51	0.91	6.6
CML91.NC414 × FR992.FR1064	1.67	6.5	CML373 × LH132.LH51	0.90	6.5
CML176.NC382 × FR992.FR1064	1.62	7.1	NK91-R9	0.89	7.7
CML10.NC414 × FR992.FR1064	1.60	7.3	CML343.NC382 × FR992.FR1064	0.89	7.3
CML108.NC414 × FR992.FR1064	1.53	6.6	CML274 × LH132.LH51	0.87	7.7
CML38.NC418 × FR992.FR1064	1.51	6.4	CML16.NC418 × FR992.FR1064	0.85	6.5
CML269.NC374 × FR615.FR697	1.49	6.8	LH200 x LH262	0.84	7.3
CML274.NC382 × FR992.FR1064	1.49	6.9	BO46W × LH132.LH51	0.83	7.1
CML341.NC414 × FR992.FR1064	1.47	7.2	DeKalb 697	0.83	7.5
CML38 × LH132.LH51	1.45	6.4	CML69.NC414 × FR992.FR1064	0.81	6.6
Pioneer P31G98	1.43	8.2	CML341.NC374 × FR615.FR697	0.80	7.6
LH195 x LH256	1.39	6.7	89302 × LH132.LH51	0.80	6.2
CML10.NC374 × FR615.FR697	1.35	7.2	CML16.NC374 × FR615.FR697	0.80	7.6
CML327 × LH132.LH51	1.34	6.7	CML374.NC382 × FR992.FR1064	0.78	7.0
Garst 8288	1.32	7.9	CML92.NC374 × FR615.FR697	0.78	6.8
CML341 × LH132.LH51	1.28	6.7	CML108 × LH132.LH51	0.76	6.5
CML10 × LH132.LH51	1.27	6.2	CML92.NC414 × FR992.FR1064	0.75	6.7
CML157Q.NC374 × FR615.FR697	1.26	7.2	C70 × LH132.LH51	0.75	6.7
CML374.NC374 × FR615.FR697	1.26	6.8	CML69 × LH132.LH51	0.74	6.3
Tzi17 × LH132.LH51	1.21	6.1	CML116 × LH132.LH51	0.73	6.2
CML176.NC374 × FR615.FR697	1.17	6.5	CML108.NC374 × FR615.FR697	0.70	7.1
CML154Q.NC414 × FR992.FR1064	1.15	6.4	CML103.NC374 × FR615.FR697	0.67	7.0
CML91 × LH132.LH51	1.14	6.7	90156 × LH132.LH51	0.67	5.5
CML269 × LH132.LH51	1.14	6.8	CML274.NC374 × FR615.FR697	0.61	7.3
89291 × LH132.LH51	1.13	7.4	CML333.NC374 × FR615.FR697	0.52	7.1
CML216.NC382 × FR992.FR1064	1.12	6.8	CML154Q.NC374 × FR615.FR697	0.52	7.1
CML103 × LH132.LH51	1.09	6.6	NC296A × LH132.LH51	0.50	6.6
CML269.NC418 × FR992.FR1064	1.08	7.0	CML333.NC414 × FR992.FR1064	0.45	6.5
CML91.NC374 × FR615.FR697	1.06	7.2	DO940Y × LH132.LH51	0.44	6.3
CML343 × LH132.LH51	1.04	7.6	CML154Q × LH132.LH51	0.43	6.8
CML373.NC382 × FR992.FR1064	1.04	6.9	CML374 × LH132.LH51	0.41	6.7
Tzi3 × LH132.LH51	1.03	6.1	CML343.NC374 × FR615.FR697	0.28	7.4
CML373.NC374 × FR615.FR697	1.01	7.0	CML69.NC374 × FR615.FR697	0.27	6.7
CML38.NC374 × FR615.FR697	0.99	7.1	90301 × LH132.LH51	0.10	6.3
CML157Q × LH132.LH51	0.99	6.9	89199 × LH132.LH51	0.00	6.8
CML92 × LH132.LH51	0.98	6.5	87036 × LH132.LH51	0.00	5.3
VO613Y × LH132.LH51	0.98	6.1	CML216 × LH132.LH51	-0.04	6.5
CML216.NC374 × FR615.FR697	0.97	6.4	Pioneer 32R25	-0.05	8.3

Coefficient of regression, *b*, for Finlay and Wilkerson's environmental index. Regression coefficients near *b* = 1 are an indication of stability across environments. Mean yield across environments is also given.

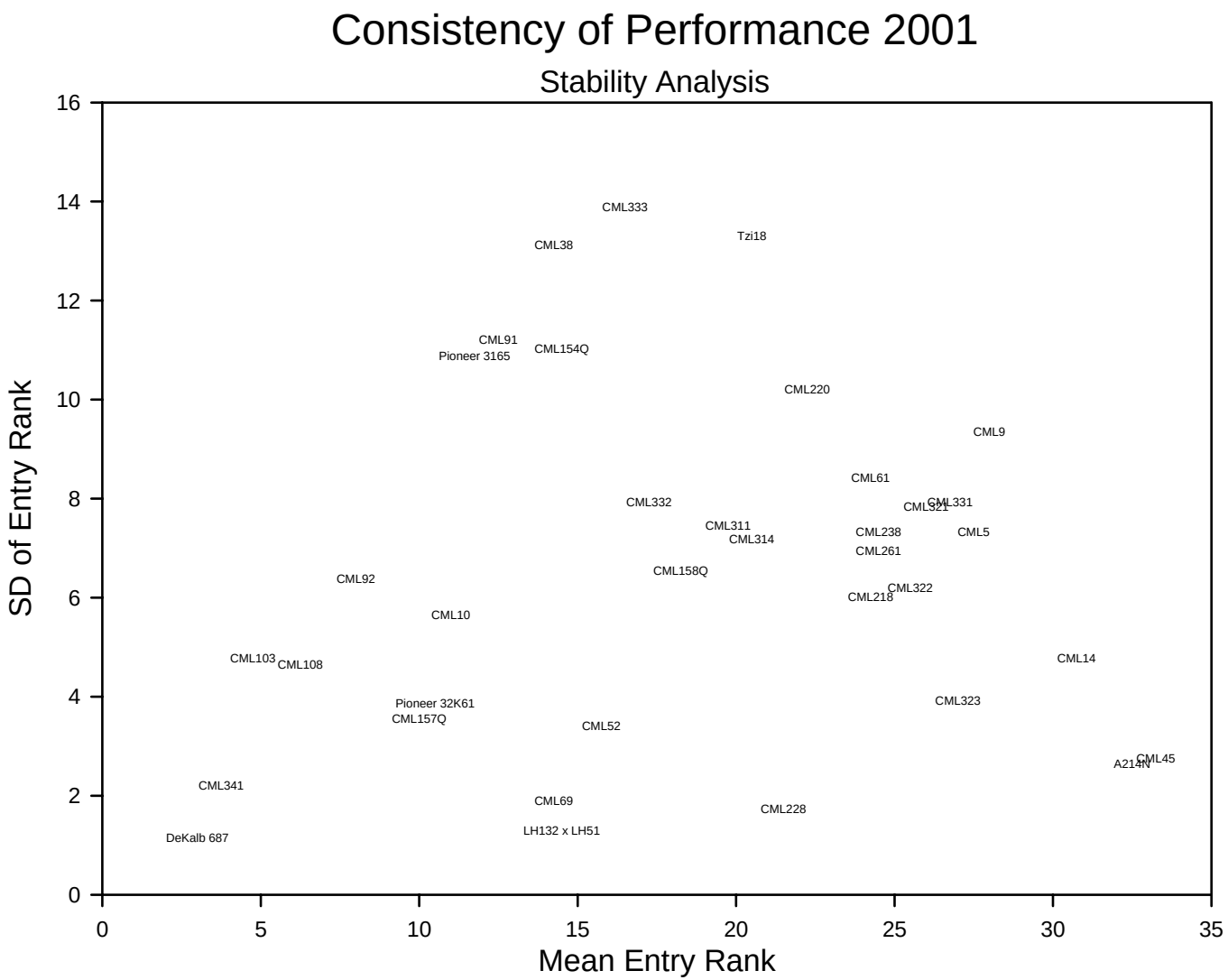

Figure B.1 Consistency of performance stability analysis for entries tested in 2001. Entries that consistently (low standard deviation (SD) of entry rank) ranked high (low mean rank) are considered stable.

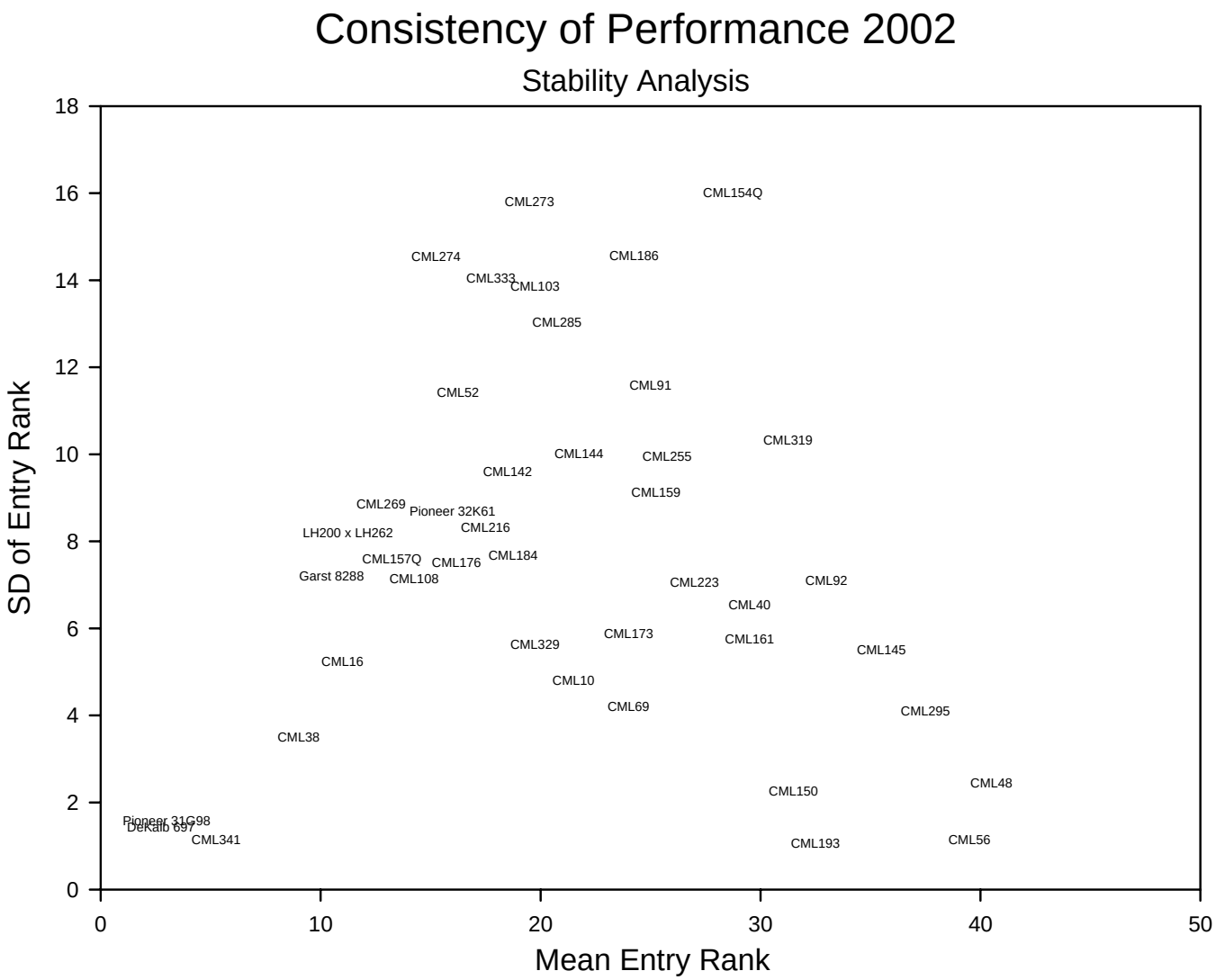

Figure B.2 Consistency of performance stability analysis for entries tested in 2002. Entries that consistently (low standard deviation (SD) of entry rank) ranked high (low mean rank) are considered stable.

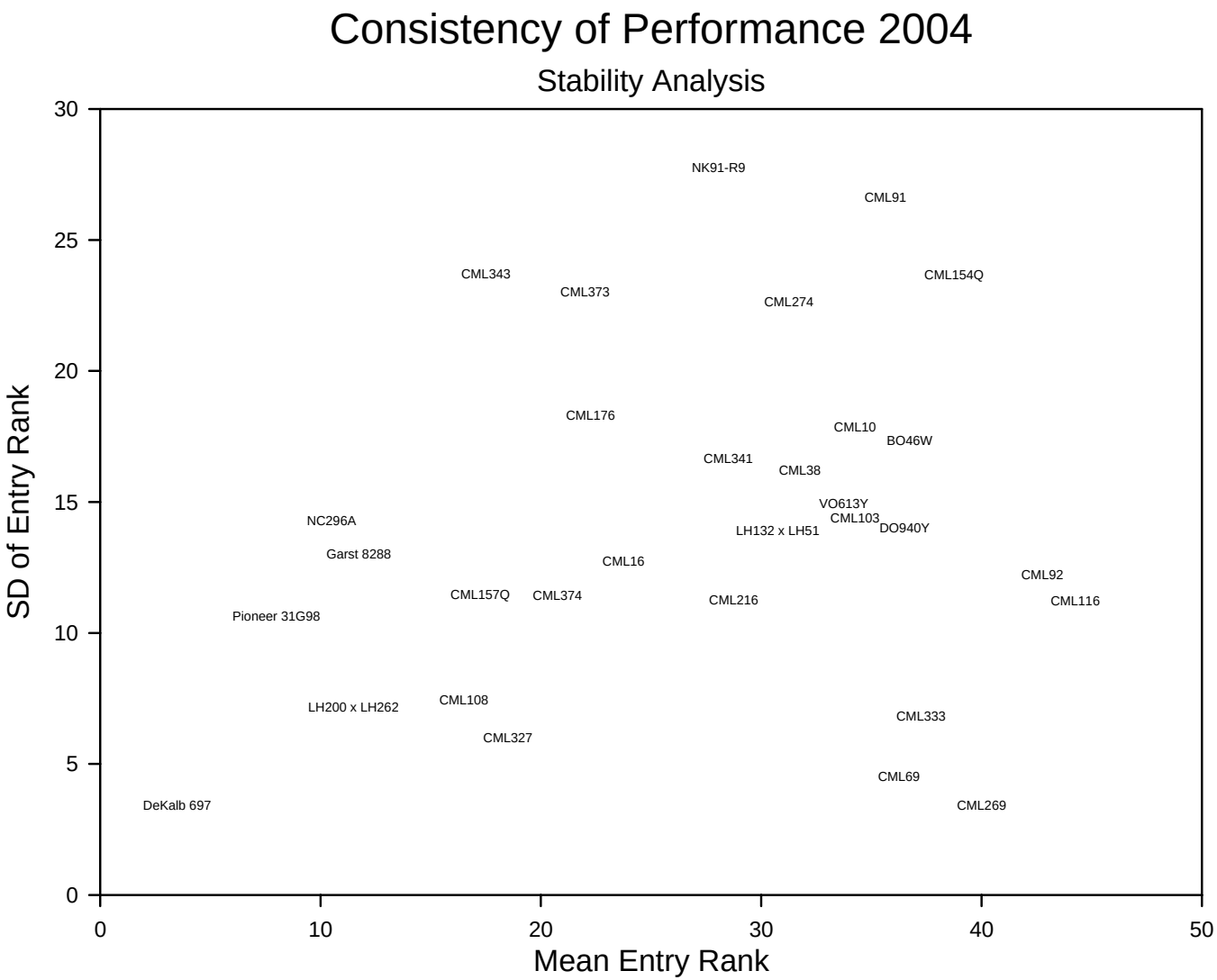

Figure B.3 Consistency of performance stability analysis for entries tested in 2004. Entries that consistently (low standard deviation (SD) of entry rank) ranked high (low mean rank) are considered stable.

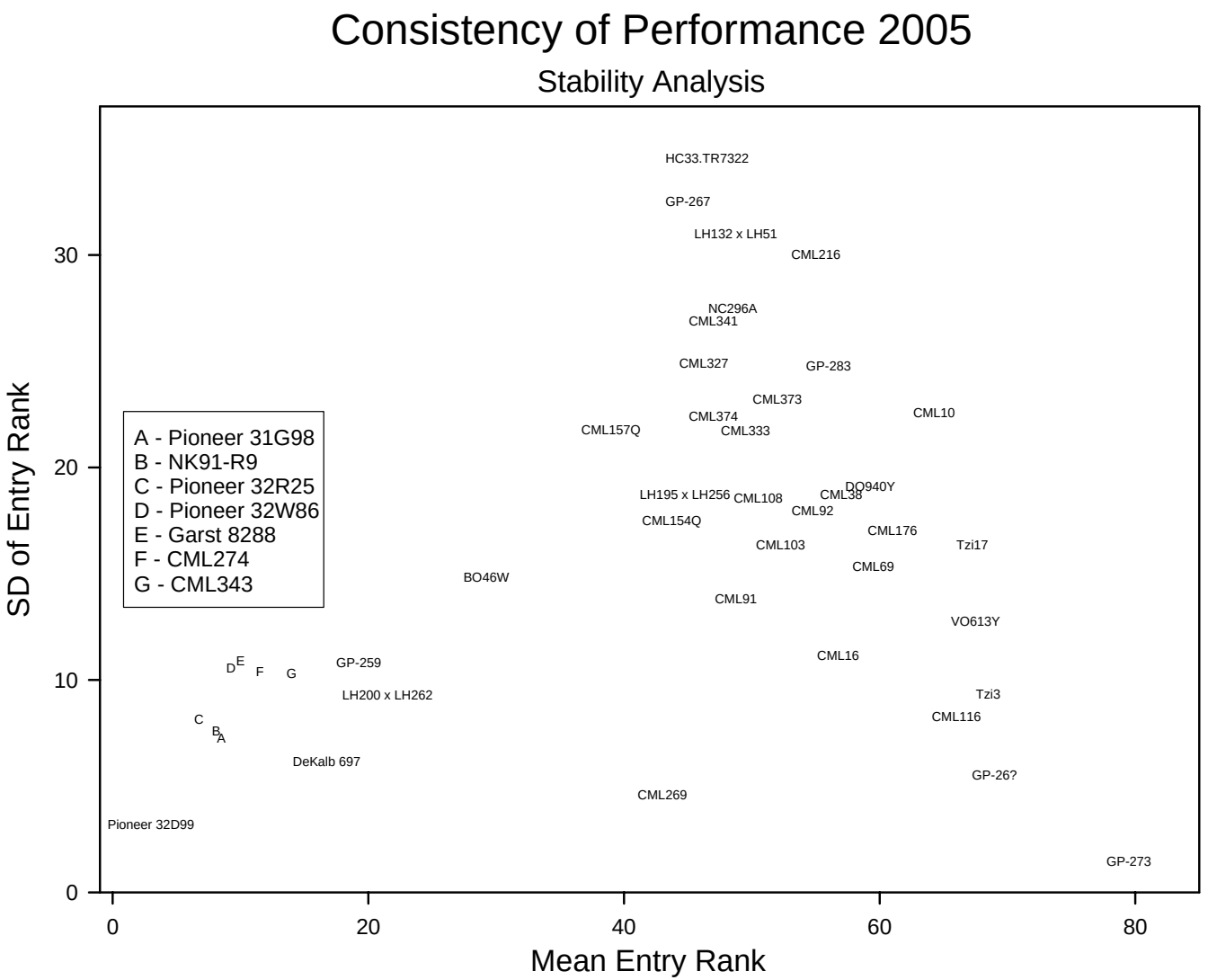

Figure B.4 Consistency of performance stability analysis for entries tested in 2005. Entries that consistently (low standard deviation (SD) of entry rank) ranked high (low mean rank) are considered stable.

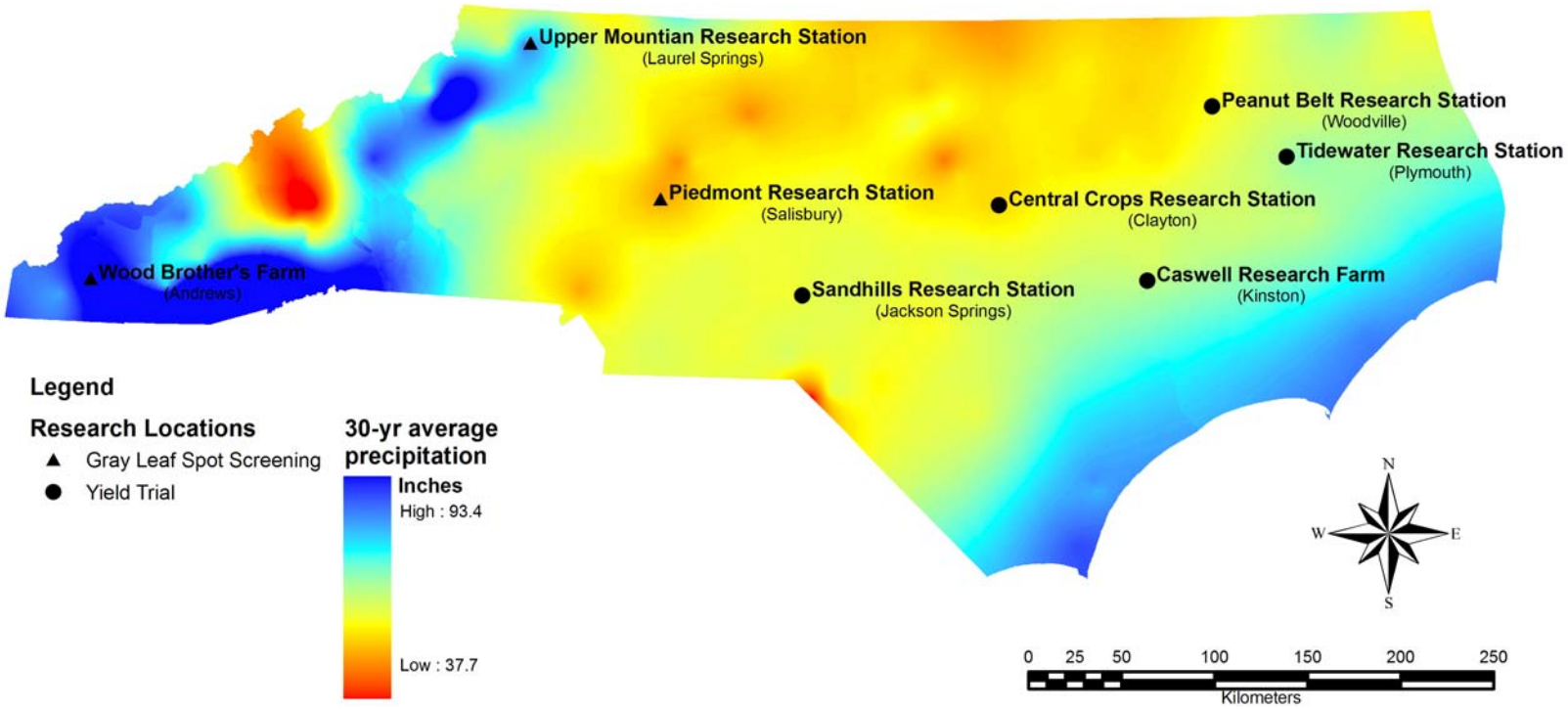

Figure B.5 Yield trial and gray leaf spot (GLS) screening locations given with 30-year average precipitation levels across the state of North Carolina. The precipitation data were complied from the National Climate Data Center monthly precipitation totals and interpolated using a linear kriging algorithm. Interpolations were run on 160 gauging stations using 500 foot square grid cells (Hirth, D.K., 1998. N.C. Dept. Environment, and Natural Resources, Division of Water Quality, Groundwater Section, Raleigh, NC).

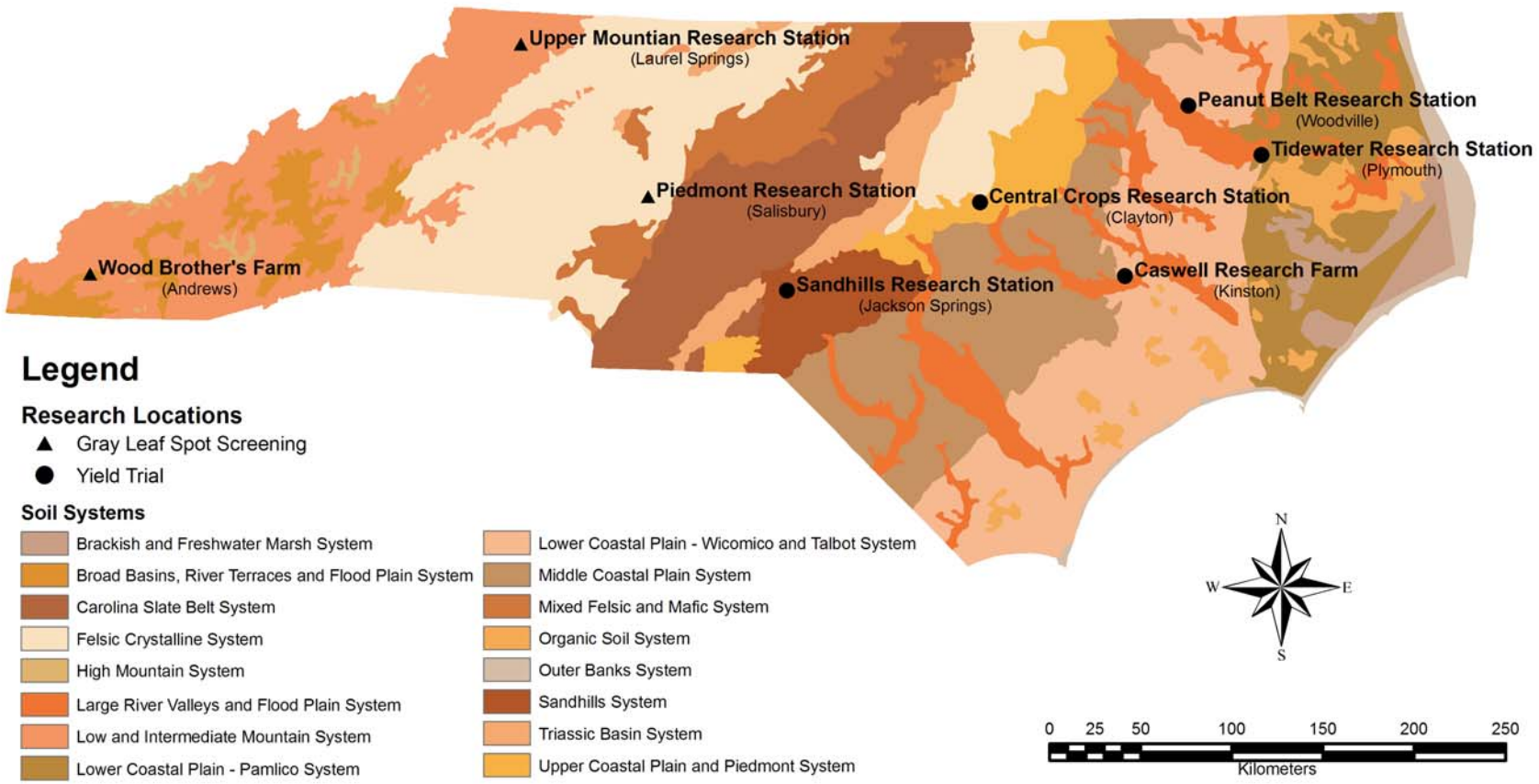

Figure B.6 Yield trial and gray leaf spot (GLS) screening locations given with soil systems across the state of North Carolina.

– APPENDIX C –

Supporting Material for Chapter IV

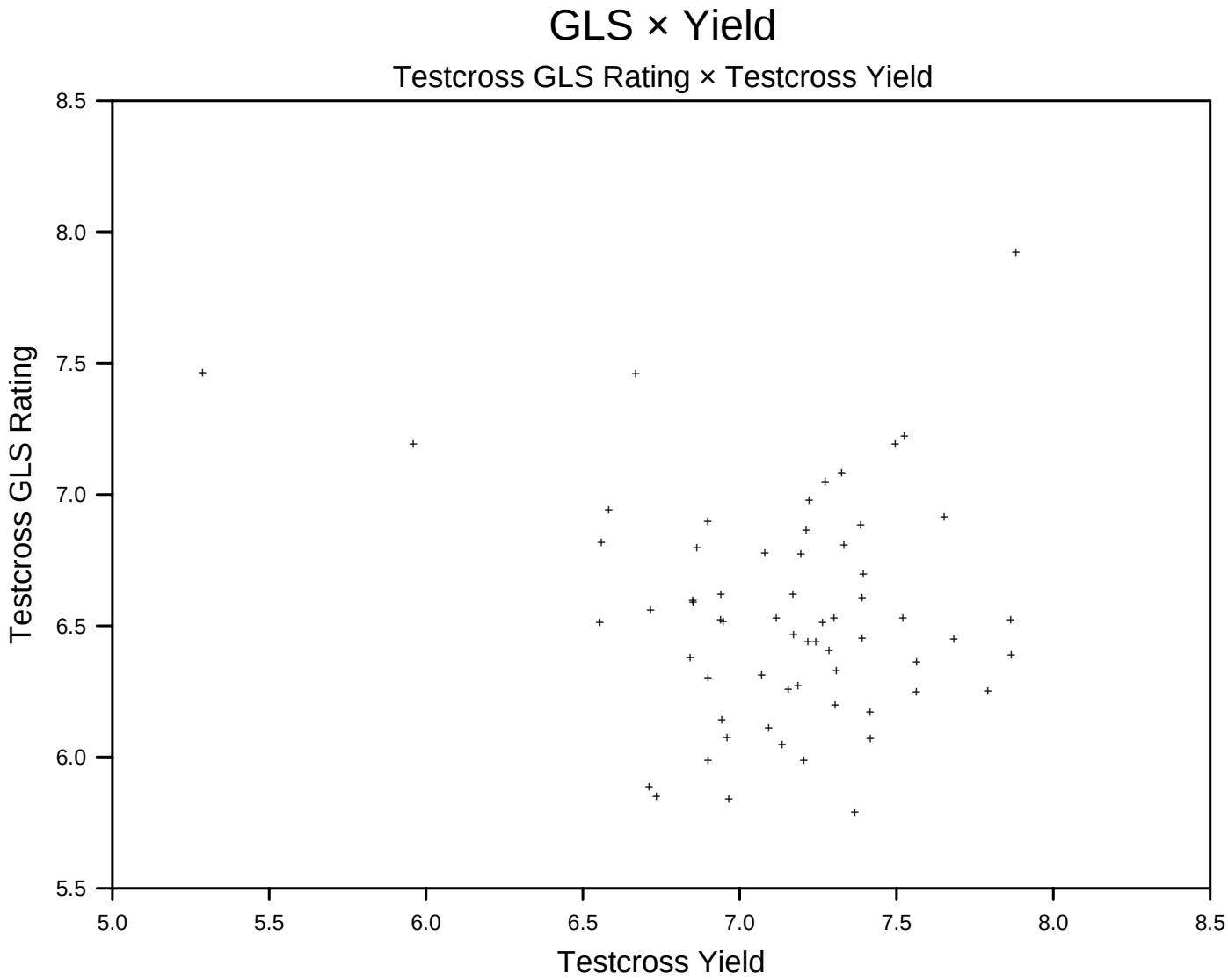

Figure C.1 Testcross GLS ratings × testcross yield, entries from Nelson et al. (2006). Coefficient of correlation, r = -0.13.

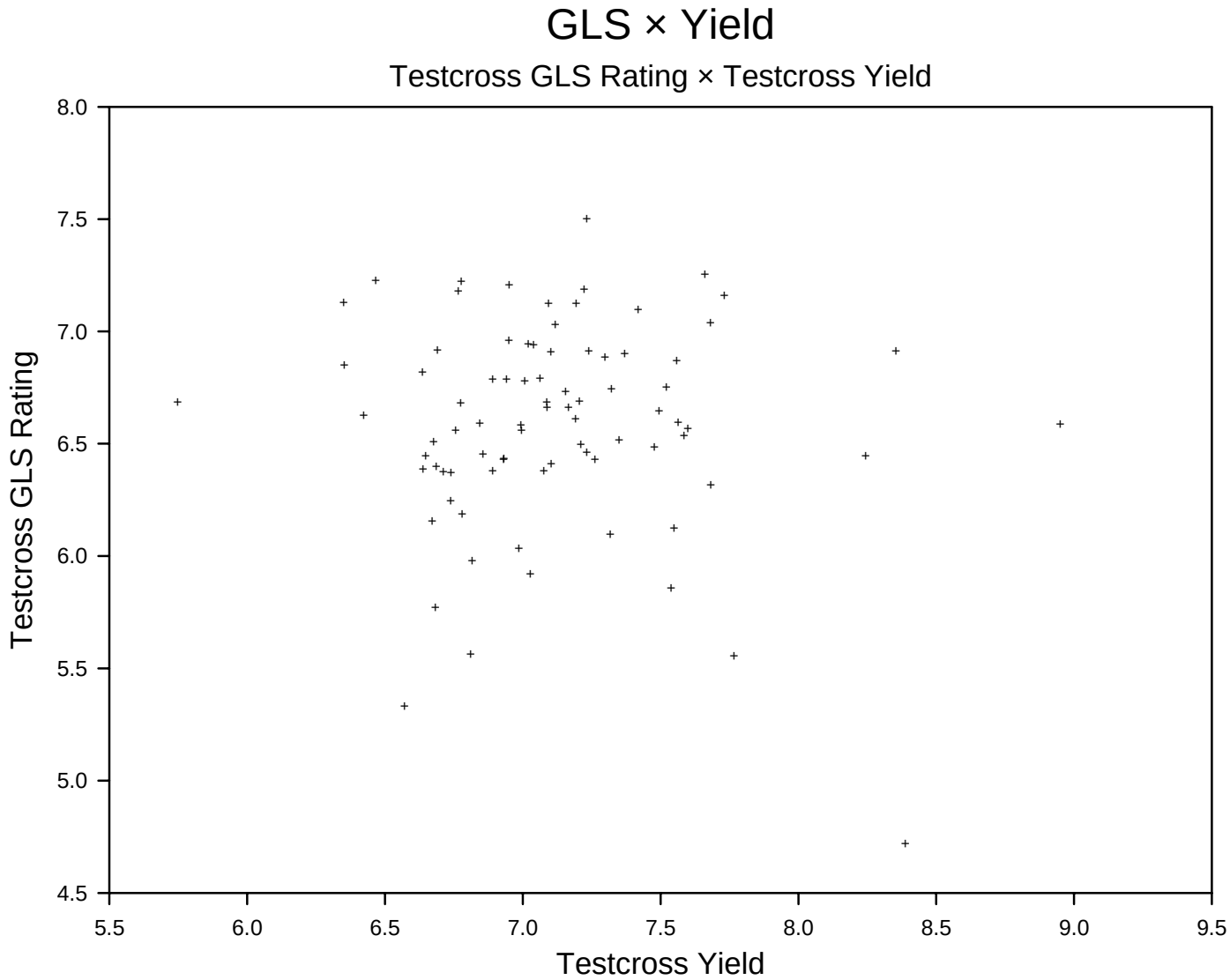

Figure C.2 Testcross GLS ratings × testcross yield, entries from Chapter 3 of this thesis. Coefficient of correlation, r = -0.08.

– Appendix D –

Common and Southern Rust Evaluation Exotic Inbreds

Occasionally, conditions in North Carolina are conducive to infestations of the maize foliar diseases common rust, caused by the fungus *Puccinia sorghi*, and southern rust, caused by the fungus *Puccinia polysora*. In 2000, common rust occurred at Laurel Springs, NC, a gray leaf spot screening location, and in 2003 southern rust occurred at Salisbury, NC, also a gray leaf spot screening locations (Appendix B, Figures B.5 and B.6). In both instances a single disease rating was taken for the respective diseases. Ratings were taken on a 1-9 scale, 1 being fully susceptible and 9 being fully resistant. Data for common rust ratings on 30 experimental inbreds and one check are provided in Table D.1 and data for southern rust ratings on 44 experimental inbreds and four checks are provided in Table D.2.

Table D.1 Common rust disease ratings.

Line	Rating	Line	Rating
A6	3	CML281	7
A214N	7	CML287	8
CML5	9	CML311	6
CML9	9	CML314	8
CML10	6	Ki3	8
CML14	8	Ki11	5
CML38	7	Ki21	8
CML45	8	Ki43	6
CML52	6	KUI2021	6
CML61	7	Tzi8	8
CML247	8	Tzi9	6
CML254	8	Tzi10	8
CML258	7	Tzi16	8
CML261	8	Tzi18	6
CML277	6	Tzi25	7
Check			
B73	6		

Ratings are on a 1-9 scale: 1 = completely susceptible, 9 = completely resistant. Data are from one rating in Laurel Springs, NC in 2000.

Table D.2 Southern rust disease ratings.

Line	Rating	Line	Rating
CML5	9	CML261	7
CML10	8	CML269	8
CML14	8	CML270	8
CML16	8	CML273	4
CML40	7	CML274	8
CML45	8	CML281	8
CML48	9	CML285	4
CML52	9	CML287	7
CML61	7	CML288	7
CML69	7	CML304	7
CML91	7	CML319	6
CML92	6	CML325	7
CML103	5	CML327	7
CML108	3	CML333	7
CML144	4	CML341	4
CML145	6	CML343	7
CML150	7	CML373	8
CML154Q	4	CML374	8
CML157Q	7	CML384	8
CML159	8	Tzi16	6
CML247	8	Tzi18	7
CML258	8	VO613Y	7
Checks			
B73	2	NC258	8
NC250	7	NC304	8

Ratings are on a 1-9 scale: 1 = completely susceptible, 9 = completely resistant. Data are from one rating in Salisbury, NC in 2003.