Evaluation of the genetic potential of prairie junegrass (*Koeleria macrantha*) for use as a low-input turfgrass

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Dedication

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Abstract

Prairie junegrass [*Koeleria macrantha* (Ledeb.) Shultes] is a perennial, short-grass prairie species distributed throughout the Northern Hemisphere. This species demonstrates tolerance to many environmental stresses found in Minnesota. In June 2007, 48 *K. macrantha* accessions from the United States National Plant Germplasm System (NPGS) were grown and evaluated in two experiments; (i) seed production characteristics and (ii) turf quality characteristics in 2 locations (St. Paul, MN and Becker, MN).

In the seed production experiment, seed was harvested in 2008, and significant variation was found among accessions for several seed production traits including harvest date, plant height, seedhead number, and seed yield. A significant correlation between seedhead number and seed yield was found, which can be utilized for indirect selection in the production nursery. Plant growth and seed yield were highest at the Becker location demonstrating the species' preference for well drained soils.

In the turf quality experiment, mowed space plants were evaluated from 2007-2009, nineteen accessions at Becker and 30 accessions at St. Paul performed with an adequate turf quality rating of 5.0 or higher when averaged over the three-year study, suggesting the potential for use in low-input areas. Prairie junegrass from northern collection regions displayed the highest ratings in spring green-up which is an important turf trait in northern climates. There was a strong negative correlation between this trait and mowing quality at Becker (r = -0.44) and at St. Paul (r = -0.34). Several accessions demonstrated acceptable mowing quality and would be candidates for integration into a native prairie junegrass breeding program.

In June 2007 a third experiment was conducted. Three hundred genotypes representing crossing blocks derived from Colorado, Nebraska, and Minnesota germplasm were grown and evaluated for turf quality characteristics in a randomized complete block design with five clonal replications at 2 locations (St. Paul and Becker) and evaluated for three years. Following establishment, plots received no supplemental irrigation or fertility and were mowed weekly to a height of 6.4 cm. Broad-sense heritability estimates were calculated on a clonal mean (Hc) and single plant (Hsp) basis for turf quality (Hc = 0.62, Hsp = 0.13), crown density (Hc = 0.55, Hsp = 0.09), mowing quality (Hc = 0.59, Hsp = 0.09), and genetic color (Hc=0.45, Hsp = 0.06). The heritability estimates indicate that selection for these traits should result in significant gains in germplasm improvement. Differences were observed for means and variances among clones, crossing blocks, and/or collection regions for many of the traits evaluated including rust (incidence and severity), spring green-up, plant height, lateral spread, vertical re-growth, and flowering traits. The positive correlations among some of these traits and those with moderate heritability estimates will allow for multi-trait selection in cultivar development. Rust (unknown *Puccinia* species) was present at both locations.

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LITERATURE REVIEW

Prairie junegrass (*Koeleria macrantha* (Ledeb.) Schultes), also known as junegrass, or (crested) hairgrass, is a perennial, short-grass prairie species distributed throughout the Northern hemisphere. Little attention has been given to North American germplasm and available prairie junegrass turfgrass cultivars have been developed from European ecotypes. These European cultivars differ from the breeding populations currently in development derived from germplasm collected in the US Great Plains. Prairie junegrass occupies a diverse natural range that provides the plant breeder with a broad genetic base from which to select traits including turf quality, color, density, mowing quality, growth habit, drought tolerance, disease resistance, and seed production. This species is known to require fewer inputs than other cool-season turfgrasses and it demonstrates tolerance to many environmental stresses found in Minnesota. The genetic improvement of native prairie junegrass into top-performing turfgrass varieties should reduce water, fertilizer, and pesticide inputs resulting in environmental benefits and reduced costs. Native grasses are excellent choices for reduced water use, conservation of native species, and esthetic and practical qualities such as erosion control .

To date, only a handful of prairie junegrass cultivars have been developed throughout the world for turf, forage, or restoration purposes. Outside of the few named cultivars, most commercially available plants and other germplasm have not undergone any selection. In revegetation sites, maintaining diversity within the stand is important, but for turf this leads to inconsistent stands. A Canadian cultivar ‘ARC Mountain’ was developed for forage use in reclamation and revegetation sites. Several turfgrass cultivars have been derived from European ecotypes including the Estonian cultivar ‘Ilo’ (Soovali and Bender, 2006) and two Dutch cultivars, ‘Barleria’ and ‘Barkoel’ which have been released by Barenbrug Holland B.V. (Oosterhout, The Netherlands) (Alderson and Sharp, 1994). In a low-input study in Manitoba, Canada, Barkoel was a top performer compared to other species and exhibited excellent color, density, and drought tolerance in turf trials, but was subject to leaf shredding (Mintenko et al., 2002). Unimproved native germplasm exhibited early spring green-up almost immediately following snow melt, sooner than many other species (Mintenko and Smith, 1999). This has also been observed in Minnesota (personal observation). This characteristic is highly desired in northern climates for improved aesthetics and early season play.

Taxonomic and nomenclatural problems

The genus *Koeleria* comprises about 60 species in temperate regions throughout the world (Edgar and Gibb, 1999). *K. macrantha* is naturally distributed throughout the Northern Hemisphere and varies in morphological characteristics which makes proper identification difficult. Many subspecies, varieties, and subvarieties have been named within this species (Looman, 1978). Classification schemes may be inconsistent and inaccurate due to polyploidy and wide adaptation (Dixon, 2001). Many different names have been given to this species including: *Aira cristata* L. (Pammell et al., 1901-1904), *K. glauca* (Dixon, 2000; Dixon, 2001), *K. gracilis* (L.) Pers., *K. cristata* (L.) Pers., *K. nitida* Nutt., *K. macrantha* (Ledeb.) Schultes, (Arnow, 1994), *K. pyramidata* (Kucera, 1998), *K. pryanidata* (Hetrick and Wilson, 1990), and *K. yukonesis* (Shaw, 2008). These binomials can be found describing commercially available plant materials as well as in the literature. The lag that exists between scientists, industry, and consumers in adopting the proper nomenclature makes studying the species difficult.

Arnow (1994) determined that there was no evidence of *K. pyramidata* in North America and that *K. pyramidata* is a distinct species (unique phenotype, ecotype, geography, and cytology 2n=84). Phenotypically, *K. pyramidata* is taller, more densely tufted, and has longer and broader basal leaves. Diseases such as ergot (*Claviceps purpurea*) can cause morphological changes in the plant making species identification difficult. In addition to morphological features, laboratory techniques can be used to identify and classify species and subspecies or to describe the relatedness within the population. Genetic markers have been used in *Poa annua* (Carson et al., 2007) and in bentgrass (*Agrostis* sp.) (Hollman et al., 2005) breeding programs to correctly classify material and to differentiate genotypes. In a study of flavonoids by Rolly et al. (1988), a comparison of different *Koeleria* accessions showed unique flavonoid patterns based on cytotype (chromosome number) and geographic distribution.

Distribution

Known throughout the Northern Hemisphere, *K. macrantha* has a large range in its distribution across Europe and Asia. It is found throughout the British Isles, Russia, Siberia, Afghanistan, Iran, Lebanon, Syria, Turkey, India, Kashmir, Nepal, Tibet, China, Japan, Korea, Mongolia, etc. and into Northern Africa and areas of South Africa (Dixon, 2000). *Koeleria macrantha* is also found throughout the North American continent. It is absent in the Mid-Atlantic to Southeast United States (Kucera, 1998), but present elsewhere: north into Canada, west to the Pacific, south into northern Mexico

(Robertson, 1974) even Mexico City (Arnow, 1994), and into South America (Gleason and Cronquist, 1991). In North America, *Koeleria macrantha* is found primarily on hillsides and other well drained sites. It is found in mixed prairies and dunes, but not in valley vegetation (Barnes and Harrison, 1982). Plant communities with prairie junegrass are found in the dry soils of prairies and open woods. Prairie junegrass is generally found in sandy soils with a low water table (Mueller-Dombois and Sims, 1966). This species is more tolerant to dry conditions than *K. pyramidata* (Arnow, 1994).

Temperature, precipitation, and altitude vary greatly across the distribution of the species. *Koeleria macrantha* grows in regions where temperatures could be as low as -50°C (Siberia) in the winter and as high as 39°C (Spain) during summer months (Meteorological Office as cited in Dixon, 2000). In South Dakota, viable seed was collected from plant materials at temperatures exceeding 40°C (personal observation). Prairie junegrass has been collected in the Rocky Mountains in subalpine to alpine grasslands at altitudes of 2,200 m though the plants are shorter (Looman, 1978). Colorado ecotypes display a variety of phenotypes and morphologies suggesting regional adaptation to growth conditions and competition for different genetic sources for the populations (Robertson and Ward, 1970). In the US Midwest, *K. macrantha* is found throughout prairie ecosystems. It is not as competitive as other more robust species, but is a 'pioneer' species that reseeds bare areas and quickly establishes following soil disturbances (Coupland, 1950; Looman, 1978).

Species characteristics

Koeleria macrantha is a perennial, cool-season (C3) grass that grows to 3-6 dm in height. It is a bunch grass, generally without rhizomes or stolons, that forms a dense sod (Pammell et al., 1901-1904). In grazed areas, it mostly exhibits intravaginal tillering, but if left ungrazed may be more prostrate and creeping (Dixon, 2000). It has pubescent leaves 1-3 mm wide and pubescent sheaths (Dore and McNeill, 1980). The leaves are silvery-green (Gleason and Cronquist, 1991) to blue green (Coupland, 1950). Blades are 5-20 cm long and are nerved or heavily ridged. Looman (1978) describes the leaf emergence as rolled, later flat, then rolled or becoming twisted. A short, truncated (up to 1 mm) ligule is present (Coupland, 1950). The roots are dense and fibrous reaching 30-35 cm (Dixon, 2000). The inflorescence is a spike-like panicle (Pammell et al., 1901-1904) or panicle (Shaw, 2008) 4-5 cm long on culms 8.9-38.1 cm . The inflorescences expand during flowering but are closed before and after (Coupland, 1950). The number of spikelets per inflorescence vary from 20-200. Inflorescences are colored green to purple (Dixon, 2000). Spikelets are 2-4 flowered with 2 empty glumes below the longer, flowering glumes. The palea is 2-nerved, nearly as long at the glume. There are three stamens, styles are short, and stigmas are plumose (Coupland, 1950). Anthers are 1.5 mm, yellow or purple, and pollen is round to oval (Looman, 1978).

The majority of prairie junegrass growth occurs in early spring (Coupland, 1950). In native prairie habitats, prairie junegrass is often the earliest grasses to green-up in the spring and produces a single flush of growth that results in flowering in June, seed ripening in July, followed by a period of dormancy for the rest of the summer as water resources become limited. The species avoids the dry summer months by completing its reproductive cycle before summer drought (Barnes and Harrison, 1982).

Low-input turf

The reduction in water availability for landscape irrigation, an increase in fuel costs, and a negative perception that turfgrass fertilizers and pesticides contribute to pollution, has resulted in a need to develop and utilize turfgrasses that require fewer of these inputs. Conservation of water and other resources can be accomplished by shifting the public's expectations for lawns and changing the species utilized in landscapes (Kjelgren et al., 2000). Low-maintenance turf often has lower visual and performance expectations than highly managed areas (Johnson, 2003). Reduced maintenance areas can include home lawns, roadsides, cemeteries, low-use parks and schools, golf course roughs, and fairways (Hanks et al., 2005). These authors suggest that acceptable turf quality is defined by color, leaf texture, density, and aesthetic appeal for the particular area. Additionally, the turf area must provide uniform appearance and compete with unwanted species and stabilize the soil (Dernoeden et al., 1994a; Diesburg et al., 1997).

Native grasses

Both native and introduced grasses have been evaluated for use as low-input turf. The traditional turf grasses are better adapted to high input areas, where as native grasses perform better under lower traffic and at higher mowing heights (Johnson, 2008).

Native species are an excellent options for low and reduced maintenance turfgrass due to their ability to withstand heat and drought stress with fewer irrigation needs (Johnson, 2000). Native species should be exploited in breeding programs for their adaptation to a broad range of soil and climate conditions (Willms et al., 2005). Native grasses have evolved under the extreme conditions of North America and would be logical candidates for low-maintenance turf (Mintenko and Smith, 1999; Mintenko et al., 2002). Native accessions being developed as turf varieties must demonstrate limited growth, thin leaves, and quick recovery to traffic and wear (Romani et al., 2002). A poor tolerance to mowing, low seed production, and extended dormancy are major obstacles in developing native grasses for turf.

The native species buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] has been extensively studied for use as a low-input turf. Its benefits include tolerance to mowing and a vigorous growth habit which produces a uniform turf (Johnson, 2008). Research has shown that buffalograss requires more mowing than other species in both optimal and low-input treatments (Brede, 2002). Another potential limitation of this species is that as a warm-season grass, buffalograss may be dormant during cool temperatures which can limit its use in the northern United States (Johnson, 2003). Other native grasses that have been evaluated for use as low-input turf include prairie junegrass (Watkins and Clark, 2009), sheep fescue (*Festuca ovina* L.) (McKernan et al., 2001), and tufted hairgrass [*Deschampsia caespitosa* (L.) P. Beauv.] (Watkins and Meyer, 2005). Despite research into these and other native grasses, very few turfgrass cultivars have been developed. Brede (2000) encouraged consumers to seek low-input grass seed from growers producing seed material for government, roadway, and reclamation projects. Seed can be limited and expensive when grown for these projects as production technologies have not been studied extensively on the species and there is limited market share outside of government contracts.

Drought tolerance and avoidance

As water restrictions increase, turfgrass cultivars will need to be developed that are resilient to drought stress. Understanding the physiology of the drought response would allow breeders to screen for components of drought resistance (Johnson and Asay, 1993). Native grasses demonstrate an improved response to drought and are a logical selection for sites with limited irrigation. Prairie junegrass is typically found growing in dry soils and when in mixed vegetation is only found in the driest parts of sites (Baker, 1937). The species may not be found in all dry sites as it can not compete with larger and faster growing grass species (Looman, 1978). Prairie junegrass exhibits characteristics that make it both drought tolerant and drought avoidant. In response to drought, the plant folds or rolls it leaves. Color changes are observable leading to leaf death from drought (Dixon, 2000). The plant is able to capitalize on available moisture following summer rain events due it the shallow, finely branched, and fibrous root system (Barnes and Harrison, 1982). The greatest density of prairie junegrass roots is at 5-7 cm (Looman, 1978). Studies have shown that *K. macrantha* has a plastic root system and is able to utilize water from low water table conditions (Mueller-Dombois and Sims, 1966). Following a dry down experiment, *Koeleria macrantha* was able to respond to watering where as *Briza media* died (Milnes et al., 1998). Prairie junegrass is drought avoidant in that the majority of its growth occurs in April and May while temperatures are cooler and moisture is more readily available (Coupland, 1950). The plant can complete vegetative growth, flowering, and seed set before going dormant prior to summer drought (Dixon, 2000). In the present study, the Becker, MN location is comprised of well-drained, sandy soils and is likely to provide information regarding a genotype x environment interaction in drought response. Drought response was not measured directly in this study, but can be inferred from turf quality ratings and dormancy when grown in low-input conditions (i.e. no supplemental irrigation).

Diseases

Several fungal diseases have been associated with prairie junegrass. Mild rust infestation (species unknown) was observed for 2 years during hot, humid periods by Mintenko (2002). Looman (1978) indicates that the rust fungus *Puccinia graminis* has been observed on *K. macrantha.* Mains (1933) reports a number of *Puccinia* species reported on *K. macrantha*, including *P. koeleriae*. Dixon (2000) also indicated this rust as well as infection by powdery mildew (*Erysiphe graminis*), smut (*Ustilago striiformis*), and the rust *P. scarlensis*. Several fungal *Septoria* diseases are also present in *Koeleria* which cause blackening of sheaths and culms, ultimately reducing seed fertility (Pirozynski and Smith, 1972). *Claviceps purpurea* has been reported in populations from several states and may cause enlarged inflorescences making species identification difficult (Arnow, 1994). Another smut pathogen, *Anthracoidea koeleriae*, has also been identified on *Koeleria cristata* (Vanky, 1997). Powdery mildew (*Blumeria graminis* DC.) has been observed in the Estonian turf breeding program and has been shown to impact seed yield. Maintaining correct fertilization and plant density can reduce risk of the disease, though weather has the most impact on disease development (Soovali and

Bender, 2006). Tanspot or yellow leaf spot (*Pyrenophora tritici-repentis*) that normally infects wheat has been isolated on *K. macrantha*, although it appears to be non-pathogenic (Krupinsky, 1992).

RESEARCH OBJECTIVES

Prairie junegrass has several attributes that would make it useful as a low-input turfgrass. Prairie junegrass is adapted to dry, sandy soil (Pammell et al., 1901-1904) and drought conditions (Milnes et al., 1998). It exhibits flexibility in its roots to adapt to water availability (Mueller-Dombois and Sims, 1966). McKernan et al.(2001) showed that native accessions of prairie junegrass exhibited moderate drought tolerance similar to hard fescue (*Festuca brevipila* Tracey) and tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort = *Lolium arundinaceum* (Schreb.) Darbysh]. This species is also slow growing (Dixon, 2000; Soovali and Bender, 2006) which could be potentially useful in reducing mowing costs. Prairie junegrass can be mowed as turf when grown in areas with low annual precipitation and has been found to be somewhat shade tolerant (Brede, 2000).

The research objectives of the current study are to examine the species diversity of *Koeleria macrantha* accessions that are part of the University of Minnesota turf breeding program. This plant material has been developed from collections within Colorado, Nebraska, and Minneosta. At the onset of a breeding initiative, it is important to gain an understanding of the complexities of the germplasm within the available material. Determining which material in the program has the greatest genetic potential will be important in the choice of germplasm and mating design. Evaluating the crossing blocks from which the breeding populations were derived as well as understanding distinctions among the collection sites (i.e. states) will aid in selecting germplasm to advance in the breeding program. In addition to identifying top performing native germplasm, this research will also evaluate plant material collected from around the globe and available from the USDA National Plant Germplasm System (NPGS). This research will help in identifying key regions from which to collect additional germplasm for cultivar development.

Quantifying the variation within the material will assist the breeder in choosing the appropriate characteristics, selection intensities, and mating designs to achieve top performing cultivars. Heritability estimates are useful tools at the beginning of a breeding program to determine the direction of the program and to determine if sufficient variation is present in the current population to make significant gains. Additionally, studying the seed production characteristics of the material is crucial in selecting germplasm that is capable of meeting the agronomic demands of turf seed production. A new variety must meet the needs of the producer to be profitable, the processor to produce materials, and the standards required by the consumer (Baenziger et al., 2006).

Seed production traits

Seed production traits of prairie junegrass will be important for selection of high yielding genotypes with quality turf performance. Little is known about the flowering characteristics (anthesis date, pollination shed times, seed set date, yield, vernalization requirement) of this species as it has not been investigated intensively as a seed crop. Growth of prairie junegrass generally begins in April and inflorescences appear throughout June depending on the ecotype (Coupland, 1950). Prairie junegrass is a cross-pollinating species with a low incidence of selfing (Dixon, 2000; Looman, 1978). Dore and McNeill (1980) suggest that when grown in isolation, *Koeleria macrantha* has no seed set and seems self-incompatible. Floral initials form in the fall following the first frost. Normal flowering occurs in the spring. Greenhouse grown plants will not flower unless given a cold weather vernalization treatment although the duration and temperature requirements are unknown (Looman, 1978). At maturity, 65% of seed sheds up to one meter, with the rest remaining on the panicles (Dixon, 2000). Darris (2005) estimates that there are 1,250,000 seeds/lb including hulls. Seeds are said to have a liquid endosperm (Dore, 1956).

Researchers in Estonia have examined the cultivation practices for maximizing seed yield in *Koeleria* following the release of the first cultivar ‘Ilo’ (Bender and Aavola, 2006; Bender and Aavola, 2007). In these studies, variation in planting date, sowing spacing, sowing rate, and fertilizer treatments all affected seed yield. Understanding the variation of seed production traits of individual genotypes and families within a population is critical in the selection for top performing germplasm for cultivar development. Adequate seed production is crucial to ensure the agronomic success of a cultivar. Growers will not invest in a cultivar that has unproven yields and low profit margins, which leads to an increased price for the consumer (Hacker and Cuany, 1997). Seed fill may be poor in this species and dormancy mechanisms have not been thoroughly studied. In seed production programs for native grasses for restoration use, the selection for non-dormant seed is not an option in an effort to maintain species diversity (Darris, 2005). However, for turf cultivars these issues will need to be addressed. In other species, inflorescence number, more than inflorescence length and/or size was more positively correlated with seed yield, and could be used as an indirect selection criterion (Hacker and Cuany, 1997). Selection for seed production should occur concurrently with the other traits of interest.

The germination requirements for *Koeleria macrantha* have not been closely studied. The germination characteristics most often studied are the response to light, response to temperature, and the length of time from planting to germination. Seed age, handling, dormancy mechanisms, and storage also play a role in the germination response. Limited research by Looman (1978) suggests high germination rates in the fall following harvest (80-95%) in 6-10 days in petri dishes or 8-14 days in soil. Germination can occur in light or dark conditions, in temperatures ranging from 5-30°C (Dixon, 2000).

Turf quality traits

Measuring turf quality is a difficult and subjective task that relies on the breeder's visual ratings over time to evaluate a variety of characteristics (Morris and Shearman, 2008). The National Turfgrass Evaluation Program (NTEP) provides guidelines to assist the researcher in evaluating the traits that comprise turf quality: color, density, uniformity, texture, and disease and stress response. Beard (1973) includes many of these in his definition of turf quality and also lists growth habit and smoothness. Each of these can be rated individually on a scale 1 (lowest) to 9 (highest), or concurrently to give an overall turf quality rating. Additionally, the 1-9 scale is used to describe spring green-up, seasonal color changes, and response to drought stress. As part of a breeding program, additional phenotypic traits are evaluated including: re-growth (height after mowing) (Wofford and Baltensperger, 1985), lateral spread, and mowing quality. Genetic color ratings range from light to dark with dark green being generally preferred. In addition to the color of the leaf blades, other color factors that influence a color rating include senescing tissue, colored sheaths, dead tissue, and soil. Density is defined as the number of leaves or shoots per unit area and is also rated on a 1 to 9 scale. Guidelines for NTEP evaluation were developed for sown turfplots (not space plantings), therefore some traits such as uniformity and texture cannot be measured in spaced plantings. On individual plants these measurements can be quite variable. The growth habit is described by the horizontal/vertical positioning of leaf blades and may include the presence of rhizomes or stolons. The response to environmental stresses and diseases were recorded when present.

Genetic variation and heritability estimates

In their historical look at crop breeding, Baenziger et al. (2006) highlight the three basic pillars of a plant improvement: define breeding objectives, create genetic variability, and identify superior genotypes. A breeding program should utilize plants from a wide distribution from variable environments to capitalize on genetic diversity and ecotypic differentiation which would allow them to acclimate to changes in the environment (Robertson, 1976). Understanding the phenotypic variation of morphologic and agronomic traits within a breeding population is crucial to the plant breeder in determining the potential application of the material, such as for turf (Wright et al., 1983).

Selecting the correct germplasm to advance in a breeding program requires understanding the material being studied and how it was derived. The selection of material to advance in a breeding program can be based on the performance of the genotype per se as well as the performance of its relatives. Evaluating the performance of collection regions and collection sites within regions could indicate that a particular set of germplasm has greater genetic potential than the other material in the study. Superior performance could be due to a significant combining ability, a high mean performance of desired traits, sufficient variation within the population, or high heritability.

It is important to evaluate the presence of genetic variability in the base population before initiating a selection program, as limited variability will lead to less significant gains, especially over time (Surprenant and Michaud, 1988). Genetic variation and heritability estimates give the plant breeder the tools for predicting response to selection for desired traits (Dudley and Moll, 1969). Estimating heritability, which is the amount of phenotypic variation in a population due to genetic differences (Fehr, 1991), is important in choosing appropriate traits for which to select. Selecting for characteristics with high heritability will lead to increased gains in the offspring compared to when heritability is low (Browning et al., 1994). Highly heritable traits could be correlated with important or complex traits, and a breeder would want to exploit these interactions (Kenworthy et al., 2006). Cross-pollinated perennial grasses are typically bred to develop synthetic crosses or improved populations (De Araujo and Coulman, 2002).

Genetic variation is determined in many crops and forage populations to estimate heritability and investigate correlations between traits to improve selection gains. Traits evaluated when developing forage grasses are often similar to those in the turf breeding program. These include growth under reduced irrigation, increased soil salinity, low fertility (Jensen et al., 2006), maintaining adequate growth (forage production) or turf quality, and seed production characteristics. Like in other agronomic crops, seed production in turfgrass is important, but the turf breeder must balance seed yield with other performance traits (i.e. turf quality) which are often inversely related (Johnson et al., 2003). Forage and turf grasses both require resiliency to defoliation by grazing or mowing and plants that have evolved under a defoliation regime would be useful in a breeding program to improve mowing quality. Understanding the variation and heritability of this trait will allow the breeder to select for plants that are mowed without excessive tissue damage. Using genotypes based on performance in spaced plantings that exhibit improved mowing (or grazing in forage) will be more adapted for those conditions in the field.

Heritability estimates generally apply only to the population being studied. In a new breeding program the selection of the parent material will be chosen from this population. Additionally, data on relatives can be used to make inferences on the performance of parents, full sibs, or half sibs that are evaluated separately. Different selection strategies may be needed based on the population being used (Surprenant and Michaud, 1988).

SUMMARY

Prairie junegrass has many characteristics that would make it an ideal low-input turfgrass. The species' low and slow growing habit, tolerance to drought and extreme environmental conditions, and its wide natural distribution make it a strong candidate for development as a turfgrass. The research objectives of the current project are to examine variability in both native and NPGS germplasm, identify key regions for germplasm collection, characterize seed production traits, evaluate turf quality performance, and calculating broad-sense heritability estimates of turf quality traits. Understanding these characteristics will be important in developing low-input turfgrass cultivars of prairie junegrass.

Seed Production Characteristics of Prairie Junegrass Germplasm Accessions

INTRODUCTION

Prairie junegrass, also known as junegrass or crested hairgrass, is a perennial, short-grass prairie species distributed throughout the Northern Hemisphere. This species has several traits that would make it useful as a low-input turfgrass including flexibility in roots to adapt to water availability (Mueller-Dombois and Sims, 1966), drought tolerance (Milnes et al., 1998), adaptation to sandy soil (Pammell et al., 1901-1904) and alkaline soil (Looman, 1978), and survival at extreme temperatures (Dixon, 2000). *Koeleria macrantha* is slow growing (Dixon, 2000; Soovali and Bender, 2006) which could be useful in reducing mowing frequency. The fact that this species is found in a diverse natural range provides plant breeders with a broad genetic base from which to select important traits including turfgrass quality, color, density, growth habit, drought tolerance, disease resistance, and seed production.

Turfgrass cultivars have been developed from European *K. macrantha* germplasm, but little attention has been given to North American germplasm. Utilizing native grasses could provide several benefits including reduced water use, conservation of native germplasm, and erosion control (McClaran, 1981). Prairie junegrass cultivars for turf use could lead to reductions in water, fertilizer, and pesticide inputs resulting in environmental benefits and reduced management costs.

To date, only a few *K. macrantha* cultivars have been developed for turf or other landscape purposes. The Estonian cultivar Ilo was released in 1997 for use as a lawn grass (Soovali and Bender, 2006). Two Dutch cultivars, Barkoel and Barleria, were released by Barenbrug Holland BV (Oosterhout, The Netherlands) (Alderson and Sharp, 1994). In Manitoba, Canada, Barkoel exhibited high turf quality ratings in low-input trials, but did not exhibit spring green-up as early as North American *K. macrantha* ecotypes suggesting that native accessions may provide unique and beneficial traits (Mintenko et al., 2002).

Growth of *K. macrantha* generally begins in April and depending on ecotype, the seedheads emerge throughout June (Coupland, 1950). The seedhead has been described as a spikelike panicle (Hitchcock, 1971; Kucera, 1998; Pammell et al., 1901-1904) or panicle (Shaw, 2008) on culms of varying heights. Spikelets are colored green to purple and the number of spikelets per inflorescence may vary from 20-200 (Dixon, 2000). *Koeleria macrantha* is a cross-pollinating species with a low incidence of selfing (Dixon, 2000; Looman, 1978). Dore and McNeill (1980) suggest that when grown in isolation, the species has no seed set and seems self-incompatible. At maturity, 65% of seed disperses up to one meter from the maternal plant, with the rest remaining on the panicles (Dixon, 2000). Little is known about seed production characteristics such as seedhead emergence date, harvest date, and seed yield of this species as it has not been investigated intensively as a crop.

Understanding the variation of seed production traits among germplasm accessions is important for cultivar development. Seed growers will not invest in a cultivar that does not have reliable yields or low profit margins, and a low seed yield leads to increased prices for the consumer that may hinder marketability (Hacker and Cuany, 1997; Wilkins, 1991).

The objectives of this study were to evaluate the variation in the NPGS accessions of prairie junegrass for seed production traits, and to explore the relatedness of the accessions based on this variation. It was hypothesized that seed production traits, including yield, will vary among the accessions.

MATERIALS AND METHODS

The USDA NPGS provided the germplasm in this study through the USDA Regional Plant Introduction Station at Pullman, WA. The origin of the material spans the species range including accessions from Canada, China, Ireland, Mongolia, Russia, South Africa, Turkey, and the United States. The initial material was primarily collected as seed from unimproved local populations, but also included the improved turf cultivar Barkoel (PI 601393, PI 554139).

Seeds from the 68 available accessions were placed into individual glass vials and pre-treated with a solution of 200 µL ethephon (Proxy (Bayer Environmental Science, Research Triangle Park, NC)) in 500 mL deionized water for 24 h to break seed dormancy as modified from Shahba et al. (2008). Seeds were sown into Metro-Mix 200 soilless media (Sun Gro Horticulture, Bellevue, WA) and allowed to germinate in greenhouse conditions in early April 2007. Individual seedlings were transplanted into 96-cell flats and were grown until they were an appropriate size for transplanting into the field.

Forty-eight accessions demonstrated high germination and were selected for advancement into the seed production trials. The intended control, Barkoel, did not germinate with enough plants to be included in this trial. The experiment was arranged as a randomized complete block design with 5 replications and planted at 2 locations (University of Minnesota-St. Paul Campus, St. Paul, MN (44°59´23˝ N, 93°10´28˝ W), and the Sand Plains Agricultural Experiment Station, Becker, MN (45°23´47˝ N, 93°53´21˝ W)). Each accession was represented by four randomly selected genotypes. In late June 2007, transplants were planted into prepared fields on 0.46 m centers. The soil at St. Paul is a Waukegan silt loam (fine-silty over sandy, mixed, mesic Typic Hapludoll), and the soil at Becker is a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludoll). Fertilizer was applied at a rate of 48 kg P_2O_5 ha^{-1} (12-24-12 N-P-K) at the time of planting and in a late autumn application at a rate of 48 kg N ha^{-1} (22-0-22 N-P-K). Irrigation was provided at each location only during establishment. At Becker, up to 1.27 cm of water was provided each week in two applications. At St. Paul, water was provided twice daily initially for several weeks and one time daily until plants were thoroughly established (early August 2007). Pendimethalin (LESCO, Clevland, OH), a pre-emergent herbicide, was used to control weeds. Manual weeding was conducted as needed throughout each growing season.

Winter survival and density were rated on a 1-9 scale (9 = best winter survival or highest density) in early spring 2008 following National Turfgrass Evaluation (NTEP) guidelines (Morris and Shearman, 2008). Plants were determined to have reached seedhead emergence when three or more seedheads had extended beyond the boot stage and the seedhead emergence date was recorded as days after 1 May. The anthesis date was determined when three or more seedheads had started anthesis and was recorded as days after 1 June. Observations were made on 2-3 day intervals to capture the initiation of anthesis (Hacker and Cuany, 1997). Average height (cm) was measured from the soil surface to the tip of three randomly selected seedheads. At harvest (days after 1 July), the number of seedheads per plant was counted and an average seedhead length (mm) was measured on three randomly chosen seedheads.

Individual plants were harvested when they reached maturity. Seed was dried for 3-7 d at 32°C, threshed, and then weighed to determine seed yield (g). Plants at the Becker location were significantly larger and more robust than at the St. Paul location. Seed yield was very low and nearly undetectable after threshing for many of the plants harvested at St. Paul.

Data was subjected to an analysis of variance (ANOVA) to compare the means for the 48 accessions. Means separation analyses (LSD) were further performed on accession means for each location. Principal component analysis and cluster analysis were used to group accessions on their performance for mean seed production traits at each location. Multivariate analysis has been used with a variety of grass species to examine the relationships among accessions (Casler and vanSanten, 2000; Greene et al., 2008; Oliveira et al., 2008). The clustering of accessions may provide a biological meaning for the relatedness of the accessions based on the variables examined (Iezzoni and Pritts, 1991). Correlations were calculated among various seed production characteristics and seed yield to determine factors associated with seed yield. The SAS statistical software package v.9.1 was utilized for all data analyses: ANOVA (PROC GLM), correlation (PROC CORR), principal components analysis (PROC PRINCOMP), and cluster analysis (PROC CLUSTER) (SAS, 2002).

RESULTS

The analysis of variance revealed significant differences ($P < 0.05$) for winter survival, density, seedhead emergence, seedhead number, seedhead length, and yield among accessions, replications, and locations (Table 1.1). The plants at the Becker location were taller, produced more seedheads, produced longer seedheads, and had higher yields. The significant location x accession interaction required that each location be analyzed separately. Though replications were also significant for several traits, these differences may be the result of using unique genotypes instead of clones within each replication for each accession.

The accession means for selected seed production characteristics are shown for each accession at the two locations (Table 1.2). [A complete table of seed production characteristics is shown for Becker (Appendix A) and St. Paul (Appendix B).] Means separation analysis revealed that the native accession from Iowa (PI 639190) had the highest yield performance (20.11 g) at Becker (Table 1.2). At St. Paul, the largest accession mean yield was considerably less at 3.34 g (PI 44045). Plant height also varied considerably among accessions and locations, with taller plants at Becker. The number of seedheads was also higher at Becker, which corresponded with increased yields at that location.

There was a significant difference among accessions and between locations for date of seedhead emergence, anthesis initiation, and harvest date. There was no significant difference in the duration from emergence to harvest between locations. Accessions at the Becker location were only slightly (one day to several days) later for these traits compared to accessions at St. Paul. Most individual accessions performed similarly at both locations (i.e. early, intermediate, or late at both locations).

Correlations based on accession means were calculated among the seed production traits for each of the experimental locations (Table 1.3). At both St. Paul and Becker there was a significant correlation between seedhead number and yield (r =0.92 and 0.79 respectively), and a moderate correlation between seedhead length and yield (r = 0.53 and 0.38 respectively). Winter survival and density were strongly correlated at both locations and these traits were also correlated with seedhead number. Seedhead emergence, anthesis, and harvest date were all strongly correlated. There was no strong correlation among these flowering traits and yield.

Principal component analysis (PCA) revealed that the first and second principal components (PC1 and PC2) accounted for 97.65% of the variation at Becker, and 89.78% at St. Paul (Table 1.4). At Becker, PC1 accounted for 92.66% of the variation and correlated primarily with seedhead number. Principal component 2 accounted for 4.99% of the total variation and was correlated with seedhead length and plant height. At St. Paul, PC1 accounted for 72.74% of the variation and was correlated with (in descending order) the seedhead number, seedhead length, and plant height. PC2 accounted for 17.04% of the variation and was correlated with (in descending order) seedhead length, harvest date, seedhead emergence date, and date of anthesis.

The cluster analysis, using the same principal components, was useful in identifying accessions with unique phenotypes. The cluster analysis generally revealed no geographic relationship among accessions. However at both St. Paul and Becker, some accessions with a distinct phenotype distinguished by a prostrate, mat-like growth habit and very open (lateral) culms grouped together (Figures 1.1 and 1.2). These accessions were generally collected from Turkey and Armenia. At St. Paul (Figure 1.1), cluster analysis revealed four distinct clusters with one outlier population (PI 430287, from Ireland). At Becker, cluster analysis revealed four main clusters and two outlier populations (PI 477978, from New Mexico; PI 538972, from the Russian Federation) (Figure 1.2).

DISCUSSION

The high levels of variation in the germplasm indicate the potential for developing high-yielding prairie junegrass cultivars, as variation in quantitative traits are of agronomic importance (Panthee et al., 2006). The differences in plant size (and ultimately seed yield) observed between the two locations suggests that when grown for seed production, *K. macrantha* is better adapted to a well-drained, sandy soil, which confirms previous reports (Dixon, 2000).

The strong correlation between seedhead number and yield makes it a useful criterion for indirect selection. Seedhead length may not be a good measure of productivity as the density of spikelets, a measure of seed per unit area, varies among accessions. In African bristlegrass [*Setaria sphacelata* (Schumach.) Stapf & C.E. Hubb.], seedhead number, more than seedhead length and/or size, was more positively correlated with seed yield, and could be used as an indirect selection criterion (Hacker and Cuany, 1997). This is in contrast to perennial ryegrass (*Lolium perenne* L.) where the number of seedheads did not generally differ among cultivars and was not associated with seed yield (Elgersma, 1990a). Counting the number of seedheads on each plant in a nursery is impractical; however, a rating could easily be used by a breeder to select the more productive plants. Additionally, floret fill seems to be a problem in this species which would greatly influence seed yield. A large proportion of threshed seed in this study may in fact be unfilled florets or chaff that is not easily separated from viable seed when cleaning small quantities of seed from individual plants.

The simultaneous selection for excellent turf performance and superior seed production is crucial for development of this species as a low-input turf. In perennial ryegrass, some agronomic traits such as herbage production are negatively correlated with seed production (Wilkins, 1991). The current study revealed several accessions and individual genotypes that demonstrated excellent turf quality traits (dark green vegetation, high density, and/or low growth habit) in the nursery with very low to no seed production.

Multivariate analysis did not reveal any obvious geographic relatedness based on country of origin. There is insufficient information regarding specific locations within these large and diverse countries, making further analysis on latitude or altitude difficult. Previous research has examined the effects of the native latitude (day length) or altitude (light intensity) in this species when accessions are grown in a similar environment. McMillan (1959) showed that diverse prairie junegrass specimens were influenced more by conditions in the local habitat than by their native latitude. In contrast, Robertson and Ward (1970) evaluated several Colorado prairie junegrass ecotypes and determined that native moisture regimes, more than native altitude, influenced plant growth when accessions were evaluated in a similar environment. Our data support these later findings in that there were significant flowering differences among accessions within the growing environments. However, the native accession (PI 639190 Iowa) which was collected closest to the experimental environments, exhibited the greatest seed yield at the Becker location. In the seed production nursery, information on flowering regimes for the accessions is important to ensure a successful polycross and to maintain uniform maturity in the field, maximizing harvest yields.

Multivariate analysis has been used with a variety of species to examine the relationships among accessions of diverse germplasm including carpetgrass (*Axonopus fissifolius* Raddi) (Greene et al., 2008) and fine fescue (*Festuca* sp.) (Oliveira et al., 2008). Cluster analysis revealed a grouping of accessions that had a prostrate growth habit, lower seed yields, smaller seedheads, and shorter plants than the other clusters. Many of the accessions with prostrate phenotypes appear to be very slow growing with vegetative heights under 6 cm after 2 years (personal observation). These accessions could be adapted for use in no-mow settings where seedheads were removed seasonally prior to flowering to encourage vegetative growth. Seed production could be difficult with this phenotype as nearly prostrate culms would need to be cut very low at harvest. This could result in damage crowns, increased seed shattering, and a need to change equipment to accommodate this growth habit. Research suggests that this growth habit may not be favorable for turfgrass applications due to potential issues with mowability (Waldron et al., 1998).

Several genotypes flowered in late October 2007 at the Becker location before the expected winter vernalization requirement was met. Many temperate grasses require a vernalization period to induce floral production (Wang et al., 2003). The specific vernalization requirement for this species is unknown, and may vary by ecotype (Heide, 1994). Many of the genotypes that exhibited fall flowering also had reduced vegetation (lower density and winter survival ratings) and reduced seed production in spring 2008, presumably as the precocious reproductive tillers were killed over the winter. Other genotypes were assumed to not be *K. macrantha* as they exhibited distinct floral phenotypes and did not survive the winter.

Evaluating unique genotypes instead of clones allowed for general characterizations to be made about each accession, and facilitated assigning each accession an agronomic value based on seed production characteristics (Oliveira et al., 2008). It also made it possible to screen a large number of unique genotypes. An advantage of this design is the identification of disease resistance or other favorable traits in individual plants within accessions. Several genotypes were identified as having potential ornamental qualities such as distinctly colored flag leaves, culms, or seedheads, and/or a balanced or unique plant size, shape, or appearance.

The breeder must determine a threshold for advancing individual plants or accessions based on seed yield while balancing other important traits. Additional research is needed to determine estimates of heritability for seed yield, stability of seed yield over time, and identification of locations for economically viable seed production. Further research should examine seed production for prairie junegrass using grower standards as some research has shown a low correlation between yield from spaced plants and drilled plots for perennial ryegrass (Elgersma, 1990b). Researchers in Estonia have examined the agronomic requirements necessary for maximizing seed yield in the *K. macrantha* cultivar Ilo and found that variations in planting date, sowing spacing, sowing rate, and fertilizer treatments all affect seed yields. (Bender and Aavola, 2006; Bender and Aavola, 2007). In tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort = *Lolium arundinaceum* (Schreb.) Darbysh.], residue management (burning) and narrower row spacing have been suggested for increasing seed per unit area (Young et al., 1998a; Young et al., 1998b).

The variation found in the NPGS junegrass accessions in this study supports the hypothesis that the extensive species variability will provide the plant breeder with diverse germplasm from which to select for a variety of traits. The high seed yields at the Becker location suggest that this species will have sufficient seed yields to be economically viable. The strong correlation between yield and seedhead number should assist the breeder in the selection of productive phenotypes. Germplasm collection should focus on identifying quality genotypes that exhibit flowering regimes that coincide with the native breeding populations. The evaluation of germplasm in this study also revealed unique phenotypes that may provide other landscape functions including no-mow turf (prostrate phenotypes) and decorative ornamentals.

Chapter 1, used with permission from Crop Science, including accompanying tables and figures below.

Table 1.1. Analysis of variance for winter survival, density, seedhead emergence date (SHE date), anthesis date, harvest date, height, seedhead number, seedhead length, and seed yield for prairie junegrass accessions grown at two locations.

Source of Variance	Winter Survival	Density	SHE Date	Anthesis Date	Harvest Date	Height	Seedhead Number	Seedhead Length	Seed Yield
Location (L)	***	***	*	***	**	***	***	***	***
Replication (R)	***	***	*	NS	NS	NS	***	***	***
Accession (A)	***	***	***	***	***	***	***	***	***
L X A	***	***	***	***	**	***	***	*	***
L X R	***	***	*	*	NS	***	***	***	***
R X A	***	***	***	***	***	*	*	*	*
L X A X R	***	***	***	***	***	*	**	NS	*

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 1.1 used with permission from Crop Science

Table 1.2. Origin and selected mean seed production components of prairie junegrass accessions at St. Paul and Becker, MN harvested July 2008. Harvest date refers to days after 01 July.

Accession	Origin	Harvest date SP	Harvest date B	Height SP	Height B	Seedheads SP	Seedheads B	Seed yield SP	Seed yield B
				---cm---		----*N*---		---g---	
639190	Iowa, USA	14	15	32.7	69.6	20	186	1.18	20.11
23304†	Kazakhstan	3	2	37.9	73.8	28	172	1.36	13.53
440454	Stavropol, Russian Fed.	4	6	49.7	69.5	47	153	2.14	11.99
538972	Russian Federation	4	8	36.9	56.3	42	250	1.77	10.72
21380†	Mongolia	2	3	32.0	58.1	11	204	0.13	10.14
502394	Ukraine	2	5	44.7	85.3	67	185	2.38	10.12
502395	Former Soviet Union	4	4	43.5	72.2	45	214	1.90	9.37
440451	Stavropol, Russian Fed.	3	4	47.2	70.4	59	167	2.30	9.17
636566	Bulgaria	16	18	39.3	44.7	29	140	0.69	8.77
618749	Mongolia	2	3	38.7	59.7	54	166	2.60	8.42
314377	Stavropol, Russian Fed.	4	5	35.9	74.8	49	147	1.31	8.33
502391	Russian Federation	2	3	43.7	72.1	48	163	1.91	7.67
619546	Mongolia	5	4	27.5	46.5	28	176	1.18	7.48
502390	Stavropol, Russian Fed.	5	3	42.6	71.4	36	105	2.08	7.45
229463	Iran	8	9	47.6	75.7	45	113	2.42	7.28
538975	Kazakhstan	6	6	40.4	62.2	43	128	2.06	7.04
502393	Russian Federation	4	5	39.8	69.9	61	142	2.08	6.64
440455	Former Soviet Union	3	5	43.0	70.1	69	100	3.34	6.60
314378	Stavropol, Russian Fed.	3	7	36.8	65.8	30	134	0.95	6.25
21268†	Mongolia	4	3	29.6	63.6	13	121	0.27	6.02
312456	Former Soviet Union	5	5	38.5	64.7	40	103	1.20	5.69
21553†	Mongolia	5	7	41.0	62.9	18	106	0.65	5.27
21169†	Mongolia	10	9	29.4	63.4	14	91	0.24	5.14
538968	Russian Federation	10	12	25.4	72.3	11	55	0.29	4.75
387927	Canada	11	10	26.0	49.0	15	70	0.23	4.69
204452	Turkey	12	12	46.6	64.7	61	80	2.89	4.49
19186†	Bilecik,Turkey	17	18	33.8	49.5	18	76	0.77	4.09
502389	Russian Fed.	13	12	50.8	83.5	52	72	2.33	4.08
19198†	Ankara, Turkey	16	17	39.4	50.6	24	50	0.90	3.26
255364	Yugoslavia	7	6	36.3	63.5	29	56	0.93	3.24
18194†	Mongolia	2	2	33.6	57.4	14	75	0.29	2.68
430287	Ireland	11	15	10.6	41.6	7	89	0.03	2.55
568184	Afyon, Turkey	18	19	38.0	45.8	23	36	0.76	2.03
314440	Former Soviet Union	5	7	34.5	58.0	40	45	1.25	1.87
383672	Turkey	17	17	33.4	43.6	16	51	0.33	1.85

383673	Turkey	16	17	30.2	46.0	22	55	0.58	1.69
24110†	Armenia	16	17	38.5	46.8	10	39	0.17	1.58
410152	South Africa	14	2	52.7	76.2	38	164	1.30	1.26
440456	Former Soviet Union	12	14	35.8	59.7	14	21	0.49	1.09
314700	Former Soviet Union	4	8	33.6	57.2	14	28	0.46	1.01
204451	Turkey	18	17	31.8	45.3	43	31	1.67	0.99
383674	Turkey	15	15	32.4	41.3	19	34	0.61	0.94
477978	New Mexico, USA	10	15	41.5	61.7	27	9	0.69	0.29
230267	Iran	13	11	31.0	45.9	14	14	0.12	0.20
383675	Turkey	13	13	32.6	47.3	14	17	0.28	0.14
532937	Pakistan	2	3	30.6	47.7	19	9	0.24	0.08
230256	Iran	11	10	35.6	46.1	8	6	0.03	0.01
250651	Pakistan	7	15	31.9	38.0	15	1	0.23	0.00
	LSD (0.05)	3	4	9.9	13.4	31	73	1.40	3.29

† Signifies accessions designated by the U.S. National Plant Germplasm System as “W6” accessions, all other accessions “PI”.

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Table 1.3. Correlation coefficients among several seed production characteristics of prairie junegrass accessions at St. Paul, MN above diagonal and Becker, MN below.

	Winter survival	Density	SHE date†	Anthesis date	Plant height	Seedhead number	Seedhead length	Seed yield	Harvest date
Winter survival		0.69***	-0.29***	-0.27***	0.31***	0.29***	0.24***	0.28***	-0.14***
Density	0.85***		-0.13***	-0.06	0.48***	0.50***	0.36***	0.43***	0.01
SHE date	-0.49***	-0.39***		0.75***	-0.20***	-0.29***	-0.01	0.24***	0.66***
Anthesis date	-0.46***	-0.35***	0.81***		-0.14**	-0.23***	-0.04	0.19***	0.76***
Plant height	0.44***	0.39***	-0.34***	-0.35***		0.56***	0.61***	0.55***	-0.10*
Seedhead number	0.55***	0.68***	-0.31***	-0.28***	0.30***		0.50***	0.92***	-0.17***
Seedhead length	0.21***	0.17***	-0.01	-0.02	0.51***	0.23***		0.53***	0.00
Seed yield	0.56***	0.56***	0.18***	-0.14**	0.36***	0.79***	0.38***		-0.13**
Harvest date	-0.38***	-0.30***	0.69***	0.76***	-0.30***	-0.30***	-0.05	-0.19***	

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
†SHE, seedhead emergence.

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Table 1.4. Eigenvectors of the principal component axes, eigenvalues, and their contribution to total variation in principal components 1 and 2 (PC1 and PC2) from principal component analysis (PCA) on flowering characteristics of prairie junegrass germplasm accessions at two locations. (Used with permission from Crop Science.)

	PCI		PC2	
Character	St. Paul	Becker	St. Paul	Becker
Winter survival	0.03	0.02	-0.02	0.02
Density	0.02	0.02	0.01	0.00
Seedhead emergence	-0.09	-0.04	0.41	-0.05
Anthesis date	-0.11	-0.03	0.38	-0.05
Plant height	0.29	0.11	0.23	0.59
Seedhead number	0.87	0.99	-0.20	-0.10
Seedhead length	0.35	0.03	0.65	0.80
Seed yield	0.04	0.06	0.00	0.04
Harvest fate	-0.10	-0.05	0.42	-0.07
Eigenvalue	392.54	4227.84	91.98	227.66
% Total variation	72.74	92.66	17.04	4.99

Figure 1.1. Cluster dendrogram of 48 accessions of prairie junegrass at St. Paul, MN, on the basis of several seed production characteristics. Accessions followed by a ‘p’ indicate a prostrate growth habit. (Used with permission from Crop Science.)

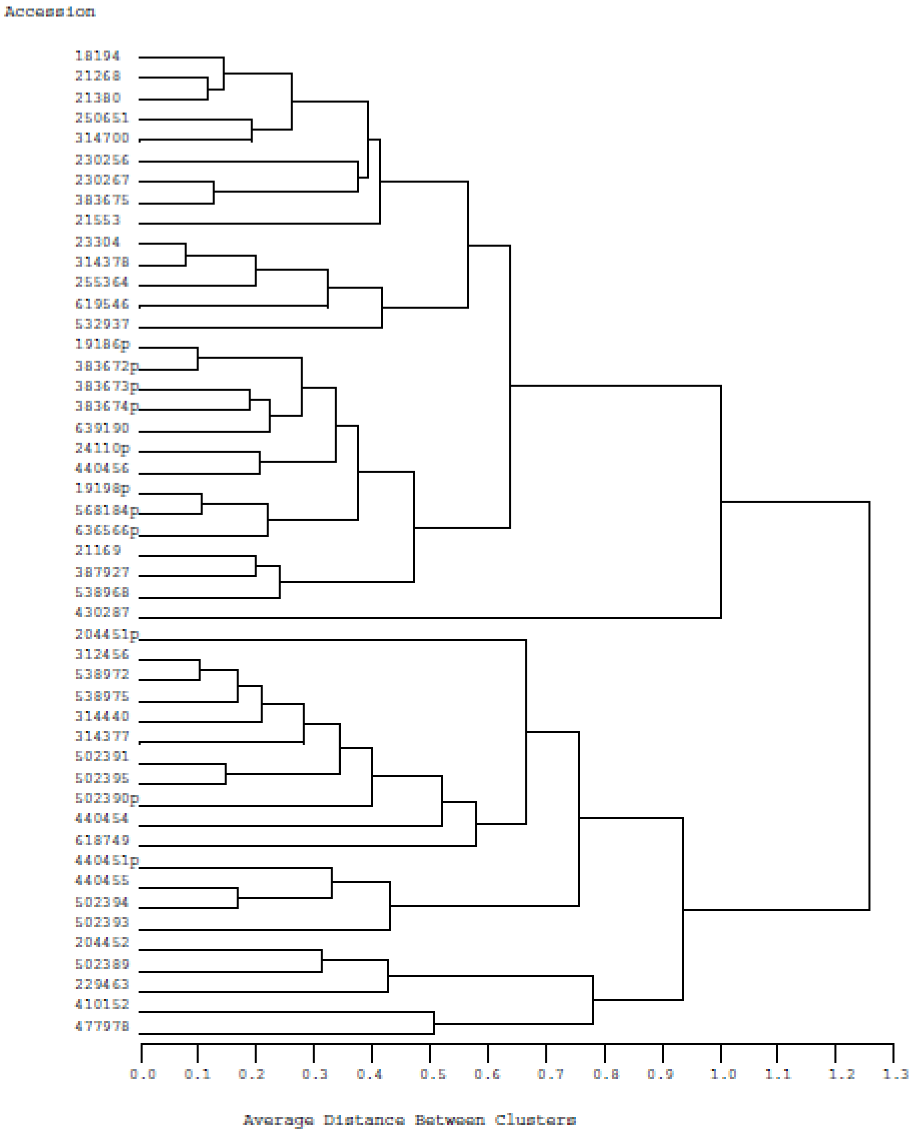
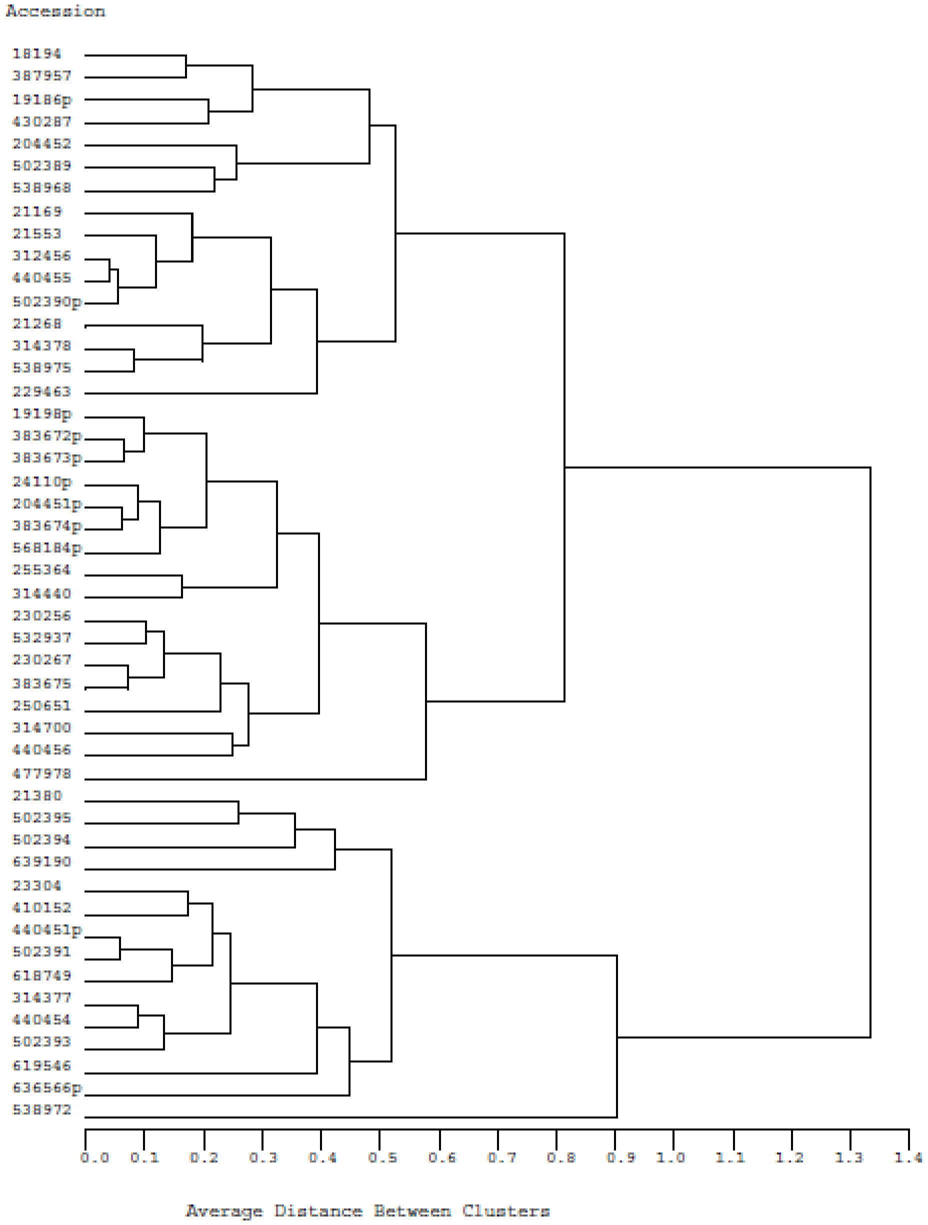


Figure 1.2. Cluster dendrogram of 48 accessions of prairie junegrass at Becker, MN, on the basis of several seed production characteristics. Accessions followed by a ‘p’ indicate a prostrate growth habit.



Turfgrass Characteristics of Prairie Junegrass Germplasm Accessions

INTRODUCTION

The reduction in water availability for landscape irrigation (Kjelgren et al., 2000), an increase in fuel costs and restricted budgets (Brede, 2002), and the negative perception that turfgrass fertilizers and pesticides contribute to pollution (Cheng et al., 2008; Haith and Duffany, 2007), has led to the need to develop and utilize turfgrasses that require fewer of these inputs. Water and other resources can be conserved by changing the turfgrass species utilized in landscapes and shifting the public's expectations for lawns (Kjelgren et al., 2000). Low-input turf areas often have lower visual and performance expectations than highly managed areas (Johnson, 2003). These areas can include home lawns, roadsides, cemeteries, low-use parks and schools, or golf course roughs. Hanks et al. (2005) suggested that acceptable turf quality is defined by color, leaf texture, density, and aesthetic appeal for the particular area in which it is grown. Low in-put turf must demonstrate visual quality, but it must also have functional quality. The area must provide uniform appearance, compete with unwanted species, and stabilize the soil (Dernoeden et al., 1994a; Diesburg et al., 1997).

Prairie junegrass is a native, cool-season, perennial, short-grass prairie species distributed throughout the Northern Hemisphere, including the United States (Robertson, 1974). Many synonyms for this species are found in the literature including: *Aira cristata* L. (Pammell et al., 1901-1904), *K. glauca* (Dixon, 2000; Dixon, 2001), *K. gracilis* (L.) Pers., *K. cristata* (L.) Pers., *K. nitida* Nutt., *K. macrantha* (Ledeb.) Schultes, (Arnow, 1994), and *K. yukonesis* (Shaw, 2008). Most authors agree that the basic chromosome number for *Koeleria macrantha* is x=7, 2n=14 (Bowden, 1960; Reeder, 1977) or tetraploid 2n=28 (Robertson, 1974; Robertson, 1976).

Also commonly known as junegrass or crested hairgrass, this species has several attributes that would make it useful as a low-input turfgrass. Prairie junegrass is adapted to dry, sandy soils (Pammell et al., 1901-1904) and drought conditions (Milnes et al., 1998). It exhibits flexibility in its roots to adapt to water availability (Mueller-Dombois and Sims, 1966). McKernan et al.(2001) showed that native accessions of prairie junegrass exhibited moderate drought tolerance similar to fine fescues and tall fescue [*Schedonorus phoenix* (Scop.) Holub]. This species is also slow growing (Dixon, 2000; Soovali and Bender, 2006) which could be potentially useful in reducing mowing costs. Prairie junegrass can be mowed as turf when grown in areas with low annual precipitation and has been found to be somewhat shade tolerant (Brede, 2000).

Several turfgrass cultivars of prairie junegrass have been derived from European ecotypes including the Estonian variety ‘Ilo’ (Soovali and Bender, 2006) and the cultivars ‘Barleria’ and ‘Barkoel’ released by Barenbrug Holland (Alderson and Sharp, 1994). In low-input turfgrass trials in Manitoba, Canada, Mintenko et al. (2002) evaluated prairie junegrass along with several other native North American species including alpine bluegrass (*Poa alpine* L.), alkaligrass [*Puccinellia nuttalliana* (Shultes) A. Hitchc.], alpine fescue (*F. brachyphylla* Schult. ex Schult. & Schult. f.), Canada bluegrass (*Poa compressa* L.), fowl bluegrass (*Poa palustris* L.), Idaho bentgrass *(Agrostis idahoensis* Nash), marsh muhly [*Muhlenbergia racemosa* (Michx.) Britton et al.], rough hairgrass (*Agrostis scabra* Willd.), tufted hairgrass [*Deschampsia cespitosa* (L.) P. Beauv.], blue grama grass [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths], buffalograss

[*Buchloe dactyloides* (Nutt.) Engelm.], and side-oats grama [*Bouteloua curtipendula* (Michx.) Torr]. The four prairie junegrass entries evaluated were Barkoel and ecotypes originating from Minnesota, Alberta, and Iran. Barkoel was the top overall performer over all years on turf-quality ratings at three mowing heights (62, 38, and 18 mm). Barkoel also exhibited excellent color and density, and moderate drought tolerance. The native North American prairie junegrass germplasm from Minnesota and Alberta had earlier spring green-up than Barkoel (Mintenko et al., 2002).

Barkoel was also trialed for use as a low-maintenance orchard floor along with tall fescue, Chewing's fescue (*F. rubra* L. ssp. *falax* Thuill), and hard fescue (*F. brevipila* Tracey) (Willmott et al., 2000). Unlike the low-input turfgrass trial above, Barkoel did not have adequate turf quality or density, and had the highest weed levels of the four species tested. However, it did not exhibit damage from equipment traffic, unlike the hard and Chewing's fescues. The authors suggest that increased seeding rates and improved site preparation may increase the performance of the species. Wear tolerance for Barkoel was evaluated under fairway conditions where it had the highest cover and visual ratings compared to sheeps (*F. ovina* L.), Chewing's, and slender red creeping fescues [*F. rubra* ssp. *litoralis* (G.F.W. Meyer) Auquier] (Newell and Wood, 2003). In natural stands, prairie junegrass is tolerant of trampling on paths and provides complete cover (Dixon, 2000).

Significant variation has been shown among 48 globally diverse National Plant Germplasm System (NPGS) accessions of *K. macrantha* for important seed production characteristics (Clark and Watkins, 2010). Robertson and Ward (1970) found significant ecotypic differences within a much smaller collection region within Colorado for prairie junegrass germplasm on several developmental and phenotypic traits. The diverse natural range of NPGS accessions for this species should provide plant breeders with a broad genetic base from which to select important turfgrass quality traits. Identifying plant material with enhanced mowing quality (i.e. reduced leaf shredding) would contribute greatly to the development of prairie junegrass cultivars (Mintenko et al., 2002). We propose that North American ecotypes can provide additional unique and beneficial traits including disease resistance and adaptation to local growing conditions. Understanding the phenotypic variation of morphological and agronomic traits, especially turf quality characteristics, within a breeding population is crucial to the plant breeder for determining the potential application of the material, whether for turf, forage, restoration, or ornamental use (Wright et al., 1983). Identifying genetic variability in the base population before initiating a selection program is essential, as limited variability will lead to less significant gains, especially over time (Surprenant and Michaud, 1988).

The objectives of this study were to (1) evaluate accessions from NPGS for turf quality traits under low-input conditions for use in a prairie junegrass breeding program and (2) identify key geographical locations for future germplasm collection efforts.

MATERIALS AND METHODS

Sixty-eight NPGS germplasm accessions were obtained from the USDA Regional Plant Introduction Station at Pullman, WA. The origin of the material spans the species range including accessions from North America, Europe, and Asia. The material obtained from NPGS was primarily collected as seed from unimproved local populations, but also included Barkoel (PI 601393, PI 554139).

Seeds from each accession were placed into glass vials and pre-treated with a solution of 200 µL ethephon (Proxy [Bayer Environmental Science, Research Triangle Park, NC]) in 500 mL deionized water for 24 h to break seed dormancy as modified from Shahba et al. (2008). Seeds were then sown into Metro-Mix 200 soilless media (Sun Gro Horticulture, Bellevue, WA) and allowed to germinate in the greenhouse in early April 2007. The greenhouse was maintained at 23.9 °C, 16 h days supplemented with high pressure sodium lamps, no humidity control, and fans for cooling. Forty-eight accessions (Table 2) had a sufficient number of seedlings to be utilized in the trial. Individual seedlings from these accessions were transplanted into 96-cell flats and grown until they were an appropriate size for transplanting into the field. Barkoel was not included as it did not have successful germination.

The experiment was arranged as a randomized complete block design with five replications and was planted at two locations (University of Minnesota-St. Paul Campus, St. Paul, MN [44°59´23˝ N, 93°10´28˝ W], and the Sand Plains Agricultural Experiment Station, Becker, MN [45°23´47˝ N, 93°53´21˝ W]). Four genotypes were selected from each accession and placed into each replication. In late June 2007, transplants were planted into dead sod on 30.5 cm centers. The soil at St. Paul is a Waukegan silt loam (fine-silty over sandy, mixed, mesic Typic Hapludoll) with pH 6.5, and the soil at Becker is a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludoll) with pH 6.9. Fertilizer was applied at a rate of 24 kg ha^{-1}N, 48 kg ha^{-1} P_2O_5, and 24 kg ha^{-1} K_2O at the time of planting. At Becker, 0.635 cm of water was applied in two applications each week. At St. Paul, an equivalent volume of water (0.127 cm) was applied each week with daily irrigation events. Irrigation was only provided at each location from the time of planting until August 21, 2007. Pendimethalin (LESCO, Cleveland, OH), a pre-emergent herbicide, was applied each spring to control weeds at a rate of 1.68 kg ha^{-1} active ingredient. Plots were weeded by hand or using hoes as needed throughout each growing season. Following establishment, plots were mowed weekly to 6.4 cm. In early spring 2009, plots were mowed twice weekly to match the pace of growth and to remove emerging inflorescences.

To maintain consistency, the same person performed all ratings using a relative scale for the plants within the study as prairie junegrass is not typically grown for turf and species standards have not been developed. Turf characteristics including turfgrass quality (overall uniformity, density, texture, color, etc.), density, color, spring green-up, and fall color were rated visually using a 1-9 scale (9 = best turf quality or highest density) following the guidelines provided by National Turfgrass Evaluation Program (NTEP) (Morris and Shearman, 2008). A rating of 5.0 or higher indicates acceptable performance for that trait. A similar scale was utilized to score mowing quality, i.e. the amount of leaf shredding (9 = no shredded leaf tips). Inflorescence emergence was rated using a 1-9 scale to describe the number of inflorescences observed in relation to a plant’s size (9 = no inflorescences, 1 = all tillers flowering). Two weeks after the inflorescence rating, straw persistence was rated on a 1-9 scale as the amount of straw or other inflorescence debris still present after two weeks of mowing (9 = least amount of straw and/or debris). Rust incidence (unknown *Puccinia* species) was also recorded in September 2009 (1 = present, 0 = absent). At the end of the study, lateral spread (diameter [mm] at 4 cm above the soil) was measured at the widest expanse of the crown in one direction. Observations were also made on plant growth habit to identify any rhizomes, stolons, or unique phenotypes such as a prostrate growth habit.

All data were subjected to analysis of variance (ANOVA) using PROC GLM of the SAS statistical software package v.9.1 (SAS, 2002). Means separation analyses was calculated for both accessions and sub-groups. The 20 sub-groups each consisted of accessions from a similar place of origin (country, state, etc.) which was determined by utilizing geographic information from the Germplasm Resources Information Network (GRIN). Correlations were calculated among the turfgrass quality characteristics using PROC CORR of the SAS program.

RESULTS

Analysis of variance revealed significant differences ($P < 0.05$) for turfgrass quality (averaged over years 2007-2009), mowing quality, lateral spread, spring green-up, density, color, and fall color across locations and accessions (Table 2.1). Because there was a significant location x accession interaction, data from each location was analyzed separately. There was no significant difference in inflorescence emergence between the locations, but these means were analyzed separately for ease of reporting the data. Replication was also significant for several of the traits; however these differences may be the result of using individual genotypes to represent the accession instead of using clones across replications.

The St. Paul location had a greater number of accessions demonstrating adequate turfgrass quality (rating > 5.0) and component turfgrass quality traits (Table 2.2). Plants at this location were significantly larger and had higher crown density. Accession means for selected turf quality characteristics are shown for both locations in Table 2.2. Means separation analysis revealed that the accession from Ireland (430287) had the highest average turf quality performance for three years at both locations. This accession was significantly higher for turfgrass quality at Becker, but was not significantly different than the Mongolian accession 619546 at St. Paul. There were 19 accessions at Becker and 30 accessions at St. Paul that received an average turf quality rating of 5.0 or higher, suggesting adequate turf quality performance when averaged over all three years. When excluding the establishment year ratings, there were 17 accessions at Becker, and 38 accessions at St. Paul that demonstrated acceptable quality (rating > 5.0) (data not shown).

There were significant differences for turf quality components among accessions for mowing quality, lateral spread, spring green-up, crown density, color, and rust. Mowing quality was variable among the accessions ranging from 3.8 (502393 from the Russian Federation) to 8.6 (430287 from Ireland) at Becker and 2.7 (440451 from Stavropol, Russian Federation) to 8.1 (430287 from Ireland) at St. Paul. At Becker, the accession with the largest lateral spread was from Ireland (430287). An accession from the Russian Federation (502389) had the largest diameter at St. Paul and the second largest diameter at Becker (though not significantly different from the top performing accession 430287). Spring green-up rating was highest (8.5) at St. Paul for the Mongolian accession (619546). At Becker, the accession with the highest green-up rating (7.8) was from Kazakhstan (538975). The lowest rating for green-up was a South African accession (410152) which did not survive at either location, and for Pakistan (250651) which had a score of 1.0 at St. Paul and had no survival at Becker. Rust incidence ranged from no infection for several accessions, to 100% of the genotypes for an accession showing signs of infection.

Means separation analysis on an origin basis revealed that collection regions differed in performance for most traits (Table 2.3). The single accession from Ireland (430287) (which was considered a collection region) performed the highest in turf quality and mowing quality. Other collection origins with high mowing quality included Pakistan, Turkey (including Afyon, Ankara, and Bilecik), Pakistan, Armenia, and Bulgaria. Many of the accessions with a distinct prostrate phenotype were from these collection regions. The lowest rated accessions for turf quality at Becker included the accessions from Canada (4.6), Iowa (4.4), New Mexico (3.8) (represented by one accession each), Ankara, Turkey (4.3), as well as an accession from Armenia (4.4). The lowest rated accessions for turf quality at St. Paul included accessions from Canada (4.1), New Mexico (4.2) (represented by one accession each), and an accession from Armenia (4.5).

At Becker the spring green-up rating was highest for collections from Ukraine (7.2), Russian Federation (6.4), Stavropol, Russian Federation (6.8), Kazakhstan (7.4), and the former Soviet Union (6.1). At St. Paul the highest spring green-up ratings by collection region were from Kazakhstan (7.4), Ukraine (8.3), Stavropol, Russian

Federation (7.2), Mongolia (6.7), Iowa (6.4), Iran (6.3), and the former Soviet Union (6.1). These collection regions represent the more northern collection areas with latitudes > 40°N.

Correlations based on the 48 accession means were calculated among the turf quality traits for each of the experimental locations (Table 2.4). As expected, there were generally positive correlations between overall turfgrass quality and the turfgrass quality components. Following the establishment year, as more plants reached the mowing height and were cut, there was a correlation between overall turfgrass quality and mowing quality at both locations. At Becker and St. Paul there was a significant negative correlation between spring green-up and mowing quality (r = -0.34 and -0.44, respectively). At Becker and St. Paul there was a strong positive correlation between lateral spread and turf quality (r = 0.61 and 0.57, respectively). At Becker and St. Paul there was a significant positive correlation between mowing quality and straw persistence rating (r = 0.43 and 0.41, respectively). There was a negative correlation at Becker between inflorescence emergence and turf quality (r = -0.30) and between inflorescence emergence and density (r = -0.20). There was a small significant negative correlation between inflorescence emergence and the presence of straw (r = -0.11 [St. Paul] and r = -0.22 [Becker]). This suggests that mowing can effectively remove straw or other inflorescence debris from plants that flower. There was a low negative correlation between mowing quality and inflorescence emergence (r = -0.11 [St. Paul] and r = -0.07 [Becker]).

Results for South Africa (410152) and Pakistan (250651) means are skewed or missing as these accessions did not have a large number of observations after 2007 due to winter kill. It is proposed that many of the genotypes in these accessions were not *K. macrantha* as they exhibited a distinct phenotype (inflorescence) and poor winter survival.

DISCUSSION

The range of variation in the germplasm indicates that there is potential for developing prairie junegrass cultivars for use as low-input turf. In low-input conditions, several accessions showed an acceptable turf quality performance of 5.0 or higher. The number of individual accessions with adequate turf performance and other traits suggests that this species should be the target of germplasm improvement efforts for use as a low-input turf.

The analysis of collection regions allowed for the identification of future germplasm collection sites. This includes collecting plant material from northern latitudes for improved spring green-up. The collection of local germplasm would be useful in acquiring plant material with local rust resistance. Collection of germplasm within Ireland may offer germplasm with high turf quality performance; however, the ploidy level for this material appears to be higher which will present challenges to the plant breeder. The very low growing, prostrate phenotype observed in the accessions from Armenia, Bulgaria, Turkey, and Stavropol, Russian Federation make these areas strong candidates for obtaining plant material that could contribute to reducing mowing requirements. The Russian Federation could also be explored for prairie junegrass resources that exhibit the aggressive growth habit observed in accession PI502389. The accessions with unique phenotypes may be sub-species of *K. macrantha* or may in fact be different species that had been erroneously identified and included in the NPGS collection.

Spring green-up is an important trait for northern climates with short summers (Mintenko and Smith, 1999). Though early spring green-up may be an advantage to turf managers, it was negatively correlated with other important traits. The negative correlation between spring green-up and mowing quality may be a reflection of the phenology of the species. Most mowing ratings were taken later in the season when the majority of the season's growth may have been completed and tissue was mature and more prone to leaf shredding. The majority of prairie junegrass growth occurs in early spring (Coupland, 1950). In native prairie habitats, prairie junegrass is often the earliest to green-up in the spring and produces a single flush of growth that results in flowering in June, seed ripening in July, followed by a period of dormancy for the rest of the summer as water resources become limited. The species avoids the dry summer months by completing its reproductive cycle before summer drought (Barnes and Harrison, 1982). Summer dormancy was not observed in this trial, though it could be problematic in some turf applications.

The shredding of leaf tissue was a major contributor to a low mowing quality rating and has been seen in other turfgrass species, such as perennial ryegrass (*Lolium perenne* L.) due to tough vascular bundles (Turgeon, 2005). The shredded leaf tissue remained on the leaf blade and continued to persist with each mowing. As an individual leaf blade elongated, each mowing resulted in additional, persistent shredded tissue. Mowing quality ratings may vary throughout the growing season depending on the maturity of the leaf tissue and if plants are actively growing. The persistent shredded tissue would also contribute to subsequent lower mowing quality ratings later in the season. Due to height and growth habit, some plants were not mowed during the entire three-year study. Leaf shredding may occur in these genotypes in environments where plant height allows for mower to leaf contact. Mowing ratings were based at the 6.4 cm height, thus genotypes that were not mowed because of the prostrate growth habit or slow growth rate would have a higher mowing rating even though leaf tissue may not have been mown. Plants with a low growth habit and with tolerance to close mowing will be important in cultivar development (Meyer and Funk, 1989). It is possible that mowing could be conducted in the spring and less frequently through the summer to encourage vegetative growth while also removing inflorescences and straw.

The small significant negative correlation between emerging inflorescences and the persistence of straw suggests that some of the flowering plants retained culms and/or other inflorescence debris after mowing. The removal of the discolored straw and inflorescences can improve the overall appearance of the turf. There was a low negative correlation between mowing quality and inflorescence emergence at Becker; however this interaction was not significant at St. Paul. Mowing quality was positively correlated with a good straw persistence rating. In a low-input setting, flowering plants may be acceptable to a turf manager, especially if the straw is easily removed and does not affect the overall season’s turf quality.

Summer dormancy was not observed in the germplasm, despite the lack of supplemental irrigation or fertility. Rain events throughout each summer provided adequate moisture to prevent drought-induced dormancy. At Becker there were fewer rain events in August 2008 (Figure 2.1) than at St. Paul (Figure 2.2) which may have contributed to better overall turf quality at St. Paul (State Climatology Office, 2010). It appears that regular mowing and the elimination of floral tissue also encouraged continued vegetative growth. Mowing commenced earlier in spring 2009 in order to reduce flowering. Mowing frequency was increased to twice weekly during active flowering. Flowering occurred on lateral stems (that were subsequently not mown) and also on shortened stems with inflorescences persisting at or below the mowing height.

Lateral spread is a measurement of plant vigor and an indicator of the ability to adequately cover the soil surface as a uniform turf. There was a strong correlation between lateral spread and turf quality. Accession 502389 (Russian Federation) exhibited vigorous growth and had the largest lateral spread. This aggressive accession had a number of extravaginal tillers (though not rhizomes) that emerged through the soil one to several cm from the main crown. This trait is desirable in turfgrass to fill in gaps of a turf canopy caused by damage or wear.

Plant density appeared to be influenced by environmental factors like crown damage (mowing and winter-kill) and by genetic factors such growth habit and plant architecture. At Becker, inflorescence emergence and density were negatively correlated as many of the plants exhibited tiller die-out after flowering. The long-term perenniality of this species is not known, although as an un-mown plant, center die-off has been apparent at 6-7 years (Looman, 1978). A number of the accessions at each location demonstrated an adequate density rating (>5.0). The variation observed in the germplasm will be useful in selecting genotypes with the high density ratings. It is unknown how single plant density ratings will correlate with the density of a turf plot.

Genetic color of this species ranges from blue-gray to blue-green to greenish-yellow to dark green. To assess genetic color, color ratings were averaged from observations made in May 2008 during the most active growth and in August 2009 following more stressful growing conditions. The NTEP guidelines for rating genetic color were not well suited for this trial as there is no accepted standard from which to judge this species. Ratings were based on a relative scale against the top performing accession PI 430287. This accession appears to be tetraploid and its color may be the result of an increased chloroplast number per cell (Butterfass, 1973). A more appropriate rating would be to categorize the accessions using a Munsell-type color chart (Morris and Shearman, 2008). Fall color changes were observed though this trait was not strongly correlated with any other traits. Fall colors observed in this trial included hues of red, orange, yellow, and purple.

Rust (unknown *Puccinia* species) was observed on a number of genotypes. Prairie junegrass is known to be susceptible to *P. graminis* (Looman, 1978) and *P. koeleriae* (Mains, 1933) in addition to other rust pathogens. Infection was first observed in August and persisted into the fall months. Rust incidence was higher at the St. Paul location. Infection resulted in damage to leaf tissue, necrosis, and leaf senescence in more susceptible genotypes. Rust susceptibility for each accession varied by location, suggesting a large environmental effect. The environmental effect and continuous distribution of rust across the accessions suggests that resistance is quantitatively inherited (Bokmeyer et al., 2009). The data suggests a local adaptation of resistance to the presence of local rust populations (less incidence of rust in Iowa and Canadian accessions).

CONCLUSION

Evaluating unique genotypes instead of clones allowed for general characterizations to be made about each accession based on the performance on turf quality characteristics (Oliveira et al., 2008). This approach allowed for the screening of a large number of unique genotypes. An advantage of this design is the identification of genotypes within accessions which may possess unique traits such as disease resistance. The variability in turf quality traits observed in the NPGS accessions supports their use in a breeding program for the development of low-input turf. The utilization of accessions with high mowing quality performance will be critical in germplasm improvement of native plant material which does not tolerate mowing.

It will be necessary to examine the better performing accessions for turf quality in seeded turf plots. Comparing these accessions to other species, cultivars, or as mixtures in turf plot trials would also provide useful information for plant breeders. Other management practices including seeding rates, weed control, and fertility regimens will also need to be evaluated in order to provide recommendations to end users (Johnson, 2008). The development of management practices, specifically pertaining to mowing frequency and cutting height, could be very important. Weekly mowing may not be necessary with this species after flowering has ceased which could greatly reduce inputs associated with mowing.Table 2.1. Analysis of variance for mean turf quality (2007-09), mowing quality, lateral spread, spring green-up, density, color, fall color, inflorescence emergence, straw persistence, and rust incidence for prairie junegrass accessions grown at two locations.

Table 2.1. Analysis of variance for mean turf quality (2007-2009), mowing quality, lateral spread, spring green-up, density, color, fall color, inflorescence emergence, and straw persistence for prairie junegrass accessions grown at two locations.

Source of Variance	Turf quality 2007-09†	Mowing quality‡	Lateral spread§	Spring green-up¶	Density#	Color††	Fall Color††	Inflors. ‡‡	Straw§§	Rust¶¶
Location (L)	37.56***	228.69***	1289063.52***	22.72***	40.83***	27.50***	25.54***	3.54NS	67.51***	1.03***
Replication (R)	0.51NS	1.17NS	2914.36***	20.38***	1.10*	3.72***	6.29***	26.59***	34.19***	1.39***
Accession (A)	9.03***	40.75***	8429.99***	45.47***	9.91***	4.23***	13.46***	14.55***	15.45***	2.34***
L X A	1.37***	1.28***	2744.47***	11.20***	2.59***	0.60***	6.45***	5.11***	3.64***	0.38***
L X R	0.40NS	3.41***	3679.30***	1.26NS	1.97***	1.11***	6.13***	26.15***	34.35***	0.69***
R X A	0.61***	0.96***	620.22*	2.55***	0.85***	0.66***	2.77***	3.69***	2.74***	0.30***
L X A X R	0.82***	1.08***	558.68NS	3.05***	1.10***	0.51***	2.64***	3.89***	2.47***	0.28***

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Turf quality was rated at least twice monthly visually using a 1-9 scale (9 = best turf quality) and averaged over years (2007-2009).

‡ Mowing quality was rated was rated two times in both 2008 and 2009 on a 1-9 scale (9 = best quality, less shredding).

§ Lateral spread (mm) was measured as the diameter of the crown at its widest point at a 4 cm height.

¶ Spring green-up was rated at Becker (5/9/2008 and 4/24/2009) and at St. Paul (4/30/2008 and 4/18/2009) visually using a 1-9 scale (9 = darkest green color).

Density was rated once during establishment, and twice year after, visually using a 1-9 scale (9 = highest crown density).

†† Color (including fall color) was rated once in 2008 and once in 2009 visually using a 1-9 scale (9 = darkest green accession in the study (430287)).

‡‡ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size visually (9 = fewest inflorescences).

§§ Straw persistence was visually rated on a 1-9 scale as the proportion of straw and inflorescence debris present two weeks after inflorescence rating, after mowing (9 = least amount of straw/debris).

¶¶ Rust incidence was rated at Becker (9/3/09) and at St. Paul (9/24/09) as 0 = no infection, 1 = infection.

Table 2.2. Mean separation analysis of selected turf quality characteristics of prairie junegrass accessions at Becker (B) and St. Paul (SP), MN grown in low-input conditions and mowed weekly from 2007-2009. Ranked by average turf quality at St. Paul.

Accession	Origin	Turf quality †		Mowing quality‡		Lateral spread§		Spring green-up¶		Density#	
		B	SP	B	SP	B	SP	B	SP	B	SP
						------mm------					
430287	Ireland	7.6	6.6	8.6	8.1	133.8	130.4	5.2	2.9	7.6	6.3
619546	Mongolia	5.7	6.3	7.9	6.8	91.3	156.2	5.8	8.5	6.5	6.7
204452	Turkey	5.9	6.0	7.2	6.5	95.0	187.9	6.1	5.2	6.3	6.2
229463	Iran	5.5	5.9	5.8	5.6	98.2	173.6	7.0	7.3	6.0	5.9
502389†††	Russian Fed. (RF)	5.0	5.8	4.7	4.8	127.5	196.9	5.8	7.3	5.2	5.6
230256	Iran	4.7	5.7	7.9	6.0	68.9	149.6	5.5	5.8	5.0	6.6
502395	F Soviet Union	4.9	5.6	4.8	3.8	80.2	157.3	6.6	7.6	5.4	5.6
636566##	Bulgaria	5.0	5.5	6.8	6.0	98.9	184.6	4.5	3.2	4.9	5.7
204451##	Turkey	4.8	5.5	7.1	6.2	94.6	170.6	5.7	4.5	4.9	5.6
538975	Kazakhstan	5.1	5.4	4.9	4.1	86.3	174.5	7.8	7.2	5.4	5.3
21380	Mongolia	5.1	5.4	5.9	5.4	68.9	128.6	4.9	7.5	6.2	6.2
538972	Russian Fed.	5.1	5.4	6.6	5.8	79.8	160.5	5.9	7.4	5.7	6.5
502394	Ukraine	5.0	5.4	4.6	3.0	72.6	153.5	7.2	8.3	5.2	5.3
568184##	Afyon, Turkey	4.7	5.4	6.7	5.6	83.1	192.5	4.5	4.6	5.0	5.7
19186##	Bilecki, Turkey	4.5	5.4	6.6	5.7	93.7	174.7	4.3	3.4	4.3	5.3
230267	Iran	4.4	5.4	7.8	6.3	60.3	140.1	4.4	5.9	4.9	5.7
502393	Russian Fed.	5.0	5.3	3.8	3.5	69.5	151.0	7.7	7.9	5.5	5.2
255364	Yugolavia	5.0	5.3	5.5	4.3	75.1	143.3	5.7	4.9	5.3	5.5
502390##	Stavropol, RF	4.9	5.3	4.6	3.6	69.1	161.3	6.9	6.2	5.5	5.3
383673##	Turkey	4.8	5.3	8.3	6.3	89.2	160.2	4.5	4.4	4.5	5.6
410152‡‡‡	South Africa	5.1	5.2	--	6.0	--	--	--	--	5.1	6.3
440454	Stavropol, RF	5.0	5.2	4.8	3.9	78.5	151.1	6.8	7.2	5.2	5.2
314378	Stavropol, RF	4.8	5.2	4.4	2.9	77.7	142.4	6.8	7.4	5.4	5.2
314700	Former Soviet Union	4.6	5.2	6.0	5.3	70.8	136.4	6.3	5.2	5.2	5.6
538968	Russian Federation	5.2	5.1	5.9	5.6	114.1	139.6	5.8	5.7	5.7	5.4
502391	Russian Federation	5.0	5.1	4.2	3.2	77.6	149.3	6.7	8.4	5.5	5.3

312456	Former Soviet Union	4.9	5.1	4.9	3.9	69.7	145.1	5.6	6.0	5.1	5.2
314377	Stavropol, RF	4.8	5.0	4.7	3.5	68.5	131.9	6.1	7.4	5.3	5.1
618749	Mongolia	4.6	5.0	5.6	4.5	71.2	126.4	3.2	6.6	5.3	5.8
532937	Pakistan	4.2	5.0	7.4	6.3	60.0	122.4	4.5	3.8	4.5	5.2
314440	Former Soviet Union	5.0	4.9	4.8	4.1	78.5	137.5	5.8	6.1	5.1	5.3
383672##	Turkey	4.7	4.9	6.7	5.8	81.3	158.4	4.8	3.6	4.4	5.3
23304	Kazakhstan	4.5	4.9	4.4	3.4	70.1	144.4	6.9	7.6	4.6	4.8
21553	Mongolia	4.5	4.9	5.2	4.7	53.9	110.1	4.1	5.8	5.4	5.5
19198##	Ankara,Turkey	4.3	4.9	7.4	5.8	75.9	161.5	5.3	3.6	4.0	5.0
440455	Former Soviet Union	5.1	4.8	4.5	3.9	70.9	136.8	6.9	7.6	5.6	5.1
383674##	Turkey	4.7	4.8	6.9	5.7	72.0	182.3	4.8	4.2	4.8	5.0
383675	Turkey	4.0	4.7	7.5	7.0	72.5	134.5	4.5	4.6	4.8	5.8
21268	Mongolia	4.7	4.6	5.0	4.7	68.5	109.0	5.1	6.4	5.4	5.2
440451##	Stavropol, RF	4.6	4.6	4.0	2.7	66.3	132.2	7.2	7.9	4.8	4.8
639190	Iowa, USA	4.4	4.6	4.1	3.9	77.1	129.2	5.8	6.4	4.6	4.6
24110##	Armenia	4.4	4.5	6.8	5.6	89.4	149.6	4.7	3.8	4.1	5.2
440456	Former Soviet Union	4.3	4.5	6.7	5.4	66.3	114.4	5.0	3.8	4.6	5.4
18194	Mongolia	4.2	4.4	4.6	3.8	56.8	121.6	4.9	6.9	4.7	5.1
250651‡‡‡	Pakistan	5.0	4.3	--	7.0	--	85.0	--	1.0	4.5	4.6
477978	New Mexico, USA	3.8	4.2	5.5	4.7	85.4	112.8	3.4	3.9	3.7	4.6
387927	Canada	4.6	4.1	5.9	5.5	82.4	129.4	5.8	5.1	5.0	4.6
21169	Mongolia	3.7	4.0	6.4	5.6	71.3	102.4	4.5	5.1	4.0	4.3
	LSD (0.05)	0.5	0.4	0.6	0.5	13.6	19.8	0.7	0.7	0.5	0.4

(additional traits shown below)

Table 2.2 (continued) Mean separation analysis of selected turf quality characteristics of prairie junegrass accessions at Becker (B) and St. Paul (SP), MN grown in low input conditions and mowed weekly from 2007-2009. Ranked by average turf quality at St. Paul.

		Color††		Fall color††		Inflors. ‡‡		Straw§§		Rust¶¶	
Accession	Origin	B	SP	B	SP	B	SP	B	SP	B	SP
										-----%----	
430287	Ireland	7.2	6.8	8.4	7.9	5.3	5.1	6.8	6.3	6	20
619546	Mongolia	4.8	5.1	6.2	7.3	8.0	6.8	6.8	6.6	81	95
204452	Turkey	5.1	5.9	7.0	7.2	5.8	7.5	6.8	5.9	67	95
229463	Iran	5.0	5.2	6.9	7.4	6.8	7.4	6.3	6.5	67	71
502389†††	Russian Fed.	4.9	5.2	6.4	7.5	8.5	8.3	6.8	6.5	0	5
230256	Iran	4.8	5.3	6.5	6.8	8.9	7.7	8.3	7.5	7	76
502395	Former Soviet Union	5.1	5.3	6.1	7.3	8.6	8.7	5.3	5.9	28	33
636566##	Bulgaria	5.0	5.3	8.6	7.4	7.2	5.7	6.9	5.4	5	10
204451##	Turkey	4.7	5.2	7.1	6.9	7.0	8.5	7.9	6.6	100	30
538975	Kazakhstan	4.8	5.1	6.3	6.7	7.6	8.5	5.6	5.5	42	42
21380	Mongolia	4.7	5.1	6.1	6.9	8.3	7.3	6.2	6.2	29	30
538972	Russian Fed.	5.2	5.2	6.4	6.9	7.0	7.9	6.7	5.1	54	100
502394	Ukraine	4.9	5.6	5.7	7.1	8.8	7.9	6.1	5.5	6	33
568184##	Afyon, Turkey	4.8	5.3	7.9	7.5	7.2	8.0	6.4	6.2	0	12
19186##	Bilecki, Turkey	4.6	5.4	8.0	7.1	7.2	7.7	5.7	6.3	0	0
230267	Iran	4.6	5.3	6.5	7.3	9.0	8.9	8.2	7.4	57	50
502393	Russian Fed.	5.3	5.6	7.4	6.7	8.2	8.3	5.1	5.3	7	27
255364	Yugolavia	5.0	5.4	6.3	6.8	8.8	8.0	6.8	5.9	35	53
502390##	Stavropol, Russ. Fed.	4.8	5.3	6.0	6.8	8.7	7.5	5.7	5.2	45	67
383673##	Turkey	5.1	5.0	7.7	7.6	9.0	8.4	8.0	6.9	20	47
410152‡‡‡	South Africa	4.2	4.2	6.5	6.2	9.0	9.0	--	6.0	--	--
440454	Stavropol, RF	5.1	5.4	5.9	7.0	8.3	8.5	6.1	5.4	13	60
314378	Stavropol, RF	4.9	5.1	6.1	6.8	8.5	8.2	5.5	5.6	39	56
314700	Former Soviet Union	4.6	5.0	5.8	7.2	8.7	8.3	6.5	6.9	33	71
538968	Russian Federation	4.8	5.0	5.9	6.4	7.7	8.3	5.4	5.9	71	47
502391	Russian Federation	5.0	5.6	6.5	6.6	9.0	8.4	5.6	5.6	19	31
312456	Former Soviet Union	5.1	5.3	6.6	7.0	7.5	7.9	6.1	5.9	7	25

314377	Stavropol, RF	5.0	5.3	6.0	6.7	8.7	7.5	6.4	5.9	46	47
618749	Mongolia	5.2	5.1	5.9	6.5	7.7	7.7	6.3	6.2	56	90
532937	Pakistan	4.4	4.8	6.2	7.4	8.8	8.1	7.5	6.9	57	73
314440	Former Soviet Union	5.0	5.2	6.8	6.6	7.6	7.7	6.6	5.6	25	10
383672##	Turkey	5.0	4.8	8.6	6.8	7.8	8.4	6.7	6.6	0	33
23304	Kazakhstan	4.7	5.2	6.6	6.9	8.8	8.9	4.9	5.2	100	92
21553	Mongolia	5.1	5.1	6.6	6.3	7.3	7.5	6.1	6.3	25	0
19198##	Ankara,Turkey	4.7	4.8	8.3	7.0	7.0	8.0	6.9	6.3	22	5
440455	Former Soviet Union	4.9	5.3	6.0	7.3	8.4	7.3	5.7	5.6	65	32
383674##	Turkey	5.0	4.9	7.6	7.3	8.8	8.3	7.2	6.6	0	17
383675	Turkey	4.8	5.2	6.3	7.4	9.0	8.4	8.1	7.0	90	94
21268	Mongolia	5.3	5.2	7.2	7.0	8.1	8.5	6.9	6.0	88	80
440451##	Stavropol, RF	4.9	5.2	6.8	6.9	8.3	7.6	5.8	5.4	28	28
639190	Iowa, USA	4.8	5.1	5.4	5.4	4.6	7.0	4.8	5.6	6	0
24110##	Armenia	4.4	4.7	7.4	7.1	8.9	8.4	8.2	6.4	91	100
440456	Former Soviet Union	4.5	4.6	5.9	6.4	8.8	8.2	6.9	6.4	87	100
18194	Mongolia	5.0	5.0	6.1	6.6	8.6	7.0	5.8	5.7	50	94
250651‡‡‡	Pakistan	4.8	5.0	7.7	6.8	--	6.0	--	6.0	--	--
477978	New Mexico, USA	4.4	4.9	6.9	7.1	8.5	9.0	7.5	6.0	69	37
387927	Canada	5.2	5.0	7.2	7.0	7.4	7.4	6.8	5.7	57	31
21169	Mongolia	5.0	4.8	6.7	7.8	8.1	8.2	7.9	6.3	100	87
	LSD (0.05)	0.3	0.3	0.7	0.5	1.1	0.7	0.9	0.5	26	23

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† Turf quality was rated at least twice monthly visually using a 1-9 scale (9 = best turf quality) and averaged over years (2007-2009).

‡ Mowing quality was rated was rated two times in both 2008 and 2009 on a 1-9 scale (9 = best quality, less shredding).

§ Lateral spread (mm) was measured as the diameter of the crown at its widest point at a 4 cm height.

¶ Spring green-up was rated at Becker (5/9/2008 and 4/24/2009) and at St. Paul (4/30/2008 and 4/18/2009) visually using a 1-9 scale (9 = darkest green color).

Density was rated once during establishment, and twice year after, visually using a 1-9 scale (9 = highest crown density).

†† Color was rated at Becker (5/19/2008 and 8/6/2009) and at St. Paul (5/20/2008 and 8/11/2009) visually using a 1-9 scale (9 = darkest green accession in the study (430287)). Fall color was rated at Becker and at St. Paul.

‡‡ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size visually (9 = fewest inflorescences).

§§ Straw persistence was visually rated on a 1-9 scale as the proportion of straw and inflorescence debris present two weeks after mowing (9 = least amount of straw/debris).

¶¶ Rust incidence (percentage of infected genotypes within an accession) was rated at Becker (9/3/09) and at St. Paul (9/24/09) as 0 = no infection, 1 = infection.

\#\# Indicates accessions with a prostrate phenotype.

††† Indicates an accession with rhizomatous growth habit.

‡‡‡ Data missing as indicated by (--) due to low plant survival after 2007.

Table 2.3. Means separation analysis of selected turf quality characteristics by origin of prairie junegrass germplasm accessions grown at Becker and St. Paul, MN 2007-2009.

		Turf quality 2007-09†		Mowing quality‡		Lateral spread§		Spring green-up¶		Density#		Color††		Fall Color††		Inflors. ‡‡		Straw§§	
Origin	Accession	B	SP	B	SP	B	SP	B	SP	B	SP	B	SP	B	SP	B	SP	B	SP
	n					----mm----													
Armenia	1	4.4	4.5	6.8	5.6	89.4	149.6	4.7	3.8	4.1	5.2	4.4	4.7	7.4	7.1	8.9	8.4	8.2	6.4
Bulgaria	1	5.0	5.5	6.8	6.0	98.9	184.6	4.5	3.2	4.9	5.7	5.0	5.3	8.6	7.4	7.2	5.7	6.9	5.4
Canada	1	4.6	4.1	5.9	5.5	82.4	129.4	5.8	5.1	5.0	4.6	5.2	5.0	7.2	7.0	7.4	7.4	6.8	5.7
Frmr. Sov. Union	6	4.8	5.0	5.2	4.4	73.1	137.8	6.1	6.1	5.2	5.4	4.9	5.1	6.2	6.9	8.2	8.0	6.1	6.1
Iowa, USA	1	4.4	4.6	4.1	3.9	77.1	129.2	5.8	6.4	4.6	4.6	4.8	5.1	5.4	5.4	4.6	7.0	4.8	5.6
Iran	3	4.8	5.7	7.1	5.9	77.4	154.2	5.7	6.3	5.3	6.1	4.8	5.2	6.7	7.1	8.0	8.0	7.4	7.1
Ireland	1	7.6	6.6	8.6	8.1	133.8	130.4	5.2	2.9	7.6	6.3	7.2	6.8	8.4	7.9	5.3	5.1	6.8	6.3
Kazakhstan	2	4.8	5.2	4.7	3.7	78.6	159.1	7.4	7.4	5.0	5.0	4.7	5.1	6.5	6.8	8.1	8.7	5.2	5.3
Mongolia	7	4.7	5.0	5.7	5.0	69.2	123.2	4.6	6.7	5.4	5.6	5.0	5.1	6.4	6.8	8.0	7.5	6.5	6.2
New Mexico, USA	1	3.8	4.2	5.5	4.7	85.4	112.8	3.4	3.9	3.7	4.6	4.4	4.9	6.9	7.1	8.5	9.0	7.5	6.0
Pakistan	2	4.7	4.6	7.4	6.4	60.0	120.1	4.5	3.4	4.5	4.9	4.6	4.9	7.0	7.1	8.8	7.9	7.5	6.8
Russian Fed. (RF)	5	5.0	5.4	5.0	4.6	95.7	160.6	6.4	7.3	5.5	5.6	5.0	5.3	6.5	6.8	8.2	8.2	6.0	5.7
Stavropol, RF	5	4.8	5.1	4.5	3.4	72.1	144.4	6.8	7.2	5.2	5.1	4.9	5.3	6.2	6.9	8.5	7.9	5.9	5.5
South Africa¶¶	1	5.1	5.2	--	--	--	--	--	1.0	5.1	6.3	4.2	4.2	6.5	6.2	9.0	9.0	--	6.0
Turkey	6	4.8	5.2	7.2	6.3	85.2	165.0	5.2	4.4	5.0	5.6	5.0	5.2	7.4	7.2	7.7	8.3	7.3	6.6
Afyon, Turkey	1	4.7	5.4	6.7	5.6	83.1	192.5	4.5	4.6	5.0	5.7	4.8	5.3	7.9	7.5	7.2	8.0	6.4	6.2
Ankara, Turkey	1	4.3	4.9	7.4	5.8	75.9	161.5	5.3	3.6	4.0	5.0	4.7	4.8	8.3	7.0	7.0	8.0	6.9	6.3
Bilecik, Turkey	1	4.5	5.4	6.6	5.7	93.7	174.7	4.3	3.4	4.3	5.3	4.6	5.4	8.0	7.1	7.2	7.7	5.7	6.3
Ukraine	1	5.0	5.4	4.6	3.0	72.6	153.5	7.2	8.3	5.2	5.3	4.9	5.6	5.7	7.1	8.8	7.9	6.1	5.5

Yugoslavia	1	5.0	5.3	5.5	4.3	75.1	143.3	5.7	4.9	5.3	5.5	5.0	5.4	6.3	6.8	8.8	8.0	6.8	5.9
LSD (0.05)		0.4	0.4	0.8	0.6	14.0	17.0	0.8	1.1	0.5	0.4	0.3	0.3	0.7	0.5	1.1	0.9	0.9	0.6

† Turf quality was rated at least twice monthly visually using a 1-9 scale (9 = best turf quality) and averaged over years (2007-2009).

‡ Mowing quality was rated was rated two times in both 2008 and 2009 on a 1-9 scale (9 = best quality, less shredding).

§ Lateral spread (mm) was measured as the diameter of the crown at its widest point at a 4 cm height.

¶ Spring green-up was rated at Becker (5/9/2008 and 4/24/2009) and at St. Paul (4/30/2008 and 4/18/2009) visually using a 1-9 scale (9 = darkest green color).

Density was rated once during establishment, and twice year after, visually using a 1-9 scale (9 = highest crown density).

†† Color was rated at Becker (5/19/2008 and 8/6/2009) and at St. Paul (5/20/2008 and 8/11/2009) visually using a 1-9 scale (9 = darkest green accession in the study (430287)). Fall color was rated at Becker and at St. Paul.

‡‡ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size visually (9 = fewest inflorescences).

§§ Straw persistence was visually rated on a 1-9 scale as the proportion of straw and inflorescence debris present two weeks after mowing (9 = least amount of straw/debris).

¶¶ Data missing as indicated by (--) due to low plant survival after 2007.

Table 2.4. Correlation coefficients among several turf quality characteristics of prairie junegrass accessions at St. Paul, MN (above diagonal) and Becker, MN (below the diagonal).

	Turf quality†	Mowing quality‡	Lateral spread§	Spring green-up¶	Density#	Color††	Fall color††	Inflors.‡‡	Straw§§
Turf quality		0.29***	0.57***	0.20***	0.76***	0.35***	0.09**	-0.03NS	0.14***
Mowing quality	0.20***		0.11**	-0.44***	0.38***	0.02NS	0.23***	-0.11**	0.41***
Lateral spread	0.61***	0.23***		0.07*	0.27***	0.10**	0.05NS	0.08**	-0.02NS
Sp. green-up	0.33***	-0.34***	0.09*		0.14***	0.08*	-0.03NS	-0.04NS	-0.26***
Density	0.72***	0.14***	0.37***	0.00***		0.26***	0.08*	-0.08	0.22***
Color	0.48***	0.15***	0.25***	-0.02NS	0.38***		0.13***	-0.13***	-0.04NS
Fall color	0.21***	0.24***	0.16***	-0.18***	-0.03NS	0.30***		-0.06*	0.15***
Inflors.	-0.30***	-0.07NS	-0.28***	0.05NS	-0.20***	-0.21***	-0.15***		-0.11**
Straw	0.00NS	0.43***	0.05NS	-0.11**	-0.04NS	-0.14***	0.09*	-0.22***	

*, **, *** Significant at the 0.05, 0.01, and 0.001 levels, respectively.

† Turf quality was rated at least twice monthly visually using a 1-9 scale (9 = best turf quality) and averaged over years (2007-2009).

‡ Mowing quality was rated was rated two times in both 2008 and 2009 on a 1-9 scale (9 = best quality, less shredding).

§ Lateral spread (mm) was measured as the diameter of the crown at its widest point at a 4 cm height.

¶ Spring green-up was rated at Becker (5/9/2008 and 4/24/2009) and at St. Paul (4/30/2008 and 4/18/2009) visually using a 1-9 scale (9 = darkest green color).

Density was rated once during establishment, and twice year after, visually using a 1-9 scale (9 = highest crown density).

†† Color was rated at Becker (5/19/2008 and 8/6/2009) and at St. Paul (5/20/2008 and 8/11/2009) visually using a 1-9 scale (9 = darkest green accession in the study (430287)). Fall color was rated at Becker and at St. Paul.

‡‡ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size visually (9 = fewest inflorescences).

§§ Straw persistence was visually rated on a 1-9 scale as the proportion of straw and inflorescence debris present two weeks after inflorescence rating, after mowing (9 = least amount of straw/debris).

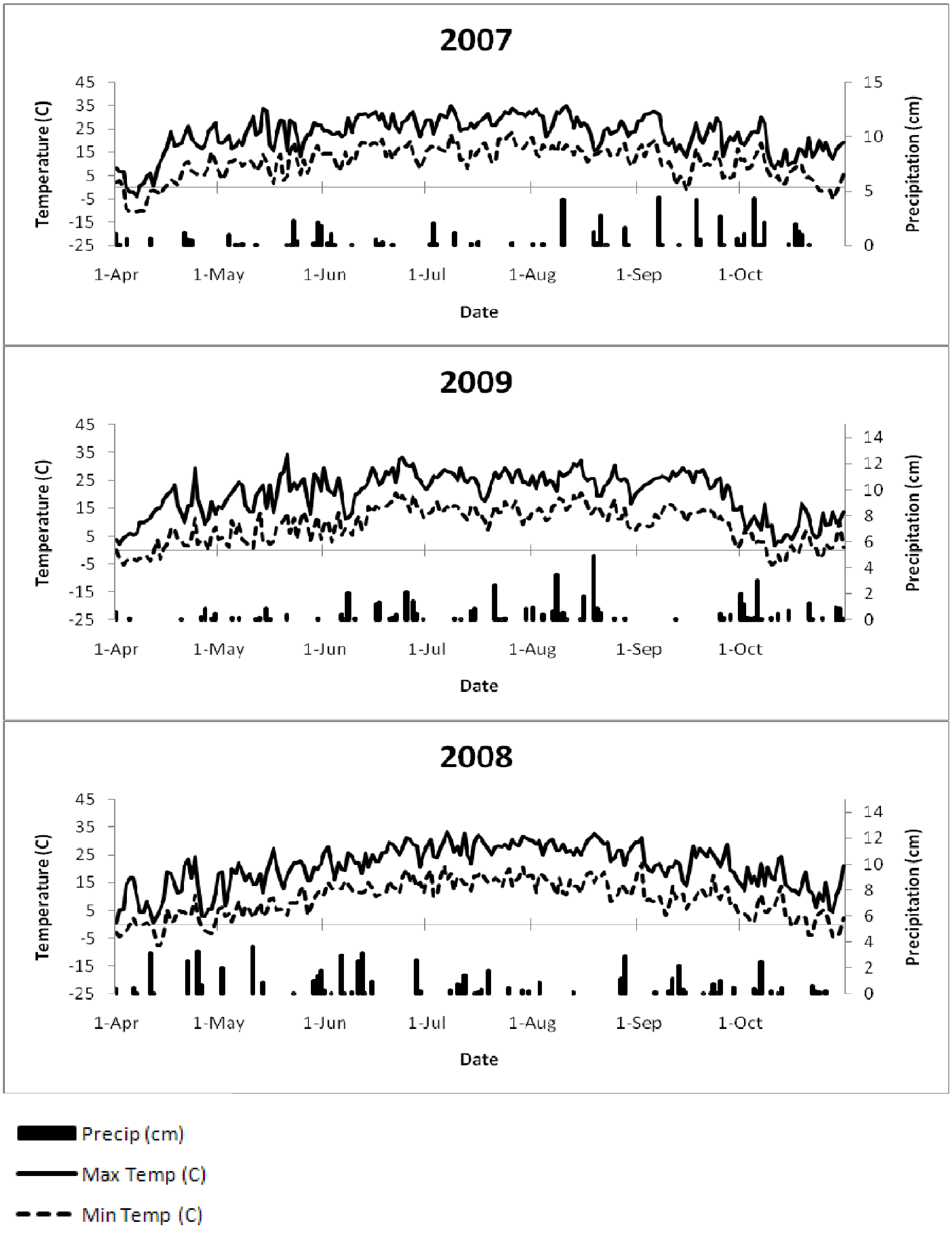

Figure 2.1. Minimum and maximum daily temperatures (C) and daily precipitation (cm) at Becker, MN from 1 April to 1 October for 2007, 2008, and 2009 (State Climatology Office, 2010).

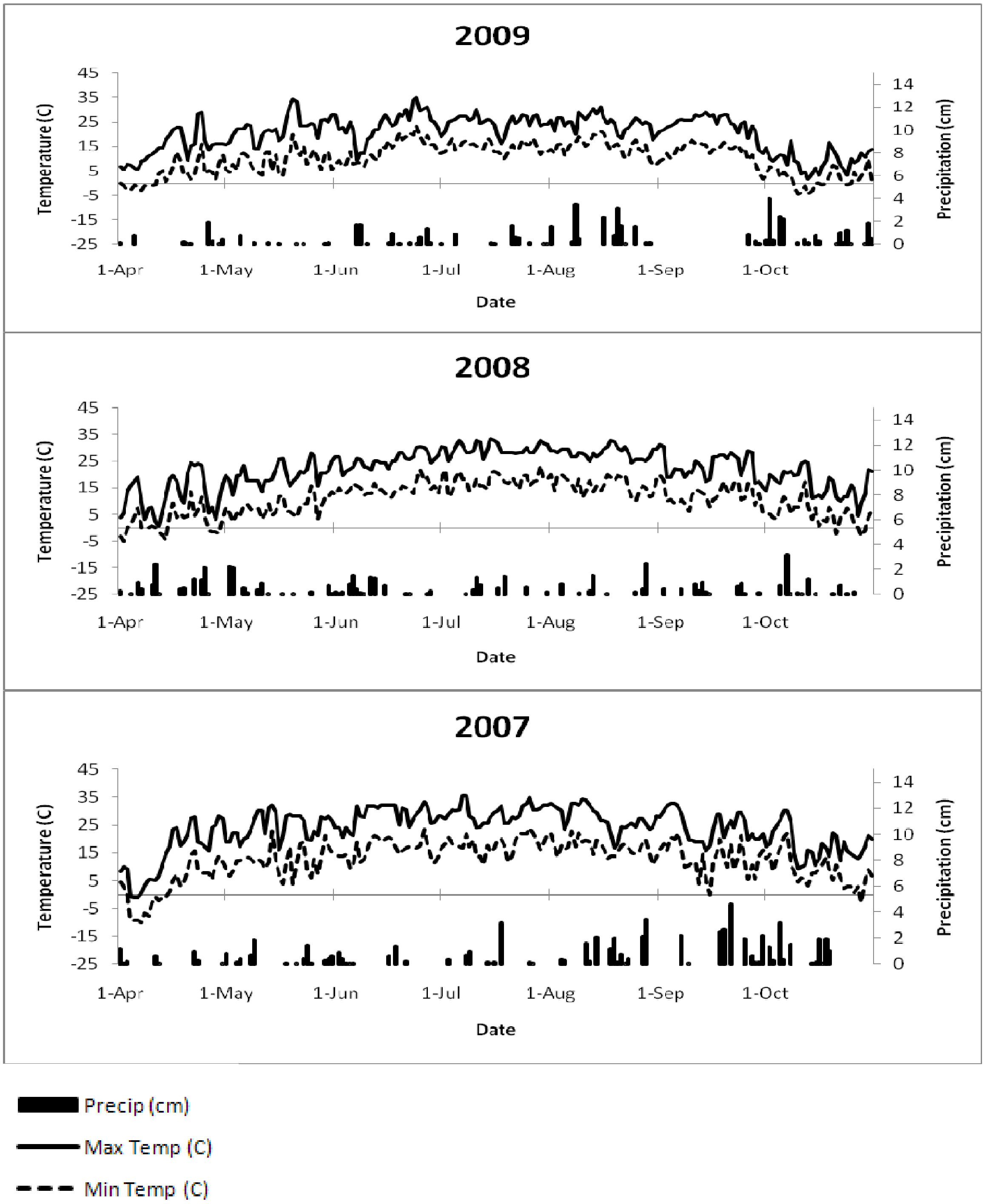

Figure 2.2. Minimum and maximum daily temperatures (C) and daily precipitation (cm) at St. Paul, MN from 1 April to 1 October for 2007, 2008, and 2009 (State Climatology Office, 2010).

Broad-Sense Heritability Estimates of Turfgrass Quality Characteristics in Native Prairie Junegrass Germplasm

INTRODUCTION

Native grass species, when utilized as low-input turfgrasses, offer many benefits that could address concerns about water use, sustainability, and increased turf management operating expenses (Diesburg et al., 1997). Low-maintenance turf often has lower visual and performance expectations than highly managed areas, and lower quality may be acceptable to the turf manager (Johnson, 2003). Hanks et al. (2005) suggested that acceptable turf quality is defined by color, leaf texture, density, and aesthetic appeal for the particular area in which it is grown. Low-input turf areas can include home lawns, roadsides, cemeteries, military installations, low-use parks and schools, or golf course roughs (Dernoeden et al., 1994b; Hanks et al., 2005). The low-input turf area must provide a uniform appearance, compete with unwanted species, and stabilize the soil (Dernoeden et al., 1994b; Diesburg et al., 1997).

Plant breeders have been evaluating and developing native and introduced grasses for use as low-input turf. The traditional turfgrasses are better adapted to high input areas, whereas native grasses perform better under lower traffic and at higher mowing heights (Johnson, 2008). Native grasses which have evolved under local conditions in North America are logical candidates for low-maintenance turf (Mintenko and Smith, 1999; Mintenko et al., 2002). Native species should be exploited in breeding programs for their adaptation to a broad range of soil and climate conditions (Willms et al., 2005) and their ability to withstand heat and drought stress with fewer irrigation needs (Johnson, 2000). Major obstacles in developing native grasses for turf include a poor tolerance to mowing, low seed production, and extended summer dormancy. Native accessions being developed as turf cultivars must also demonstrate limited growth, fine textured leaves, and quick recovery to damage from traffic and wear (Romani et al., 2002).

The native species buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] has been extensively studied and developed for use as a low-input turf. Its benefits include tolerance to mowing and a vigorous, stoloniferous growth habit which allows for a dense, uniform turf (Johnson, 2008). However, it requires more mowing than other species in both optimal and low-input treatments (Brede, 2002). Another potential limitation for this species is that as a warm-season grass, buffalograss may be dormant during cool temperatures which can limit its use in the northern United States (Johnson, 2003). Meyers and Pedersen (1999) evaluated buffalograss and the native warm-season blue grama (*Bouteloua gracilis* 'Alma' [Willd. Ex Kunth] Lag. ex Griffiths) as low input alternatives and found that neither provided acceptable cover, color, or quality. Other native grasses that have been evaluated for use as low-input turf include prairie junegrass (Watkins and Clark, 2009), sheep fescue (*Festuca ovina* L.) (McKernan et al., 2001), and tufted hairgrass [*Deschampsia caespitosa* (L.) P. Beauv.] (Watkins and Meyer, 2005). Very few native turfgrass cultivars have been developed.

For areas of the northern United Sates, the native cool-season grass, prairie junegrass, may provide earlier spring green-up and produce adequate turf stands earlier in the season than buffalograss. Found throughout the Northern Hemisphere, prairie junegrass is a native, perennial, short-grass prairie species that has several attributes that would make it useful as a low-input turfgrass. This species demonstrates drought tolerance (Milnes et al., 1998), has a flexible root system which allows it to adapt to water availability (Mueller-Dombois and Sims, 1966), is adapted to sandy soil (Pammell et al., 1901-1904), and survives at extreme temperatures (Dixon, 2000). This species is also slow growing (Dixon, 2000; Soovali and Bender, 2006) which could reduce mowing requirements.

The Estonian cultivar ‘Ilo’ (Soovali and Bender, 2006) and two Dutch cultivars ‘Barleria’ and ‘Barkoel’ released by Barenbrug Holland B.V. (Oosterhout, The Netherlands) (Alderson and Sharp, 1994) are the only cultivars of this species developed for use as turf and all were derived from European germplasm. ‘Barkoel’ was a top performer in turf quality compared to other native species in low-input turfgrass trials in Manitoba, Canada (Mintenko et al., 2002). In another low-input study, unimproved native prairie junegrass accessions displayed early spring green-up almost immediately following snow melt, sooner than many other species (Mintenko and Smith, 1999). This has also been observed in Minnesota (personal observation). This characteristic is highly desired in northern climates for improved aesthetics and early season play and sets this species apart from warm season native grasses. It is proposed that due to their local adaptation, North American prairie junegrass ecotypes can provide unique and beneficial traits to the breeding program.

The diverse natural range of this species provides plant breeders with a broad genetic base from which to select important turfgrass quality traits. Significant variation has been shown among 48 globally diverse National Plant Germplasm System (NPGS) accessions of prairie junegrass on important seed production characteristics(Clark and Watkins, 2010) and turf quality traits (Clark and Watkins, 2009).

Quantifying this variation will assist the breeder in choosing the appropriate characteristics, selection intensities, and mating designs to achieve top performing cultivars. It is important to evaluate the presence of genetic variability in the base population before initiating a selection program, as limited variability will lead to less significant gains over time (Surprenant and Michaud, 1988). Understanding the phenotypic variation of morphological and agronomic traits within a breeding population is crucial to the plant breeder in determining the potential application of the material, such as for turf (Wright et al., 1983).

Genetic variation and heritability estimates help predict the response to selection for desired traits (Dudley and Moll, 1969). Estimating heritability, which is the amount of phenotypic variation in a population due to genetic differences, is important in choosing appropriate traits for selection (Fehr, 1991). Selecting for characteristics with high broad-sense heritability will lead to faster and increased gains in the offspring than when selecting for traits with low heritability (Browning et al., 1994). Highly heritable traits could be correlated with important or complex traits, and these intereactions could be exploited by the plant breeder (Kenworthy et al., 2006).

The selection of material to advance in a breeding program can be based on the performance of the genotype *per se* as well as the performance of its relatives. Broad-sense heritabilities have been calculated for turfgrasses using replicated clones on both an individual plant basis as well as based on the performance of the clonal mean (Bokmeyer et al., 2009; Burton and DeVane, 1953).

In addition to evaluating individual genotypes, the performance of collection locations should be examined to elicit if any pooled set has greater genetic potential than the other materials in the study. Superior performance could be due to a significant combining ability, a high mean performance of desired traits, sufficient variation within the population, or high heritability. The objectives of this study were to (i) identify superior performing genotypes, (ii) estimate the genetic variation in native prairie junegrass collection locations; and (iii) calculate broad-sense heritability estimates for important turfgrass quality traits.

MATERIALS AND METHODS

Plant Materials

Prairie junegrass germplasm was collected as seed from five locations in western Nebraska and four locations in northeastern Colorado in July 2005. Each collection area was < 1.0 ha. In fall 2005, plants were grown from seed and planted into a nursery at the University of Minneosta-St. Paul Campus, St. Paul, MN. In June 2006, after seedhead emergence and prior to anthesis, plants from each collection site were potted-up, moved, and placed into individual, isolated crossing blocks (one block for each collection site). Plants were well watered to reduce stress. Plants within a crossing block were allowed to intercross, and seed was harvested from each plant individually. In 2006 seed was also collected from a small area (<1036 ha) in southeastern Minnesota. The Minnesota plant material was treated as its own crossing block as the plants were considered to be genetically similar. Seed collected in Minnesota was harvested from individual plants as was done with the isolated crossing blocks.

Seed was then germinated from each plant within a crossing block and from the Minnesota collection. A total of 300 genotypes were selected representing offspring from each maternal plant in a crossing block. Approximately 30 seedlings were chosen to represent each of the ten crossing blocks. The selected genotypes were vegetatively propagated to produce 10 clonal propagules each. Genotypes were labeled to indicate the origin of the material for example, an individual was labeled as “KC1-2a” where “KC” refers to the region (KC=Colorado, KN=Nebraska, and WD=Minnesota), “1” refers to the collection location within the region, “2” refers to the maternal plant in the crossing block, and “a” refers to the seedling. The Minnesota seedlings are labeled as “WD10-1”, where “10” refers to the maternal plant and “1” to the seedling.

On 20-21 June 2007, 300 genotypes were planted in a randomized complete block design consisting of five replications at two locations (University of Minnesota-St. Paul Campus, St. Paul, MN (44°59´23˝ N, 93°10´28˝ W), and the Sand Plains Agricultural Experiment Station, Becker, MN (45°23´47˝ N, 93°53´21˝ W)). Plants were transplanted into dead sod as spaced plants on 30.5 cm centers. The soil at St. Paul is a Waukegan silt loam (fine-silty over sandy, mixed, mesic Typic Hapludoll) with pH 6.5, and the soil at Becker is a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludoll) with pH 6.9. Fertilizer was applied at a rate of 24 kg ha^{-1}N, 48 kg ha^{-1} P_2O_5, and 24 kg ha^{-1} K_2O at the time of planting. At Becker, 0.635 cm of water was applied each week in two irrigation events. At St. Paul, an equivalent volume of water was applied each week with daily irrigation events. Irrigation was only provided at each location from the time of planting until August 21, 2007. Pendimethalin (LESCO, Cleveland, OH), a pre-emergent herbicide, was applied each spring to control weeds at a rate of 1.68 kg ha^{-1} active ingredient. Plots were weeded by hand or using hoes as needed throughout each growing season. Following establishment, plots were mowed to 6.4 cm weekly. In early spring 2009, plots were mowed twice weekly to remove emerging seedheads and to encourage vegetative growth.

Evaluation of Traits

Turfgrass characteristics including turf quality (overall uniformity, density, texture, color, etc.), density, texture, and color were evaluated on a 1-9 scale (9 = best rating for the specific trait) following the guidelines provided by National Turfgrass Evaluation Program (NTEP) (Morris and Shearman, 2008). Similarly, a 1-9 scale was utilized to score mowing quality (leaf shredding), spring green-up, inflorescence emergence, persistence of straw, and rust severity. Rust incidence (0=no infection, 1=infection) was also recorded in 2007 and 2009. Measurements were taken on the lateral spread (crown diameter in mm, 4 cm above the soil at the widest point) and vertical re-growth one week following mowing (longest leaf blade in mm) on 11 June 2009 at Becker and 15 June 2009 at St. Paul.

Analysis of Data

Analysis of variance was calculated for each variable to compare the mean performance by genotype, collection location, and/or collection region (i.e. state) using PROC GLM (SAS Institute, Cary, NC). Data were analyzed across environments (locations and years) and variances were estimated (Gordon et al., 1972). Means separation analyses (LSD) were performed on genotypic mean for each location. Means separation analyses was also performed on collection location means and on collection region means. Correlation coefficients were calculated among the turf quality traits using PROC CORR (SAS, 2002).

Broad-sense heritability estimates were calculated on an entry-mean basis from restricted maximum likelihood (REML) variance and covariance components using the random model of PROC MIXED (Bokmeyer et al., 2009; Bonos et al., 2004; Burton and DeVane, 1953; SAS, 2002). Broad-sense heritability was calculated on a clonal (Hc) basis as well as on a single-plant basis (Hsp) (Bokmeyer et al., 2009). The following models were used:

$$Hc = \sigma^2_c / (\sigma^2_c + \sigma^2_{cy}/y + \sigma^2_{cl}/l + \sigma^2_{cr(l)}/rl + \sigma^2_{cyl}/ly + \sigma^2_e/rly)$$

$$Hsp = \sigma^2_c / (\sigma^2_c + \sigma^2_{cy} + \sigma^2_{cl} + \sigma^2_{cr(l)} + \sigma^2_{cyl} + \sigma^2_e)$$

where σ^2_c = the total genetic variance of clones, σ^2_{cy} = clone x year variance, σ^2_{cl} = clone x location variance, $\sigma^2_{cr(l)}$ = clone x replication within location variance, σ^2_{cyl} = clone x year x location variance, and σ^2_e = experimental error (clone x year x replication within location). The denominators indicate the number of replications (5), replications within locations (10), locations (2), and years (2 or 3 depending on the trait evaluated) (Bokmeyer et al., 2009; Poehlman and Sleper, 1995).

RESULTS

Analysis of Genotypes

Traits were analyzed as a complete random block design (Table 3.1). Variance component estimates and descriptive statistics are shown for rust severity and incidence (2007), rust incidence (2009), inflorescence emergence, straw persistence, spring green-up, vertical re-growth (mm), and lateral spread (mm) (Table 3.2). Analysis of variance revealed significant variation for important turf quality traits (turf quality, density, mowing quality, and color) among the native prairie junegrass clones (Table 3.3). Means separation analysis was conducted on genotypic means and are shown for St. Paul

(Appendix D) and for Becker (Appendix E). Broad-sense heritability estimated from REML variance components on a clonal means basis were moderate for overall turf quality (H = 0.62) and three turf quality components: density (H = 0.55), mowing quality (H = 0.59), and color (H = 0.47) (Table 3.3). Utilizing clones replicated over multiple years and locations accounts for a significant amount of the genotype x environment variance thus removing it from the genetic variance (Bokmeyer et al., 2009; Burton and DeVane, 1953). The broad-sense heritability estimates based on a single plant were considerably lower: turf quality (H = 0.13), density (H = 0.09), mowing quality (H = 0.09), and color (H = 0.06).

Correlations were calculated among the turf quality traits for each of the experimental locations (Table 3.4). There was a strong correlation between average turf quality and density (Becker *r* = 0.73 and St. Paul *r* = 0.78). Average urf quality and spring green-up were significantly correlated at both locations (Becker *r* = 0.61 and St. Paul *r* = 0.46). At both Becker and St. Paul there was a strong correlation between turf quality and lateral spread (*r* = 0.69 and *r* = 0.53 respectively). Lateral spread and density were strongly correlated at both locations (Becker *r* = 0.49 and St. Paul *r* = 0.42). Mowing quality was not strongly correlated with any of the other traits. Color was moderately correlated with average turf quality. At Becker there was a significant negative correlation between density and the persistence of straw (*r* = -0.26) and a negative correlation between density and inflorescence emergence at both locations (Becker *r* = -0.38 and St. Paul *r* = -0.13). The rust incidence ratings taken in 2007 and 2009 were not significantly correlated at Becker, although there was a slight correlation between these traits at St. Paul (*r* = 0.15).

Analysis of Collection Location

Means separation analysis was conducted on the means of the ten collection locations (Table 3.5). There was a significant location effect for each of the traits ($P < 0.05$) (ANOVA not shown). The Minnesota collection location (WD) had the lowest severity for rust (2007) and lowest incidence of rust (2007 and 2009) at both locations. At Becker, the WD had a significantly higher rating for inflorescence emergence. This crossing block was also the tallest at both locations and had the lowest mowing quality rating. A collection location from Colorado (KC1) demonstrated the largest lateral spread at St. Paul (107.83 mm). This collection location also had the highest average turf quality rating at St. Paul and although ranking first at Becker, it did not differ significantly from several other collection locations at Becker.

Analysis by Collection Region

Means separation analysis was conducted by collection region (Table 3.6). There was a significant location effect for many of the traits ($P < 0.05$). At Becker, turf quality declined through 2009 growing season. The populations derived from Minnesota had the lowest incidence of rust in 2007 and 2009. At St. Paul there were no differences in inflorescence emergence. The persistence of straw was rated the highest for the Colorado region. Spring green-up was different between the locations with the Minnesota population having a higher rating at St. Paul, and Colorado and Nebraska populations having the higher rating at Becker. The Minnesota population had taller plants at both locations. At both locations, the Colorado population had the largest lateral spread, where as Minnesota had the smallest lateral spread.

The Colorado population had the overall best turf quality over years and locations, with the exception of Becker in 2009 where all populations performed similarly (data not shown). There was no difference in turf quality performance between Colorado and Nebraska at Becker, but Colorado did perform better than either Nebraska or Minnesota at St. Paul. At Becker, there was no difference in density or color among the populations. At St. Paul, the Colorado population had the best ratings for density and mowing quality.

DISCUSSION

The range of variation in the germplasm indicates that there is potential for developing prairie junegrass cultivars for use as a low-input turf. Under low-input conditions, a number of genotypes showed an average turf quality performance of 5.0 or higher (Appendices D and E). Moderate broad-sense heritability estimates were calculated for turf quality, density, mowing quality, and color. Improving overall turf quality in a breeding program is typically done through recurrent selection on multiple traits as most cultivars of cross-pollinated perennial grasses are typically bred to develop synthetic crosses or improved populations (De Araujo and Coulman, 2002). The strong correlation between turf quality and density, lateral spread, spring green-up, and color is promising for the breeder for increased gains in multi-trait selection for these important traits (Vogel et al., 1989). Multi-trait selection for turf quality and spring green-up could improve both of these traits simultaneously.

The germplasm in this study exhibited variation in crown density. Higher turf density reduces weed pressure and results in a uniform appearance. Plant density was influenced by environmental factors including: crown damage from mowing and freezing, and by genetic factors including tiller die-out after flowering, growth habit, and plant architecture. The long-term perenniality of this species is not known, although when grown as un-mown plant, center die-off was apparent at 6-7 years (Looman, 1978). At Becker, the strong negative correlations between both inflorescence emergence and density and straw persistence and density suggests that flowering in this location resulted in more tiller die-out. In low-input settings, a flowering turf may be acceptable if it does not affect the overall season's turf quality.

The moderate clonal broad-sense heritability estimate on mowing quality in our study suggests that direct phenotypic selection for this trait should result in significant gains. Early studies of prairie junegrass in low-input trials indicated that improving poor mowing quality would be necessary. The shredding of leaf tips, which is attributed to tough vascular bundles, has been observed in some perennial ryegrass cultivars and gives the mowed surface an unacceptable appearance (Turgeon, 2005). Mowing quality was not strongly correlated with any of the other traits in this study. Mowing quality was based on the 6.4 cm mowing height, and thus plants that were shorter than this height would have received a higher mowing quality rating. A benefit to these very low and/or slow growing plants is that they could be utilized in developing cultivars that would have very reduced mowing requirements.

The broad-sense heritability estimate for color, which was only calculated from two years of data, is biased upward due to underlying genotype x environment variance that was not accounted for (Poehlman and Sleper, 1995). Genetic color of this species ranges from blue-gray to blue-green to greenish-yellow to dark green. The NTEP guidelines for rating genetic color are not well suited for this species as there is no accepted standard from which to judge. A more appropriate rating would be to categorize the genotypes using a Munsell-type color chart. Alternatively, the use of digital image analysis has been shown to be an accurate way of quantifying color ratings and can improve heritability estimates (Karcher and Richardson, 2003). Color ratings may be further influenced by disease symptoms and shredded leaf tissue. At Becker there was a negative correlation between color and rust in 2007 (incidence and severity). The rust spores change the color of leaf tissue, and the disease may induce stress that also causes plants to undergo a color change. Other stressors or seasonal leaf senescence may also be involved in color changes to hues of red, orange, yellow, and purple.

Lateral spread and vertical re-growth were measured as indicators of plant vigor and were correlated at both locations on an individual genotype basis. However, on a collection region basis, the largest vertical regrowth was for the Minnesota population which had the smallest lateral spread. Multiple trait selection on lateral spread, density, and turf quality is important as they are essential components of an adequately covered and uniform turf stand. Data on plant vertical re-growth was useful in identifying lower growing genotypes but did not give a better understanding of plant vigor. The poor mowing quality made it difficult to consistently identify individual leaf blades which had been mown the prior week. Other plants in the study were slow growing and may not have been mown at all.

An unknown *Puccinia* species caused rust disease symptoms on a number of genotypes. Prairie junegrass is known to be susceptible to *P. graminis* (Looman, 1978) and *P. koeleriae* (Mains, 1933). Infection was first observed in August and persisted each fall. Continuous distribution of rust incidence across the collection locations suggests that resistance is quantitatively inherited (Bokmeyer et al., 2009). There was less incidence of rust and a lower severity of disease symptoms in germplasm collected from Minnesota showing local adaptation of resistance to the presence of local rust populations. The low correlation between rust incidence in 2007 and 2009 at St. Paul and a lack of any correlation at Becker suggests that different rust species or races may have been present in either year or location. Multiple locations should be utilized to screen the germplasm for identifying resistant material.

CONCLUSION

Broad-sense heritability on clonal means only provides an estimate for the specific germplasm in the study (i.e. the clones) in these environments (Dudley and Moll, 1969). Because broad-sense heritability accounts for all genetic effects (additive, dominant, and epistatic), this should be the maximum heritability expected when selection is based on clonal replications (Bokmeyer et al., 2009). Improvement on phenotyping accuracy could improve heritability estimates by reducing error variation.

The low broad-sense heritability estimates based on single plants indicates that selection based on non-replicated plants in only one environment would not be efficient in improving any of the traits. The moderate broad-sense heritability estimates on clonal means suggest that environment does play a significant role in these traits and that multiple replications in several environments (locations and/or years) should be utilized in screening and selecting superior genotypes.

Breeding progress can be expected in the material evaluated in this study as significant genetic variability for desired traits was observed. The moderate broad-sense heritability estimates on turf quality, color, density, and mowing quality suggest that significant gains are possible for these traits. Multi-trait selection will be a useful tool as strong positive correlations were found among many of the traits.

Table 3.1. Expected means squares from ANOVA for data over locations for genotypes of prairie junegrass.

Sources of variation	df	Mean Squares	Expected mean squares†
Location	l-1	M1	$\sigma^2 + r\sigma^2_{gl} + rg\sigma^2_l$
Replications (Loc)	l(r-1)	M2	$\sigma^2 + g\sigma^2_r$
Genotypes	g-1	M3	$\sigma^2 + r\sigma^2_{gl} + rl\sigma^2_g$
Genotype*Location	(g-1)(l-1)	M4	$\sigma^2 + r\sigma^2_{gl}$
Error	l(g-1)(r-1)	M5	σ^2

† r, replications; g, genotypes; l, locations.

Table 3.2. Variance component estimates and descriptive statistics for turfgrass quality traits of native prairie junegrass genotypes grown at Becker and St. Paul, MN.

	Variance estimates							
Source	Rust severity 2007†	Rust incidence 2007‡	Rust incidence 2009‡	Inflor.§	Straw persistence¶	Spring green-up#	Vertical re-growth (mm) ††	Lateral spread (mm)††
Location	6.18 ± 4.12	0.39 ± 0.26	0.00 ± 0.00	0.24 ± 0.16	0.03 ± 0.02	2.12 ± 1.41	242.82 ± 161.88	426.43 ± 284.35
Genotypes	0.30 ± 0.02	0.00 ± 0.00	0.07 ± 0.00	0.30 ± 0.01	0.11 ± 0.00	0.13 ± 0.00	32.16 ± 26.24	50.71 ± 288.28
Genotype*Location	1.57 ± 0.03	0.00 ± 0.00	0.01 ± 0.00	0.72 ± 0.01	0.16 ± 0.00	0.42 ± 0.00	5.42 ± 19.34	127.02 ± 399.13
Replication(Location)	0.05 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.00	0.01 ± 0.00	0.15 ± 0.00	66.08 ± 893.18	133.72 ± 3675.91
Error	2.48 ± 0.01	0.05 ± 0.00	0.16 ± 0.00	2.85 ± 0.01	0.89 ± 0.00	1.67± 0.00	225.44 ± 49.51	555.57 ± 301.28
Mean	3.01	0.49	0.50	7.14	5.30	5.16	86.23	83.83
Min.	1	0	0	1	1	1	1	2
Max.	9	1	1	9	9	9	190	219

† Rust severity was rated at Becker (9/9/07) and at St. Paul (8/30/07) using a 1-9 scale (9 = least disease symptoms).

‡ Rust incidence was rated at Becker (9/9/07) and at St. Paul (8/30/07) as 0 = no infection, 1 = infection. Rust incidence was rated at Becker (9/3/09) and at St. Paul (9/24/09) as 0 = no infection, 1 = infection.

§ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size visually (9 = fewest inflorescences).

¶ Straw persistence was visually rated on a 1-9 scale as the proportion of straw and inflorescence debris present two weeks after the inflorescence rating, after mowing (9 = least amount of straw and/or debris).

Spring green-up was visually rated Becker (4/24/09) and at St. Paul (4/25/09) on a 1-9 scale (9 = darkest green color).

†† Vertical re-growth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing at 6.4 cm. Lateral spread measured as the diameter of the crown at its widest point at a height of 4 cm.

Table 3.3. Analysis of variance and broad-sense heritability estimates (Hc clonal mean, Hsp single plant) of turf quality, density, mowing quality, and color of 300 prairie junegrass clones grown at Becker and St. Paul, MN over three years (2007-2009).

	Turf quality†					Density‡				
	df	MS	F value	*P* value	Var. comp. §	df	MS	F value	*P* value	Var. comp.
Year	2	118.22	298.54	<.0001		2	1958.12	3153.26	<.0001	
Location	1	833.19	2103.99	<.0001		1	355.65	572.73	<.0001	
Replication (location)	8	3.6	9.09	<.0001		8	7.25	11.67	<.0001	
Year x location	2	153.81	388.39	<.0001		2	237.69	382.76	<.0001	
Year x replication(location)	16	2.23	5.63	<.0001		16	3.94	6.35	<.0001	
Clone	299	4.29	10.82	<.0001	0.0957	299	5.2	8.37	<.0001	0.1014
Year x clone	598	1.05	2.65	<.0001	0.0295	598	1.9	3.05	<.0001	0.0476
Location x clone	299	1.43	3.61	<.0001	0.0222	299	2.04	3.29	<.0001	0.012
Year x location x clone	595	0.82	2.07	<.0001	0.0812	590	1.47	2.37	<.0001	0.1681
Clone x replication(location)	2339	0.7	1.77	<.0001	0.0949	2324	1.03	1.67	<.0001	0.1286
Error		0.4			0.4156		0.62			0.6448
	Hc#	0.62				Hc	0.55			
	Hsp	0.13				Hsp	0.09			

	Mowing quality††					Color‡‡				
	df	MS	F value	*P* value	Var. comp.	df	MS	F value	*P* value	Var. comp.
Year	2	373.49	274.04	<.0001		1	1603.64	3673.63	<.0001	
Location	1	488.94	358.76	<.0001		1	148.86	341.02	<.0001	
Replication (location)	8	14.18	10.41	<.0001		8	7.04	16.12	<.0001	
Year x location	2	376.33	276.13	<.0001		1	332.17	760.94	<.0001	
Year x replication(location)	16	7.43	5.45	<.0001		8	2.69	6.16	<.0001	
Clone	299	6.85	5.02	<.0001	0.1604	299	2.16	4.94	<.0001	0.039
Year x clone	598	2.65	1.94	<.0001	0.0847	299	1.31	2.99	<.0001	0.0637
Location x clone	299	2.22	1.63	<.0001	0.0276	299	0.79	1.8	<.0001	0.0006
Year x location x clone	573	1.96	1.43	<.0001	0.1203	298	0.72	1.64	<.0001	0.064
Clone x replication(location)	2317	1.63	1.2	<.0001	0	2319	0.48	1.09	0.0177	0.0142
Error		1.36			1.4626		0.04			0.4432
	Hc	0.59				Hc	0.45			
	Hsp	0.09				Hsp	0.06			

† Turf quality ratings were taken at least twice monthly and averaged for each year on a 1-9 scale (9 = best quality).

‡ Density was rated once in 2007, and twice each year after, using a 1-9 scale (9 = highest crown density).

§ Variance components were determined using restricted maximum likelihood estimation (REML) using PROC MIXED in SAS.

¶ Broad-sense heritability was determined from variance components using the following equations:

$Hc = \sigma^2_c / (\sigma^2_c + \sigma^2_{cy}/y + \sigma^2_{cl}/l + \sigma^2_{cr(l)}/rl + \sigma^2_{cyl}/ly + \sigma^2_e/rly)$ and $Hsp = \sigma^2_c / (\sigma^2_c + \sigma^2_{cy} + \sigma^2_{cl} + \sigma^2_{cr(l)} + \sigma^2_{cyl} + \sigma^2_e)$, where c = cultivar, y = year, l = location, r = replication, and e = error.

†† Mowing quality was rated once in 2007 and two times in 2008 and 2009 on a 1-9 scale (9 = best quality, least shredding).

‡‡ Color was rated once in 2008 and once in 2009 using a relative 1-9 scale (9 = darkest green plant in the study).

Table 3.4. Correlation coefficients among several turf quality characteristics of prairie junegrass accessions at St. Paul, MN above and Becker, MN below.

	Rust severity 2007†	Rust incidence 2007‡	Inflor. §	Straw persistence §	Spring green-up ¶	Vertical re-growth (mm)#	Lateral spread (mm)#	Rust inc. 2009‡	Average turf quality ††	Density ‡‡	Mowing quality §§	Color ¶¶¶
Rust severity 2007		0.37***	-0.02NS	0.07**	-0.03NS	-0.08**	0.07**	0.33***	0.05NS	0.10***	0.16***	0.03NS
Rust inc. 2007	0.89***		-0.03NS	0.04NS	-0.05NS	-0.07**	0.04NS	0.15***	0.07**	0.08**	0.04NS	0.01NS
Inflorescence	-0.15***	-0.12***		0.41***	0.01NS	0.00NS	-0.01NS	-0.01NS	0.04NS	-0.13***	0.06*	-0.05*
Straw persistence	0.12***	0.09***	0.29***		0.02NS	-0.03NS	0.05*	0.06*	0.14***	-0.03NS	-0.00NS	-0.03NS
Spring green-up	-0.03NS	-0.04NS	-0.00NS	0.07*		0.31***	0.49***	0.02NS	0.46***	0.38***	-0.08**	0.05*
Height (mm)	-0.08**	-0.06*	0.00NS	0.02NS	0.37***		0.21***	-0.01NS	0.13***	0.10***	-0.23***	0.04NS
Lateral sp, (mm)	-0.07**	-0.08**	-0.06*	0.09**	0.61***	0.36***		0.09***	0.53***	0.42***	-0.10***	0.04NS
Rust inc. 2009	0.02NS	0.03NS	-0.08**	0.00NS	-0.20***	-0.11***	-0.09**		0.25***	0.26***	0.20***	0.09***
Average turf quality	-0.17***	-0.14***	-0.21***	-0.03NS	0.61***	0.30***	0.69***	0.03NS		0.78***	0.11***	0.20***
Density	-0.13***	-0.11***	-0.38***	-0.26***	0.31***	0.25***	0.49***	0.02NS	0.73***		0.08***	0.22***
Mowing quality	.08**	.07**	-.02NS	-0.04NS	-0.18***	-0.22***	-0.13***	0.18***	-0.01NS	0.01NS		0.01NS
Genetic color	-0.30***	-0.24***	-0.28***	-0.09***	0.05NS	0.10***	0.09**	0.02NS	0.27***	0.28***	0.02NS	

*, **, *** Significant at the 0.05, 0.01, and 0.001 levels, respectively.

† Rust severity was rated at Becker (9/9/07) and at St. Paul (8/30/07) using a 1-9 scale (9 = least disease symptoms).

‡ Rust incidence was rated at Becker (9/9/07) and at St. Paul (8/30/07) as 0 = no infection, 1 = infection. Rust incidence was rated at Becker (9/3/09) and at St. Paul (9/24/09) as 0 = no infection, 1 = infection.

§ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size visually (9 = fewest inflorescences). Straw persistence was visually rated on a 1-9 scale as the proportion of straw and inflorescence debris present two weeks after inflorescence rating, after mowing (9 = least amount of straw and/or debris).

¶ Spring green-up was visually rated at Becker (4/24/09) and at St. Paul (4/25/09) on a 1-9 scale (9 = darkest green color).

Vertical re-growth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing at 6.4 cm.

Lateral spread (mm) was measured as the diameter of the crown at its widest point at a height of 4 cm.

†† Turf quality was rated twice monthly visually using a 1-9 scaled (9 = best turf quality) and averaged over years (2007-2009).

‡‡ Density was rated once during establishment, and twice each year after, using a 1-9 scale (9 = highest crown density).

§§ Mowing quality was rated once in 2007 and two times in 2008 and 2009 on a 1-9 scale (9 = best quality, least shredding).

¶¶¶ Color was rated visually using a relative 1-9 scale (9 = darkest green plant in the study).

Table 3.5. Mean separation analysis of selected turf quality characteristics of prairie junegrass collection locations (KC-Colorado, KN-Nebraska, WD-Minnesota) grown in low input conditions and mowed weekly from 2007-2009 at Becker and St. Paul, MN.

	Rust severity 2007†		Rust incidence 2007‡		Rust incidence 2009‡		Inflorescence§	
	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
KC1	1.09	5.68	0.03	0.97	0.72	0.76	3.8	3.40
KC3	1.15	4.39	0.04	0.92	0.48	0.59	2.93	2.21
KC4	1.37	5.80	0.07	0.93	0.72	0.69	3.27	2.20
KC5	1.48	5.20	0.10	0.97	0.55	0.57	3.36	2.69
KN1	1.09	4.05	0.02	0.93	0.54	0.39	2.87	2.40
KN2	1.21	5.97	0.05	0.98	0.60	0.56	2.83	2.36
KN3	1.07	5.01	0.02	0.95	0.56	0.49	2.68	2.10
KN4	1.21	4.11	0.04	0.91	0.36	0.25	2.48	2.44
KN5	1.47	5.35	0.10	0.97	0.57	0.59	3.23	2.99
WD	1.00	2.13	0.00	0.81	0.14	0.07	4.51	2.55
LSD (0.05)	0.25	0.58	0.05	0.05	0.12	0.11	0.54	0.34

	Straw persistence§		Spring green-up¶		Vertical re-growth (mm) #		Lateral spread (mm) #	
(continued)	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
KC1	5.99	5.46	3.58	6.07	66.52	92.82	65.50	107.83
KC3	5.51	5.25	4.10	6.57	72.39	96.84	72.32	102.60
KC4	5.15	5.14	3.29	5.76	72.82	92.93	56.61	92.78
KC5	5.84	5.26	3.47	6.31	68.85	97.84	60.46	102.32
KN1	5.66	5.11	4.20	6.24	73.84	100.41	80.73	102.50
KN2	5.30	5.14	3.36	5.87	70.03	95.96	57.08	94.50
KN3	4.84	4.99	3.86	6.07	69.12	96.75	61.70	93.49
KN4	5.28	4.89	4.72	6.44	70.56	92.44	69.78	95.25
KN5	5.65	5.42	3.99	6.66	75.40	100.25	66.59	101.53
WD	5.18	5.09	4.53	5.66	86.91	106.79	72.15	85.11
LSD (0.05)	0.27	0.21	0.40	0.32	3.46	4.02	7.58	5.50

	Turf quality††		Density‡‡		Mowing quality§§		Color¶¶	
(continued)	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
KC1	4.01	5.12	4.90	5.60	5.43	5.15	4.71	5.60
KC3	4.01	4.82	4.99	5.27	5.17	4.78	5.13	5.27
KC4	3.85	4.50	4.87	5.11	5.44	4.62	5.07	5.11
KC5	3.81	4.81	4.74	5.34	5.42	4.85	4.95	5.34
KN1	3.94	4.57	4.95	5.16	4.84	4.13	5.08	5.16
KN2	3.45	4.34	4.58	4.96	5.13	4.30	4.94	4.96
KN3	3.85	4.47	4.95	5.14	5.23	4.41	5.05	5.14
KN4	3.91	4.36	4.75	4.88	5.17	4.73	4.78	4.88
KN5	3.84	4.63	4.81	5.22	4.99	4.17	4.94	5.22
WD	3.66	4.15	4.77	4.63	4.24	3.53	4.98	4.46
LSD (0.05)	0.18	0.12	0.21	0.13	0.22	0.15	0.14	0.12

† Rust severity was rated at Becker (9/9/07) and at St. Paul (8/30/07) using a 1-9 scale (9 = least disease symptoms).

‡ Rust incidence was rated at Becker (9/9/07) and at St. Paul (8/30/07) as 0 = no infection, 1 = infection. Rust incidence was rated at Becker (9/3/09) and at St. Paul (9/24/09) as 0 = no infection, 1 = infection.

§ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size visually (9 = fewest inflorescences). Straw persistence was visually rated on a 1-9 scale as the proportion of straw and inflorescence debris present two weeks after inflorescence rating, after mowing (9 = least amount of straw and/or debris).

¶ Spring green-up was visually rated at Becker (4/24/09) and at St. Paul (4/25/09) on a 1-9 scale (9 = darkest green color).

Vertical re-growth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing at 6.4 cm. Lateral spread (mm) was measured as the diameter of the crown at its widest point at a height of 4 cm.

†† Turf quality was rated twice monthly visually using a 1-9 scaled (9 = best turf quality) and averaged over years (2007-2009).

‡‡ Density was rated once during establishment, and twice each year after, using a 1-9 scale (9 = highest crown density).

§§ Mowing quality was rated once in 2007 and two times in 2008 and 2009 on a 1-9 scale (9 = best quality, least shredding).

¶¶ Color was rated visually using a relative 1-9 scale (9 = darkest green plant in the study).

Table 3.6. Mean separation analysis of selected turf quality characteristics of prairie junegrass collection locations pooled by collection region (Colorado, Nebraska, Minnesota) at Becker and St. Paul, MN grown in low input conditions and mowed weekly from 2007-2009.

	Rust severity 2007†		Rust incidence 2007‡		Rust incidence 2009‡		Inflorescence§	
	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
Colorado	1.28	5.28	0.06	0.95	0.61	0.65	3.35	2.64
Nebraska	1.21	4.90	0.04	0.95	0.52	0.46	2.82	2.45
Minnesota	1.00	2.13	0	0.81	0.14	0.07	4.51	2.55
LSD 0.05	0.17	0.41	0.03	0.04	0.08	0.07	0.37	0.24
	Straw persistence§		Spring green-up¶		Vertical re-growth (mm) #		Lateral spread (mm) #	
	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
Colorado	5.63	5.28	3.64	6.18	70.1	95.15	72.15	101.56
Nebraska	5.34	5.11	4.03	6.25	71.67	97.11	67.48	97.39
Minnesota	5.18	5.09	4.53	5.66	86.91	106.79	64.23	85.11
LSD 0.05	0.19	0.15	0.27	0.23	2.34	2.79	5.18	3.84
	Turf quality††		Color‡‡		Mowing quality§§		Density¶¶	
	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
Colorado	3.92	4.82	4.98	4.78	5.37	4.85	4.87	5.33
Nebraska	3.80	4.47	4.96	4.76	5.07	4.35	4.81	5.07
Minnesota	3.66	4.15	4.96	4.46	4.24	3.53	4.77	4.63
LSD 0.05	0.13	0.08	0.1	0.08	0.16	0.11	0.14	0.1

† Rust severity was rated at Becker (9/9/07) and at St. Paul (8/30/07) using a 1-9 scale (9 = least disease symptoms).

‡ Rust incidence was rated at Becker (9/9/07) and at St. Paul (8/30/07) as 0 = no infection, 1 = infection. Rust incidence was rated at Becker (9/3/09) and at St. Paul (9/24/09) as 0 = no infection, 1 = infection.

§ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size visually (9 = fewest inflorescences). Straw persistence was visually rated on a 1-9 scale as the proportion of straw and inflorescence debris present two weeks after inflorescence rating, after mowing (9 = least amount of straw and/or debris).

¶ Spring green-up was visually rated at Becker (4/24/09) and at St. Paul (4/25/09) on a 1-9 scale (9 = darkest green color).

Vertical re-growth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing at 6.4 cm.
Lateral spread (mm) was measured as the diameter of the crown at its widest point at a height of 4 cm.

†† Turf quality was rated twice monthly visually using a 1-9 scaled (9 = best turf quality) and averaged over years (2007-2009).

‡‡ Color was rated visually using a relative 1-9 scale (9 = darkest green plant in the study).

§§ Mowing quality was rated once in 2007 and two times in 2008 and 2009 on a 1-9 scale (9 = best quality, least shredding).

¶¶ Density was rated once during establishment, and twice each year after, using a 1-9 scale (9 = highest crown density).

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APPENDIX A

Means separation analysis of seed production characteristics of prairie junegrass germplasm accessions harvested in 2008 at Becker, MN.

Accession	Winter Survival†	Density†	SHE date‡	Anthesis date‡	Height (cm)§	Seedheads	SHL (mm)¶	Seed Yield (g)	Harvest date‡
18194	6.5	5.7	24.8	9.2	57.4	74.9	58.4	2.7	1.5
19186	4.3	4.6	37.1	21.7	49.5	75.6	57.7	4.1	17.6
19198	5.1	5.2	36.3	22.7	50.6	50.3	64.0	3.3	16.5
21169	7.1	6.4	32.0	15.9	63.4	91.2	80.5	5.1	8.6
21268	7.9	7.1	27.1	9.6	63.6	121.1	62.6	6.0	3.4
21380	9.0	8.1	27.5	9.6	58.1	204.4	59.7	10.1	3.3
21553	7.5	6.8	29.9	13.0	62.9	105.6	69.7	5.3	7.3
23304	9.0	7.2	24.1	9.0	73.8	171.7	85.2	13.5	2.1
24110	3.9	4.1	36.8	22.5	46.8	38.5	67.8	1.6	17.3
204451	4.2	4.1	34.6	20.0	45.2	31.2	67.0	1.0	17.4
204452	8.0	6.7	34.6	15.8	64.7	80.5	93.5	4.5	12.1
229463	7.7	6.3	33.1	13.6	75.7	112.8	106.3	7.3	8.8
230256	4.4	4.0	30.0	13.0	46.1	6.0	65.0	0.0	10.0
230267	3.1	4.3	31.5	14.7	45.9	14.2	59.4	0.2	11.3
250651	1.1	1.0	44.0	13.0	38.0	1.0	68.0	0.0	15.0
255364	7.4	6.1	28.0	10.5	63.5	55.5	81.3	3.2	5.6
312456	7.4	6.2	28.3	10.4	69.0	102.7	75.7	5.7	5.0
314377	8.6	7.1	26.3	9.4	74.8	147.4	82.8	8.3	5.0
314378	7.9	6.4	25.7	9.1	65.8	134.1	77.1	6.3	6.9
314440	4.3	4.5	27.7	11.6	58.0	44.9	72.3	1.9	7.4
314700	6.9	5.7	28.8	11.5	57.2	27.5	57.8	1.0	7.6
383672	3.6	4.5	36.6	21.5	43.6	50.8	59.3	1.8	16.8
383673	4.7	5.4	39.5	22.4	46.0	55.2	57.8	1.7	17.0
383674	3.2	3.7	34.5	18.7	41.3	34.3	66.7	0.9	14.8
383675	3.0	3.3	30.6	13.8	47.3	16.6	65.1	0.1	12.8
387927	8.3	7.0	28.9	12.2	49.0	69.5	66.4	4.7	9.8
410152	1.6	7.0	23.0	9.0	76.2	164.0	88.3	1.3	2.0
430287	7.5	6.9	38.0	17.5	41.6	89.3	47.5	2.6	15.2
440451	8.4	6.8	25.3	9.0	70.4	166.6	75.4	9.2	3.8

440454	8.6	7.2	25.6	9.5	69.5	152.8	82.5	12.0	5.9
440455	8.0	6.1	27.0	9.5	70.1	100.3	73.9	6.6	5.1
440456	6.4	5.4	30.3	17.3	59.7	21.0	78.8	1.1	13.5
477978	1.9	2.4	41.8	19.9	61.7	8.8	109.0	0.3	14.7
502389	7.2	6.3	30.4	14.1	83.5	71.8	86.9	4.1	12.4
502390	8.4	6.5	27.3	9.5	71.4	104.7	76.9	7.5	3.4
502391	9.0	7.3	24.4	9.0	72.1	162.8	72.7	7.7	2.5
502393	8.5	7.3	24.5	9.0	69.9	141.7	75.6	6.6	4.9
502394	8.6	7.4	26.9	9.3	85.3	184.9	67.8	10.1	4.5
502395	8.1	7.1	28.2	9.9	72.2	214.1	77.7	9.4	3.7
532937	2.5	4.3	29.3	9.0	47.7	8.8	68.8	0.1	3.0
538968	7.3	6.2	34.0	17.3	72.3	55.2	89.3	4.7	11.5
538972	8.0	7.8	29.1	11.1	56.3	249.6	62.0	10.7	8.0
538975	7.3	5.7	27.2	10.8	62.2	128.2	78.9	7.0	5.8
568184	4.1	4.7	38.0	21.5	45.8	35.8	56.9	2.0	18.8
618749	8.2	8.1	27.1	11.1	59.7	166.0	67.4	8.4	3.2
619546	8.0	7.1	26.5	9.1	46.5	175.7	60.0	7.5	4.1
636566	6.1	6.5	37.9	22.8	44.7	139.9	79.4	8.8	18.1
639190	7.9	7.4	37.6	21.9	69.6	186.5	93.2	20.1	14.6
LSD (0.05)	1.25	1.13	2.86	2.02	13.41	73.45	18.08	3.29	4.12

† Winter survival and density were rated on a 1-9 scale (9 = best survival or density) in early spring 2008.

‡ Seedhead emergence date (SHE) was days after 01 May when a plant had 3 or more inflorescences beyond the boot stage; Anthesis date was recorded as days after 01 June when a plant had 3 or more inflorescences exhibiting anthesis; and Harvest date was recorded as days aver 01 July when an individual plant was harvested.

§ Height (cm) was an average height of 3 randomly selected culms, measured from the soil to the tip of the inflorescence.

¶ Seedhead length (mm) was an average length of 3 randomly selected inflorescences after drying.

APPENDIX B

Means separation analysis of seed production characteristics of prairie junegrass germplasm accessions harvested in 2008 at St. Paul, MN.

Accession	Winter Survival†	Density†	SHE date‡	Anthesis date‡	Height (cm)§	Seedheads	SHL (mm)¶	Seed Yield (g)	Harvest date‡
18194	7.3	4.9	27.4	8.2	33.6	13.7	34.0	0.3	2.3
19186	7.4	5.4	35.9	20.0	33.8	18.3	43.3	0.8	17.1
19198	8.6	6.0	35.2	19.3	39.4	24.0	50.0	0.9	16.1
21169	5.2	5.0	33.7	13.7	29.4	13.6	50.1	0.2	10.1
21268	7.7	5.4	27.2	9.2	29.6	12.5	36.1	0.3	3.7
21380	7.7	5.5	28.2	9.2	32.0	11.2	36.7	0.1	1.5
21553	6.7	5.5	30.7	11.9	41.0	17.9	43.4	0.6	5.1
23304	8.6	5.9	25.8	7.9	37.9	28.3	43.9	1.4	3.4
24110	8.3	5.6	36.3	20.3	38.5	9.6	49.5	0.2	15.6
204451	7.1	5.5	33.8	18.0	31.8	43.0	50.4	1.7	17.6
204452	8.8	6.8	35.1	12.8	46.5	60.6	71.8	2.9	11.8
229463	8.5	6.7	34.3	12.0	47.6	45.4	76.4	2.4	7.9
230256	8.6	6.1	30.5	12.5	35.6	8.0	44.4	0.0	10.8
230267	5.8	4.7	33.0	14.5	31.0	14.0	34.0	0.1	13.0
250651	7.5	5.3	28.9	12.0	31.9	14.8	40.3	0.2	6.5
255364	6.8	5.1	30.1	9.9	36.3	28.7	44.8	0.9	7.1
312456	7.8	5.7	29.3	11.0	38.5	40.0	50.0	1.2	4.8
314377	8.2	5.8	26.3	8.8	35.9	48.9	50.2	1.3	4.1
314378	7.3	4.9	26.1	7.1	36.8	29.5	43.6	1.0	3.1
314440	7.5	5.3	29.0	9.4	34.5	40.1	45.5	1.3	5.0
314700	7.8	5.1	26.4	9.2	33.6	14.2	44.0	0.5	3.8
383672	7.2	5.8	37.4	20.4	33.4	15.7	42.6	0.3	16.9
383673	8.0	6.6	37.0	20.7	30.2	22.3	46.8	0.6	15.6
383674	8.7	6.6	34.4	17.8	32.4	18.5	48.7	0.6	15.4
383675	7.0	5.1	31.5	13.6	32.6	14.3	37.2	0.3	12.6
387927	5.5	4.5	34.7	12.6	26.0	15.2	45.0	0.2	10.7
410152	5.4	5.6	40.6	19.8	52.7	38.3	64.2	1.3	13.9
430287	4.8	4.8	36.4	18.7	10.5	6.7	29.3	0.0	11.4
440451	8.5	5.7	24.5	6.8	47.2	59.1	49.7	2.3	2.5

440454	8.3	6.2	26.2	8.6	49.7	47.1	61.7	2.1	4.5
440455	8.8	6.4	27.2	6.7	43.0	69.4	54.6	3.3	2.5
440456	6.9	5.5	33.6	19.5	35.8	13.7	48.2	0.5	12.4
477978	6.3	5.4	38.6	18.0	41.5	27.2	66.1	0.7	10.0
502389	8.8	6.4	33.7	13.8	50.8	51.7	70.0	2.3	12.8
502390	8.4	5.5	28.3	8.7	42.6	35.7	56.9	2.1	4.7
502391	8.8	6.3	22.7	5.2	43.7	48.2	50.8	1.9	2.1
502393	7.9	5.7	25.7	7.0	39.8	61.0	63.2	2.1	4.1
502394	8.3	6.3	23.5	6.5	44.7	67.0	52.1	2.4	1.7
502395	8.8	6.3	25.1	7.2	43.5	45.5	52.6	1.9	3.8
532937	8.9	6.4	25.9	5.6	30.6	19.0	49.5	0.2	2.3
538968	7.3	4.7	38.1	17.0	25.4	11.1	48.5	0.3	10.4
538972	8.6	6.2	29.5	9.3	36.9	41.6	50.9	1.8	3.9
538975	8.8	6.2	26.5	9.6	40.4	43.2	48.5	2.1	5.6
568184	8.2	6.2	36.4	19.2	38.0	23.1	48.6	0.8	18.4
618749	8.8	6.5	27.9	10.8	38.7	54.4	39.2	2.6	2.4
619546	8.9	6.1	25.5	7.9	27.5	28.1	41.6	1.2	4.6
636566	6.8	6.4	36.5	20.4	39.3	28.8	45.4	0.7	15.9
639190	7.9	5.6	37.6	20.2	32.7	19.9	53.3	1.2	13.5
LSD (0.05)	1.27	0.93	2.81	1.91	9.94	31.13	14.35	1.40	2.83

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† Winter survival and density were rated on a 1-9 scale (9 = best survival or density) in early spring 2008.

‡ Seedhead emergence date (SHE) was days after 01 May when a plant had 3 or more inflorescences beyond the boot stage; Anthesis date was recorded as days after 01 June when a plant had 3 or more inflorescences exhibiting anthesis; and Harvest date was recorded as days aver 01 July when an individual plant was harvested.

§ Height (cm) was an average height of 3 randomly selected culms, measured from the soil to the tip of the inflorescence.

¶ Seedhead length (mm) was an average length of 3 randomly selected inflorescences after drying.

APPENDIX C

Means separation analysis of average turf quality ratings of prairie junegrass accessions for 2007, 2008, 2009, and averaged for 2008-09 at Becker and St. Paul, MN grown in low-input conditions and mowed weekly from 2007-2009.

		TQ 2007		TQ 2008		TQ 2009		TQ 2008-09	
Accession	Origin	B	Sp	B	Sp	B	Sp	B	Sp
18194	Mongolia	4.4	4.0	4.6	4.3	4.2	4.7	4.4	4.6
19186	Bilecik, Turkey	4.9	3.9	4.7	6.1	4.4	5.2	4.5	5.5
19198	Ankara, Turkey	5.0	3.4	3.6	5.7	4.7	4.7	4.2	5.1
21169	Mongolia	4.4	2.1	3.7	4.9	4.0	4.8	3.6	5.0
21268	Mongolia	5.3	3.2	4.5	4.5	4.6	4.8	4.6	4.6
21380	Mongolia	4.6	4.1	4.8	4.9	5.5	5.8	5.2	5.5
21553	Mongolia	4.8	4.4	4.6	4.9	4.5	4.9	4.5	4.9
23304	Kazakhstan	5.0	4.2	4.4	5.3	4.3	4.8	4.4	5.0
24110	Armenia	4.6	3.3	3.9	5.2	5.0	5.1	4.4	5.0
204451	Turkey	4.4	4.4	4.5	5.7	5.6	5.7	5.1	5.7
204452	Turkey	4.9	4.0	5.4	5.9	6.6	6.5	6.1	6.2
229463	Iran	5.1	3.1	6.0	6.1	5.9	6.3	5.9	6.2
230256	Iran	4.5	3.9	3.9	5.9	5.8	6.4	5.0	6.2
230267	Iran	4.3	3.6	2.9	5.7	4.9	5.8	4.2	5.7
250651	Pakistan	5.4	3.9	0.0	5.2	0.0	4.4	0.0	5.0
255364	Yugoslavia	4.6	3.7	4.6	5.5	5.2	5.5	5.0	5.5
312456	Former Soviet Union	5.0	3.6	4.5	5.3	5.1	5.1	4.9	5.2
314377	Stavropol, Russian Fed.	5.0	3.5	4.5	5.3	4.8	5.0	4.7	5.1
314378	Stavropol, Russian Fed.	4.8	4.3	4.5	5.3	4.9	5.2	4.8	5.3
314440	Former Soviet Union	5.1	3.9	4.3	5.1	5.3	5.0	4.8	5.0
314700	Former Soviet Union	4.7	4.0	4.8	5.3	5.0	5.4	4.9	5.4
383672	Turkey	5.0	3.7	4.3	5.5	5.0	5.0	4.7	5.2
383673	Turkey	5.0	3.6	3.4	5.7	5.0	5.3	4.4	5.5
383674	Turkey	5.0	3.3	4.2	5.8	5.1	5.4	4.8	5.5
383675	Turkey	4.2	2.8	3.0	4.8	5.1	5.8	3.9	5.2
387927	Canada	3.9	3.9	4.9	3.7	5.0	4.5	5.0	4.2
410152	South Africa	5.2	5.4	2.0	3.3	0.0	1.3	2.0	3.0
430287	Ireland	5.9	5.0	7.8	7.3	8.2	6.6	7.9	6.8

440451	Stavropol, Russian Fed.	4.9	3.1	4.4	4.9	4.5	4.9	4.5	4.9
440454	Stavropol, Russian Fed.	4.7	3.8	5.0	5.4	5.0	5.2	5.1	5.3
440455	Former Soviet Union	4.9	3.8	5.1	4.7	5.0	5.0	5.1	4.9
440456	Former Soviet Union	4.3	3.9	4.0	4.6	4.9	4.7	4.5	4.6
477978	New Mexico, USA	4.3	3.2	2.9	4.6	4.1	4.2	3.4	4.3
502389	Russian Federation	4.5	3.5	5.0	5.7	5.6	6.2	5.4	6.0
502390	Stavropol, Russian Fed.	4.8	3.9	4.7	5.4	5.0	5.5	4.9	5.4
502391	Russian Federation	5.1	3.9	4.7	5.1	5.0	5.2	4.9	5.2
502393	Russian Federation	5.5	4.6	4.9	5.4	4.8	5.3	4.9	5.4
502394	Ukraine	4.6	3.6	5.0	5.5	5.1	5.6	5.1	5.5
502395	Former Soviet Union	5.1	4.6	4.8	5.8	4.8	5.5	4.9	5.6
532937	Pakistan	4.3	3.1	2.8	5.4	5.5	5.2	4.6	5.4
538968	Russian Federation	5.1	4.2	4.7	4.8	5.5	5.4	5.2	5.2
538972	Russian Federation	4.3	4.9	5.6	5.3	5.1	5.9	5.3	5.7
538975	Kazakhstan	5.2	5.0	5.3	5.7	4.9	5.3	5.1	5.4
568184	Afyon, Turkey	5.0	3.6	4.3	5.8	5.0	5.5	4.7	5.6
618749	Mongolia	4.6	5.0	4.5	4.8	4.7	5.1	4.6	5.0
619546	Mongolia	4.8	4.9	5.7	6.2	6.1	6.6	5.9	6.4
636566	Bulgaria	4.8	3.8	5.4	6.0	5.3	5.6	5.3	5.7
639190	Iowa, USA	4.3	3.5	4.5	5.0	4.6	4.5	4.6	4.7
	LSD (0.05)	0.6	0.7	0.6	0.4	0.5	0.5	0.5	0.4

APPENDIX D

Means separation analysis of turf quality characteristics of native prairie junegrass genotypes grown in low input conditions and mowed weekly from 2007-2009 at St. Paul, MN. (KC-Colorado, KN-Nebraska, and WD-Minnesota).

Genotype	Rust Severity 2007†	Rust incidence 2007†	Rust incidence 2009†	Fall color‡	Inflorescence emergence§	Straw persistence§	Spring green-up‡	Vertical re-growth¶	Lateral spread¶	Turf Quality 2007‡	Turf Quality 2008‡	Turf Quality 2009‡	Average TQ (2007-09)	Density‡	Mowing Quality‡	Color‡
KC1-1B	7.4	1.0	1.0	5.0	4.8	5.6	7.6	112.6	124.0	3.9	5.7	5.8	5.4	6.2	3.9	5.5
KC1-1C	6.6	1.0	1.0	5.2	2.4	4.4	5.8	90.6	101.2	4.2	4.8	5.2	4.9	5.2	5.1	4.6
KC1-1D	5.0	1.0	0.4	4.8	2.6	5.2	5.8	88.8	117.6	4.2	5.8	5.6	5.4	6.0	4.5	4.5
KC1-2A	6.4	1.0	0.8	5.2	4.0	5.6	4.8	73.4	92.2	4.5	5.1	5.6	5.2	5.6	5.5	5.3
KC1-2D	5.6	1.0	1.0	4.6	3.0	6.2	6.6	97.0	117.0	4.1	5.9	5.2	5.3	5.7	5.3	4.4
KC1-3A	4.0	1.0	0.8	5.0	3.0	5.6	6.8	89.8	106.4	4.3	5.4	5.3	5.1	6.0	4.7	4.3
KC1-3B	6.0	1.0	0.8	4.6	3.0	5.8	7.8	105.6	132.0	4.2	5.3	5.3	5.1	5.6	4.5	5.0
KC1-3C	7.2	1.0	1.0	5.0	2.2	5.6	6.0	104.8	100.0	3.9	4.7	5.1	4.7	5.2	4.7	5.1
KC1-5B	8.8	1.0	1.0	5.5	3.0	6.0	6.0	94.5	110.5	4.4	5.5	4.9	5.0	5.8	5.1	4.9
KC1-5C	6.8	1.0	0.6	4.8	3.0	5.8	7.2	105.0	120.4	4.0	5.5	5.5	5.2	5.8	5.3	4.4
KC1-7A	5.4	1.0	1.0	5.0	3.2	5.4	5.8	97.0	101.3	4.4	5.5	5.5	5.2	5.9	5.0	4.8
KC1-7B	4.4	1.0	1.0	5.0	2.6	5.6	6.6	96.2	124.8	4.8	6.6	6.9	6.4	6.7	6.0	4.6
KC1-8A	7.0	1.0	1.0	5.2	3.0	5.6	6.4	99.6	113.0	4.5	5.6	5.5	5.4	5.8	5.1	4.6
KC1-8B	6.6	1.0	0.6	4.6	2.8	5.6	6.8	105.0	114.2	4.3	5.5	5.4	5.2	5.7	4.9	4.5
KC1-8C	6.0	1.0	0.8	4.6	3.4	5.2	7.4	95.8	112.0	4.6	5.7	5.4	5.4	5.8	5.8	4.4
KC1-9A	5.0	0.8	1.0	5.0	3.8	5.0	5.4	75.0	124.4	3.8	4.9	6.3	5.4	5.9	6.0	4.6
KC1-9B	3.0	1.0	0.8	3.8	3.4	6.0	7.0	91.8	116.6	4.6	6.0	6.2	5.9	6.2	5.5	4.7
KC1-9C	7.2	1.0	0.8	5.2	3.0	5.6	6.4	107.8	122.0	4.3	5.1	4.7	4.7	5.5	4.5	5.1
KC1-10A	4.8	1.0	0.8	5.2	3.8	5.2	6.6	94.4	95.6	4.2	5.7	5.9	5.5	6.0	5.7	4.9
KC1-10B	4.0	1.0	0.8	5.2	2.8	5.2	5.4	92.2	76.8	4.2	4.9	4.3	4.5	5.1	4.8	4.9
KC1-10C	1.6	0.6	0.0	5.6	2.6	4.8	6.2	84.0	102.0	4.9	5.5	5.4	5.3	5.5	5.4	4.8
KC1-11A	2.6	0.8	0.0	4.2	2.0	4.8	4.8	87.2	98.2	4.1	4.8	5.3	4.9	5.1	4.8	4.5

KC1-12A	7.0	1.0	0.2	5.6	3.0	5.2	6.4	103.8	116.4	3.9	4.9	4.3	4.5	5.0	4.0	5.0
KC1-12B	5.0	0.8	1.0	5.0	5.0	5.2	5.0	79.0	89.8	3.1	4.5	4.9	4.4	4.8	4.7	3.8
KC1-12C	5.2	1.0	0.8	5.2	3.2	5.4	6.2	100.4	111.2	4.7	5.8	6.2	5.8	6.5	5.5	4.7
KC1-13A	6.2	1.0	0.6	4.6	4.4	4.8	4.2	82.0	87.4	3.9	4.4	4.5	4.4	4.7	6.2	3.4
KC1-13B	8.2	1.0	0.8	5.0	7.4	7.0	3.2	66.8	65.8	2.9	4.6	4.4	4.2	4.3	4.0	4.6
KC1-13C	5.6	1.0	0.3	4.2	3.4	4.2	4.7	90.3	88.7	3.7	3.9	4.2	3.8	4.7	5.5	3.9
KC1-14A	7.8	1.0	1.0	4.6	3.6	6.0	5.4	91.2	109.2	4.4	5.4	5.8	5.4	5.8	6.1	4.9
KC1-14C	6.0	1.0	0.8	4.8	3.0	5.6	5.8	87.0	102.6	4.2	5.1	5.1	4.9	5.2	5.5	4.4
KC1-15A	4.4	1.0	1.0	4.6	5.0	6.2	7.6	89.8	143.0	4.7	6.2	6.6	6.1	6.5	5.9	4.2
KC3-1B	2.4	1.0	0.4	5.0	1.0	4.4	7.0	101.4	107.2	4.7	5.0	4.8	4.8	5.4	4.7	4.8
KC3-2A	1.8	0.8	0.0	6.8	2.4	5.0	7.0	99.6	115.0	5.1	5.4	6.0	5.6	5.9	4.5	6.1
KC3-2B	2.0	1.0	0.2	4.4	2.6	6.0	5.4	91.6	83.8	4.4	5.3	5.0	5.0	5.0	4.4	5.0
KC3-3A	5.0	0.8	0.8	5.4	1.8	4.6	6.4	103.6	98.8	3.9	4.4	4.1	4.2	4.6	4.6	4.8
KC3-6A	4.6	1.0	0.8	5.6	1.4	4.4	5.4	94.0	94.0	4.9	4.7	5.3	5.0	5.7	4.9	4.4
KC3-7A	3.0	1.0	0.3	7.0	2.2	4.6	6.8	95.8	95.8	4.5	4.3	4.7	4.4	4.9	5.4	4.8
KC3-8A	3.0	1.0	0.8	5.6	1.4	5.0	6.2	86.6	93.2	4.9	4.8	4.8	4.8	5.5	5.1	5.0
KC3-8B	4.2	0.8	0.0	5.2	1.8	5.2	5.5	91.0	106.5	4.5	4.8	5.3	4.8	4.9	5.1	4.8
KC3-9B	1.6	0.6	0.6	5.4	2.0	4.6	6.8	95.0	87.8	4.3	4.9	4.2	4.4	5.3	4.3	4.7
KC3-10A	6.0	1.0	1.0	5.4	1.4	5.0	6.4	95.2	103.8	4.4	4.8	4.8	4.7	5.2	4.6	4.6
KC3-11A	6.0	1.0	1.0	5.0	2.0	5.4	7.2	102.6	103.6	4.3	5.3	4.9	4.9	5.5	5.1	5.0
KC3-11B	5.0	1.0	0.4	4.6	2.4	6.2	6.2	87.0	87.4	4.1	4.8	3.8	4.3	4.6	5.3	5.0
KC3-12A	5.0	1.0	1.0	5.2	2.8	5.4	7.0	110.4	109.6	4.5	5.4	5.4	5.2	5.7	4.1	5.0
KC3-12B	1.8	0.8	0.2	5.2	2.0	5.4	8.2	91.6	109.2	4.6	5.4	5.1	5.1	5.7	4.8	5.0
KC3-13B	6.8	1.0	1.0	5.6	2.8	5.8	7.8	83.8	126.4	4.5	6.0	5.5	5.5	5.9	4.9	5.2
KC3-14A	1.6	0.6	0.0	5.8	1.6	4.8	7.2	95.8	117.2	4.6	4.8	4.7	4.7	5.2	4.5	5.0
KC3-14B	5.0	1.0	0.8	5.6	1.6	4.8	6.0	105.4	93.4	4.5	4.6	4.4	4.5	4.9	4.4	4.7
KC3-15A	4.2	1.0	0.2	4.0	3.8	6.2	5.6	105.6	79.8	3.7	4.7	4.4	4.4	4.5	4.7	4.1
KC3-15B	3.0	1.0	0.2	4.2	2.6	6.2	6.4	105.4	92.4	3.7	4.9	4.1	4.3	4.7	4.4	4.8
KC3-16A	7.2	1.0	0.8	5.4	1.8	5.8	5.4	91.2	106.4	4.2	4.5	4.3	4.4	5.0	4.9	4.3
KC3-16B	4.0	1.0	1.0	5.0	2.6	5.8	5.8	88.4	96.0	4.5	4.8	4.8	4.8	5.0	5.4	4.9
KC3-16C	1.6	0.6	0.2	4.8	4.2	5.4	7.6	104.8	130.6	4.5	5.8	5.6	5.5	5.7	4.5	4.6
KC3-17A	7.0	1.0	0.8	5.2	3.2	6.0	7.6	98.0	125.8	3.9	5.4	5.2	5.0	5.5	4.9	4.6
KC3-17B	6.4	1.0	0.8	5.2	2.0	5.2	6.6	96.6	102.2	4.2	4.6	4.6	4.5	5.2	4.5	4.7
KC3-18A	6.0	1.0	0.8	6.6	1.4	4.8	6.6	89.6	108.4	4.5	5.3	5.9	5.4	5.8	4.9	5.2
KC3-18B	5.0	1.0	0.4	5.6	2.2	4.6	7.4	84.2	122.6	4.8	5.5	5.3	5.3	5.8	4.9	4.8
KC3-19A	5.6	1.0	1.0	6.2	2.8	5.2	7.0	102.6	106.0	3.9	4.9	4.9	4.7	5.1	5.1	5.0

KC3-19B	5.0	1.0	1.0	5.4	2.0	5.2	6.2	117.6	104.2	3.7	4.9	4.9	4.7	5.1	4.5	4.5
KC3-20A	7.8	1.0	1.0	5.0	2.2	4.8	6.6	100.4	75.4	3.9	4.5	5.3	4.8	5.3	4.9	4.8
KC3-20B	5.8	0.8	0.6	6.6	2.4	5.4	5.6	87.4	96.2	4.1	4.9	4.7	4.7	5.5	4.8	4.8
KC4-2A	7.0	1.0	0.8	5.2	2.8	5.2	5.4	99.2	102.2	4.0	4.7	4.8	4.6	5.2	3.9	5.5
KC4-2B	6.0	0.8	0.6	5.4	3.0	5.6	6.0	94.0	96.2	3.9	4.6	5.3	4.8	5.2	4.5	4.6
KC4-3A	4.6	0.8	1.0	3.4	4.0	5.4	4.0	55.0	58.5	3.4	3.7	4.0	3.6	4.8	5.2	3.9
KC4-4A	5.4	1.0	0.5	5.2	2.4	4.4	7.2	91.0	86.3	3.9	4.1	4.2	4.1	4.8	4.4	4.6
KC4-4B	7.2	1.0	0.8	5.4	2.0	5.0	5.4	100.0	84.2	4.3	4.6	4.5	4.5	5.3	4.8	5.1
KC4-5A	3.8	0.8	0.3	4.2	1.6	5.6	3.3	81.5	71.0	4.0	5.0	2.7	4.2	4.9	4.8	4.3
KC4-5B	6.6	1.0	0.8	5.2	1.6	5.0	5.0	81.6	88.8	4.2	4.2	4.4	4.3	5.0	5.0	5.4
KC4-7A	6.8	1.0	1.0	5.2	1.2	5.0	6.6	100.2	116.2	4.3	5.0	5.2	5.0	5.2	4.7	4.9
KC4-8A	5.6	1.0	1.0	5.6	2.0	5.4	6.2	95.6	108.2	4.2	4.5	4.4	4.4	5.0	4.4	4.9
KC4-8B	6.4	1.0	0.5	4.8	2.6	5.6	4.0	72.3	73.3	4.3	4.7	4.0	4.3	5.2	4.8	4.8
KC4-9A	1.8	0.8	0.8	5.0	1.8	4.8	6.2	82.4	104.8	4.0	4.9	4.1	4.4	5.0	4.1	4.6
KC4-9B	1.6	0.6	1.0	5.2	3.4	5.4	7.0	96.6	91.0	4.4	5.1	4.6	4.7	5.1	4.1	4.8
KC4-10A	2.6	1.0	0.6	5.0	1.2	4.2	5.8	97.4	89.0	4.6	5.6	5.4	5.3	6.3	4.1	5.7
KC4-10B	7.2	1.0	1.0	5.6	2.4	5.0	6.2	96.5	94.8	4.1	4.5	4.8	4.5	5.2	4.8	4.9
KC4-11B	7.6	1.0	0.6	5.0	1.6	5.0	5.2	98.0	94.0	3.3	4.5	4.2	4.1	4.4	4.7	4.4
KC4-13A	4.6	1.0	1.0	5.0	2.0	5.2	6.6	112.2	90.0	3.8	5.0	4.8	4.6	5.3	4.2	5.3
KC4-14A	8.0	1.0	1.0	5.0	1.8	5.2	6.2	105.2	104.8	4.1	4.9	4.8	4.7	5.2	4.6	4.7
KC4-14B	7.2	1.0	0.6	5.2	2.0	5.4	6.6	98.8	88.4	3.9	4.8	4.3	4.4	5.3	4.8	4.8
KC4-15A	7.4	1.0	0.8	5.8	2.4	5.4	6.4	103.6	99.0	4.1	5.2	5.0	4.9	5.5	4.5	5.3
KC4-15B	8.0	1.0	0.8	5.4	1.0	4.0	5.8	93.5	82.3	4.1	4.1	4.5	4.2	5.1	4.6	5.0
KC4-16A	7.0	1.0	1.0	5.2	3.6	5.8	5.4	91.4	94.6	4.2	5.2	4.7	4.8	5.5	4.7	4.9
KC4-16B	1.4	0.4	0.2	3.8	2.0	5.8	7.2	97.4	93.0	3.9	4.9	4.8	4.7	5.0	4.1	5.1
KC4-19A	7.0	1.0	0.6	5.4	2.0	5.0	6.2	92.8	107.8	3.9	4.8	4.5	4.5	5.0	4.1	5.2
KC4-20A	8.0	1.0	1.0	5.0	3.4	5.6	5.6	103.0	102.6	4.0	4.9	5.5	5.0	5.7	4.9	4.9
KC4-21A	5.0	1.0	0.0	4.8	3.3	5.5	7.3	95.8	88.0	3.4	5.0	4.2	4.4	4.5	4.0	4.4
KC4-24A	8.2	1.0	1.0	5.2	2.4	6.0	6.0	91.2	115.6	4.1	5.0	4.7	4.7	5.3	4.7	4.1
KC4-24B	8.4	1.0	0.0	5.4	1.6	4.8	5.4	91.8	89.8	4.1	4.6	4.1	4.3	4.9	5.0	4.4
KC4-26A	2.8	0.8	0.0	5.6	1.6	4.8	5.2	79.0	96.8	4.1	5.0	4.1	4.4	4.6	5.4	5.0
KC4-27A	4.8	1.0	0.4	5.0	1.6	4.6	2.6	67.6	40.0	4.1	4.5	3.0	3.8	4.4	5.6	4.7
KC5-1A	1.8	0.8	0.4	5.8	2.4	4.6	5.8	94.0	107.6	3.7	4.6	4.5	4.4	4.9	4.9	4.8
KC5-1B	4.0	0.8	0.6	5.0	2.4	5.4	6.8	104.4	84.0	3.9	4.9	5.1	4.8	5.9	5.5	5.3
KC5-1D	2.8	1.0	0.0	5.0	2.8	4.6	5.2	102.0	76.4	3.9	4.9	3.8	4.2	4.3	4.3	4.5
KC5-1E	2.4	1.0	0.0	4.8	1.4	4.8	6.4	97.6	108.6	4.2	5.1	5.4	5.0	5.5	4.5	5.2

KC5-1F	3.4	1.0	0.6	4.8	1.8	4.4	6.2	102.0	111.8	4.5	5.1	5.1	5.0	5.7	4.3	5.0
KC5-1G	2.4	1.0	0.0	5.6	2.4	5.2	6.4	105.4	109.0	4.4	5.2	4.3	4.6	5.1	4.2	5.0
KC5-1H	4.0	1.0	0.2	5.2	1.8	4.6	7.2	96.6	99.8	4.5	5.1	4.7	4.8	5.2	4.6	4.9
KC5-2A	6.0	1.0	0.8	4.4	1.6	4.8	6.4	99.2	110.4	4.1	4.6	4.5	4.5	5.3	4.7	4.5
KC5-2C	8.0	1.0	0.8	4.8	2.4	5.6	5.0	82.6	99.2	3.8	5.0	4.9	4.7	5.0	5.3	4.6
KC5-2E	5.0	1.0	1.0	5.2	2.4	5.2	6.8	91.8	106.4	4.3	5.4	5.1	5.1	5.8	5.1	4.7
KC5-2F	4.2	0.8	1.0	5.0	2.8	5.4	7.4	81.6	111.4	4.3	5.2	5.0	4.9	5.4	5.5	5.1
KC5-2H	7.0	1.0	1.0	4.8	3.4	6.0	7.0	104.8	122.4	4.5	6.1	5.9	5.7	6.3	5.0	5.1
KC5-3A	7.8	1.0	1.0	5.2	2.2	5.4	7.0	107.2	104.6	3.9	5.1	4.8	4.7	5.3	5.0	4.6
KC5-3B	5.6	1.0	0.8	5.0	3.0	6.0	6.8	96.4	101.2	4.2	5.5	5.1	5.1	5.7	4.4	4.6
KC5-3C	7.2	1.0	0.8	5.0	2.6	5.6	6.2	91.6	105.6	4.1	5.2	4.6	4.7	5.7	4.9	4.6
KC5-3E	5.2	1.0	1.0	4.8	3.8	6.2	6.2	100.8	117.0	4.2	6.0	5.2	5.3	5.8	4.9	4.5
KC5-3G	5.6	1.0	0.8	5.0	3.0	5.8	5.6	107.2	111.0	4.0	4.8	4.7	4.6	5.2	4.5	4.8
KC5-4A	4.2	1.0	0.8	5.2	1.6	5.2	5.6	94.6	92.4	4.9	4.9	5.3	5.1	5.7	5.0	5.1
KC5-4B	4.2	1.0	0.8	5.2	2.8	5.0	7.2	108.8	106.6	4.3	5.4	5.0	5.0	5.4	4.3	4.9
KC5-4D	7.4	1.0	0.6	5.4	2.8	4.6	5.8	87.6	95.0	3.8	5.1	4.9	4.8	5.4	5.3	5.3
KC5-4E	7.0	1.0	0.8	5.4	2.6	5.0	7.6	112.8	111.6	4.4	5.1	5.2	5.0	5.7	4.9	4.8
KC5-4G	4.8	1.0	1.0	5.2	2.8	5.4	5.0	76.6	73.0	3.7	4.9	5.1	4.8	5.3	5.6	5.1
KC5-4H	6.6	1.0	0.8	4.6	2.0	5.2	6.2	90.0	109.2	4.0	4.8	5.0	4.8	5.2	5.1	4.7
KC5-5A	5.8	1.0	0.0	4.0	4.2	5.6	6.4	98.2	98.2	4.0	4.8	4.9	4.7	5.1	4.6	4.8
KC5-5B	5.8	0.8	0.0	5.4	2.0	4.8	6.6	91.6	82.8	4.1	4.6	4.1	4.3	4.9	5.1	4.8
KC5-5C	7.0	1.0	0.3	4.8	5.0	6.8	6.0	100.0	100.3	4.0	5.6	4.6	4.9	5.0	5.6	5.3
KC5-5D	3.4	1.0	0.0	3.8	2.8	5.5	6.4	112.6	104.4	3.9	5.1	5.0	4.9	5.1	5.0	4.6
KC5-5F	7.4	1.0	0.2	5.0	3.4	5.8	6.2	100.6	106.4	4.1	5.8	5.3	5.2	5.6	4.5	5.3
KC5-5G	2.0	1.0	0.0	4.2	4.4	5.2	5.6	95.6	116.2	4.2	5.1	4.5	4.7	4.9	4.5	4.7
KC5-6A	8.2	1.0	1.0	4.6	2.6	4.6	6.2	101.4	86.6	4.1	4.0	4.2	4.1	4.6	4.6	4.8
KN1-1A	4.0	1.0	0.6	5.4	1.8	4.8	7.8	92.4	110.0	4.2	5.4	5.3	5.1	6.2	4.0	5.0
KN1-1B	2.8	1.0	0.0	5.6	1.0	4.0	5.0	104.8	103.8	3.8	4.1	4.1	4.1	4.9	4.2	4.9
KN1-2A	4.4	1.0	0.2	6.2	1.8	5.0	6.8	95.6	102.6	3.9	5.0	4.1	4.4	5.0	4.3	4.9
KN1-2B	7.2	1.0	0.8	5.6	2.0	5.6	6.2	96.0	102.0	4.2	4.9	4.5	4.6	5.2	4.1	4.7
KN1-3A	1.8	0.8	0.0	5.0	5.4	5.6	6.0	97.0	101.4	3.4	4.9	4.6	4.5	4.8	3.8	5.0
KN1-3B	1.8	0.8	0.0	6.2	5.0	6.2	5.4	90.0	64.8	3.9	4.7	4.1	4.3	4.5	4.6	5.2
KN1-3C	1.6	0.6	0.0	5.8	2.2	5.2	7.8	106.0	97.2	4.3	5.3	5.0	5.0	5.4	3.9	5.3
KN1-4A	5.2	1.0	0.2	6.0	3.6	5.4	5.0	88.0	79.8	3.7	4.5	4.1	4.2	4.7	4.3	4.8
KN1-4B	6.6	1.0	0.2	5.0	1.8	5.2	6.2	93.0	99.2	3.9	4.7	4.3	4.4	5.2	3.8	4.3
KN1-5A	3.4	1.0	0.2	6.2	2.0	5.0	6.4	102.8	128.2	3.8	5.2	5.3	5.0	5.4	3.8	4.5

KN1-6B	6.0	0.8	0.6	5.6	2.4	5.2	6.6	96.0	114.5	4.1	4.9	5.0	4.7	5.4	4.7	4.9
KN1-7A	2.4	1.0	0.6	6.2	1.8	5.0	6.4	123.6	121.2	4.4	4.4	4.9	4.6	4.9	3.9	4.8
KN1-7B	4.4	1.0	0.4	6.2	1.6	4.8	6.0	91.2	116.6	4.1	4.3	4.9	4.5	5.0	4.1	4.6
KN1-7C	3.4	1.0	0.4	4.8	1.6	4.6	7.6	112.0	115.8	4.1	4.8	4.9	4.7	5.4	4.3	4.4
KN1-8A	6.8	1.0	0.0	5.8	2.4	5.2	6.0	93.0	96.0	3.5	4.8	4.4	4.4	5.0	4.3	4.9
KN1-8B	1.8	0.8	0.6	6.2	1.8	4.8	6.6	91.4	92.6	4.1	4.3	4.2	4.4	5.0	4.5	4.6
KN1-9A	3.8	1.0	0.2	5.4	2.2	6.0	4.8	93.0	73.4	3.8	4.4	4.1	4.2	4.7	5.0	5.0
KN1-10B	4.6	1.0	0.4	6.4	3.0	6.0	7.6	115.4	116.8	4.5	5.5	4.7	4.9	5.2	3.9	4.8
KN1-11A	6.4	1.0	0.6	5.0	2.4	4.8	6.8	116.4	121.4	3.9	4.7	4.7	4.6	5.3	3.7	4.5
KN1-11B	2.8	0.8	0.4	5.0	2.2	5.2	5.6	106.4	86.6	4.1	5.0	4.9	4.8	5.6	3.9	4.8
KN1-12A	3.6	1.0	0.4	5.6	2.0	4.0	6.2	100.0	98.0	3.6	4.2	4.1	4.1	4.7	4.5	4.9
KN1-12B	3.0	1.0	0.6	5.2	2.8	5.4	6.0	104.6	95.0	3.7	4.8	4.3	4.4	5.0	4.1	4.8
KN1-13A	3.0	1.0	0.2	5.4	1.4	5.0	7.6	107.2	131.4	4.4	4.9	5.5	5.1	5.8	3.9	4.2
KN1-13C	2.0	1.0	0.4	5.2	2.0	4.2	4.8	98.8	112.2	3.7	4.1	4.5	4.2	4.8	3.5	4.8
KN1-14B	7.8	1.0	0.8	5.4	3.8	6.0	5.8	94.0	121.8	4.1	5.4	5.1	5.0	5.5	4.0	5.1
KN1-14C	3.4	1.0	0.6	5.0	1.8	4.6	6.4	104.0	108.0	4.5	4.7	4.9	4.8	5.4	4.1	5.3
KN1-15A	5.0	1.0	1.0	5.0	2.6	4.2	6.3	85.2	87.0	3.7	4.3	3.9	4.0	4.6	4.5	4.5
KN1-16A	6.6	1.0	1.0	5.8	2.6	5.2	6.2	114.8	105.0	4.2	5.1	5.0	4.9	5.6	3.9	5.2
KN1-16B	1.4	0.4	0.2	5.4	2.4	5.2	5.8	101.2	100.0	3.8	4.8	4.7	4.6	5.0	4.1	4.8
KN1-17B	5.8	1.0	0.4	5.4	2.6	5.4	5.8	92.4	74.6	4.1	4.7	5.1	4.8	5.7	4.1	5.2
KN2-1A	6.4	1.0	0.8	5.4	1.4	5.0	5.0	85.6	70.0	3.9	4.5	4.4	4.3	4.8	4.5	4.6
KN2-1B	1.8	0.8	0.3	5.0	2.3	5.0	6.8	98.5	116.8	3.8	4.5	4.4	4.3	4.9	4.3	4.9
KN2-2A	5.6	0.8	1.0	5.0	2.6	4.8	6.8	89.2	100.2	3.5	4.7	4.7	4.5	5.2	4.4	4.9
KN2-2B	8.2	1.0	0.6	5.4	1.8	4.6	4.8	96.8	84.2	3.9	4.4	4.6	4.4	5.4	4.0	5.2
KN2-3A	7.4	1.0	1.0	5.6	1.4	4.8	5.2	103.0	105.2	3.8	4.2	4.4	4.2	5.0	4.5	4.9
KN2-4B	5.2	1.0	0.4	5.6	2.4	6.0	6.4	84.6	102.8	4.7	4.9	4.6	4.7	5.2	4.9	5.1
KN2-5A	8.0	1.0	0.4	5.6	2.0	5.0	6.2	99.6	87.6	4.3	4.6	4.1	4.3	5.3	4.1	5.2
KN2-5B	2.8	0.8	0.2	6.0	1.6	5.0	6.0	95.0	106.0	3.5	4.7	4.1	4.2	4.8	4.4	4.5
KN2-6A	2.8	1.0	0.4	5.6	2.4	4.6	6.4	113.4	106.0	4.1	4.7	4.8	4.6	5.1	3.4	5.0
KN2-7A	8.2	1.0	1.0	5.2	3.0	5.4	5.6	104.0	88.4	4.0	4.7	4.7	4.6	5.2	4.5	4.8
KN2-7B	6.8	1.0	0.2	5.2	2.6	5.0	5.4	100.4	88.4	4.1	4.6	4.1	4.3	4.9	4.3	4.8
KN2-8A	6.4	1.0	0.6	5.4	1.2	5.0	5.8	91.4	88.8	3.5	4.7	4.4	4.3	4.9	3.9	4.8
KN2-8B	4.2	1.0	0.6	5.4	2.0	5.4	6.0	89.2	97.8	4.0	4.8	4.8	4.6	5.0	4.2	4.7
KN2-9A	5.4	1.0	0.0	5.4	3.0	5.6	6.0	91.8	95.2	3.9	5.4	4.6	4.7	5.6	4.2	5.4
KN2-9B	7.2	1.0	0.5	5.0	1.4	5.2	6.5	107.8	99.8	3.9	5.1	4.5	4.5	5.5	4.4	4.9
KN2-11A	3.0	1.0	0.2	4.8	2.4	5.2	6.6	103.2	114.2	4.1	4.7	4.7	4.6	5.1	3.9	4.5

KN2-11B	3.6	1.0	0.5	5.0	4.3	6.7	5.8	89.5	107.8	3.2	4.0	4.6	3.9	4.7	2.7	4.0
KN2-12A	6.0	1.0	0.8	5.6	2.8	5.2	5.8	83.8	94.0	3.8	4.6	5.2	4.7	5.5	4.4	4.7
KN2-15B	6.4	1.0	0.8	5.0	3.0	6.0	4.6	93.8	81.2	4.0	3.9	4.5	4.2	5.0	4.5	4.1
KN2-16A	7.0	1.0	0.6	5.2	3.4	5.2	6.0	94.8	88.0	3.3	4.1	4.3	4.0	4.4	4.6	4.5
KN2-16B	7.4	1.0	0.6	5.6	3.2	6.0	6.2	97.6	99.4	3.5	4.4	4.8	4.4	4.8	4.6	4.6
KN2-17A	6.2	1.0	0.6	5.2	2.6	5.0	5.2	88.6	102.4	3.8	4.2	4.1	4.1	4.6	4.3	4.9
KN2-17B	8.8	1.0	0.8	5.0	3.0	5.2	5.4	81.4	84.2	3.4	4.1	4.0	3.9	4.2	4.5	4.3
KN2-18A	5.2	1.0	0.4	5.6	1.2	3.6	6.0	100.4	95.0	4.5	4.6	4.4	4.5	5.1	4.6	4.9
KN2-19B	6.6	1.0	0.4	4.6	2.8	4.4	3.8	74.6	72.4	3.5	3.4	2.6	3.1	3.3	4.9	4.6
KN2-20A	7.0	1.0	0.6	4.6	3.0	5.4	6.0	98.4	75.0	3.3	4.5	4.2	4.1	4.6	4.8	4.5
KN2-20B	5.8	1.0	0.8	5.4	1.4	5.0	6.6	104.8	106.4	4.0	4.8	4.6	4.6	5.3	4.2	4.6
KN2-21A	7.8	1.0	0.6	5.4	2.4	5.0	7.0	110.6	103.0	4.1	4.7	4.7	4.6	5.4	4.3	4.9
KN2-22A	7.2	1.0	0.6	5.0	2.0	5.2	7.0	109.2	88.0	3.5	4.7	4.4	4.3	4.9	4.4	4.8
KN2-22B	3.8	1.0	0.6	5.4	3.0	5.4	5.6	99.4	95.2	4.0	4.6	4.5	4.4	5.0	4.3	4.6
KN3-2A	7.0	1.0	0.8	4.8	1.6	4.6	7.8	99.0	99.2	4.3	4.9	4.9	4.8	5.6	4.1	4.4
KN3-2B	5.4	1.0	1.0	5.2	1.6	5.0	7.4	93.8	109.2	3.7	5.2	5.4	5.0	5.9	4.3	4.7
KN3-3A	8.0	1.0	0.8	5.6	2.0	4.8	4.6	94.6	74.0	3.9	4.3	4.4	4.2	4.9	4.8	4.7
KN3-3B	4.8	1.0	0.0	5.6	1.4	4.6	5.8	80.8	75.4	3.9	4.1	4.1	4.1	4.9	4.6	5.1
KN3-4A	2.6	0.6	0.0	5.2	2.4	4.8	5.8	101.6	100.6	3.9	4.0	4.2	4.1	4.7	3.9	4.7
KN3-4B	1.6	0.6	0.4	5.2	1.6	4.4	7.8	107.4	113.6	4.4	5.1	5.0	4.9	5.7	3.8	5.0
KN3-5A	4.8	1.0	0.4	5.0	2.8	5.2	5.6	100.6	91.0	4.3	4.4	4.7	4.5	5.2	4.4	4.7
KN3-6B	4.4	1.0	0.6	5.2	2.2	4.0	5.8	88.6	79.2	3.6	4.0	4.0	3.9	4.8	4.5	5.0
KN3-6C	7.6	1.0	0.6	6.0	1.2	4.8	6.0	91.6	79.2	4.0	4.6	4.7	4.5	5.4	4.7	4.8
KN3-7A	2.0	0.8	0.5	5.0	3.0	5.3	6.0	93.5	95.5	4.0	4.8	4.3	4.4	5.0	4.6	4.1
KN3-7B	4.5	1.0	1.0	5.0	2.8	4.3	6.3	104.3	112.8	3.2	4.8	5.0	4.8	5.5	4.8	5.0
KN3-8A	5.6	1.0	0.8	5.2	1.0	4.8	7.0	97.0	121.6	4.2	5.1	4.9	4.8	5.5	4.4	4.4
KN3-9B	6.8	1.0	1.0	5.0	1.8	4.5	6.0	87.3	94.3	3.3	4.5	4.9	4.6	5.3	4.8	4.9
KN3-10A	3.4	1.0	0.2	5.2	2.4	5.6	5.8	97.4	75.2	3.9	5.0	4.3	4.5	4.9	4.8	5.0
KN3-10B	6.4	1.0	1.0	5.0	2.8	5.2	6.5	107.5	85.3	3.9	4.6	4.6	4.4	5.1	4.3	4.7
KN3-11A	6.4	1.0	0.3	5.4	2.6	5.4	4.3	95.8	68.8	3.5	3.9	3.8	3.8	4.6	4.3	5.1
KN3-11B	6.0	1.0	0.8	5.5	2.5	5.5	5.8	99.0	111.5	3.9	5.6	4.8	4.9	5.5	4.9	5.4
KN3-12A	6.2	1.0	0.6	5.0	2.2	5.8	5.4	96.6	92.8	3.9	4.7	4.5	4.4	5.2	3.7	5.2
KN3-12B	2.0	1.0	0.0	5.6	2.2	5.2	6.4	105.2	103.0	3.5	5.1	4.0	4.3	4.8	4.0	4.8
KN3-12C	3.8	1.0	0.0	5.4	2.0	5.0	7.6	101.2	91.6	3.9	4.9	4.2	4.4	5.1	3.7	4.5
KN3-13B	7.4	1.0	1.0	4.4	2.4	5.0	6.6	92.4	101.8	3.9	5.1	5.0	4.8	5.6	4.7	4.4
KN3-14A	4.8	1.0	0.8	5.2	1.8	5.6	6.6	105.2	99.8	4.5	5.3	4.7	4.9	5.5	4.5	4.7

KN3-15B	7.6	1.0	0.4	5.6	1.8	4.8	5.4	88.2	74.2	3.7	4.0	3.6	3.7	4.5	4.2	4.9
KN3-16A	2.6	0.6	0.2	6.0	1.6	4.4	7.2	101.8	104.8	4.2	5.1	4.3	4.6	4.9	4.9	4.8
KN3-16B	3.4	1.0	0.0	5.4	2.0	4.6	6.0	105.4	94.0	3.6	4.8	4.6	4.5	5.0	4.4	4.9
KN3-17A	3.0	1.0	0.2	5.2	1.8	5.6	6.4	100.8	103.2	4.1	5.0	4.4	4.5	5.3	4.2	4.4
KN3-17B	6.8	1.0	0.2	4.6	2.0	4.8	3.4	83.8	77.0	3.7	3.9	3.6	3.7	4.3	4.9	4.8
KN3-18A	8.0	1.0	0.8	5.0	2.4	5.2	5.8	91.6	86.4	4.3	4.7	4.6	4.6	5.2	5.1	4.4
KN3-19A	2.8	0.8	0.4	5.4	2.8	5.2	6.2	107.8	100.4	4.5	5.0	5.2	5.0	5.9	4.1	5.2
KN3-19B	4.4	1.0	0.2	5.2	2.6	5.8	4.6	84.2	90.8	4.0	4.6	4.0	4.2	4.6	4.5	5.2
KN4-1A	2.8	1.0	0.0	5.0	1.4	4.4	7.2	103.6	107.6	4.5	5.4	5.1	5.1	5.4	4.2	4.9
KN4-1B	1.6	0.6	0.0	5.0	1.2	3.6	5.6	70.4	82.0	4.5	4.1	4.5	4.4	5.1	4.6	4.6
KN4-1C	4.6	1.0	0.4	5.0	2.4	5.2	6.0	98.2	88.2	3.7	4.4	4.8	4.5	5.2	4.5	5.0
KN4-1D	1.8	0.8	0.2	5.0	1.8	4.6	7.2	97.6	107.8	3.9	4.8	5.0	4.8	5.2	4.5	4.8
KN4-3A	6.8	1.0	0.4	5.0	1.8	4.6	6.4	94.2	98.4	3.9	4.4	4.5	4.3	5.1	4.2	4.7
KN4-3B	6.6	1.0	0.6	4.6	3.8	5.8	6.2	105.2	88.2	3.3	4.8	4.2	4.3	4.9	4.1	5.0
KN4-4B	6.4	1.0	1.0	4.8	2.0	4.6	5.2	82.0	101.4	4.3	4.2	4.4	4.3	4.3	5.7	4.7
KN4-4C	2.4	1.0	0.8	5.0	1.2	4.6	6.6	93.6	104.0	4.0	5.0	5.4	5.0	5.8	5.2	4.6
KN4-5A	1.8	0.8	0.0	5.2	3.0	5.6	5.8	85.6	77.8	3.6	4.8	3.9	4.2	4.8	5.3	4.7
KN4-5C	6.6	1.0	0.8	5.4	1.4	4.2	5.6	83.2	89.8	4.1	4.2	4.3	4.3	5.1	4.6	4.5
KN4-6A	4.4	1.0	0.0	3.8	3.4	4.8	8.2	106.0	99.6	3.9	4.9	5.0	4.8	5.2	4.9	4.8
KN4-6B	7.0	1.0	0.3	4.0	4.0	8.0	6.3	78.7	88.0	3.0	3.9	5.1	4.1	4.0	4.9	4.4
KN4-6C	1.8	0.8	0.0	4.8	2.6	5.4	6.8	96.2	98.0	3.6	5.0	4.8	4.6	5.3	4.7	4.8
KN4-7B	1.8	0.8	0.0	5.4	1.8	4.6	8.6	91.4	121.4	4.3	5.7	4.5	4.9	5.4	4.5	4.5
KN4-7C	6.2	0.8	0.0	5.2	1.2	4.4	5.0	73.2	83.2	4.0	3.9	4.1	4.0	4.7	4.7	4.7
KN4-8A	5.2	1.0	0.4	5.2	2.2	4.0	5.8	100.0	87.6	3.5	3.9	4.3	4.0	4.9	4.9	4.2
KN4-8C	5.2	1.0	0.0	3.8	2.5	4.8	8.0	96.0	100.5	3.5	5.5	4.2	4.2	4.6	5.1	4.1
KN4-9A	2.8	0.8	0.2	4.4	3.0	5.4	6.4	96.2	109.2	3.7	5.3	3.9	4.4	4.6	5.1	4.4
KN4-9B	4.0	1.0	0.4	4.8	1.6	3.6	6.2	87.8	81.0	3.7	4.1	4.0	4.0	4.4	4.5	4.8
KN4-9D	2.8	1.0	0.2	3.8	4.4	5.4	6.2	103.2	99.6	3.4	4.8	4.1	4.2	4.5	5.0	4.0
KN4-11B	4.0	1.0	0.0	2.5	7.0	6.3	7.3	102.7	78.3	3.2	4.6	5.0	4.0	4.3	4.7	4.2
KN4-11C	2.8	1.0	0.2	4.6	2.0	5.4	8.0	108.6	105.2	4.3	5.5	5.0	5.0	5.8	4.5	5.0
KN4-12A	5.0	1.0	0.2	4.4	4.0	5.8	5.4	74.2	67.0	3.1	4.0	3.1	3.5	3.8	4.8	4.3
KN4-12C	2.4	0.4	0.0	5.0	2.2	4.8	7.2	103.0	110.2	3.9	4.9	4.6	4.6	5.1	4.1	4.6
KN4-13A	4.2	1.0	0.5	5.2	2.2	4.2	7.0	78.3	98.0	3.5	4.4	4.5	4.1	4.8	5.0	4.9
KN4-13B	6.6	0.8	0.4	5.2	1.0	4.4	7.0	95.6	89.8	3.9	4.8	4.3	4.4	5.1	4.9	4.8
KN4-15A	1.8	0.8	0.2	5.0	2.6	5.0	5.4	98.8	96.6	3.6	5.0	4.8	4.6	5.2	4.9	4.6
KN4-15B	6.0	1.0	0.2	4.8	2.0	5.6	5.2	84.6	98.8	3.9	4.8	3.7	4.1	4.7	4.5	4.8

KN4-15C	4.0	0.8	0.0	5.2	3.6	5.6	5.8	87.8	101.6	3.6	4.7	4.5	4.4	4.9	5.3	4.6
KN4-16B	4.0	1.0	0.0	5.2	2.6	5.0	6.2	94.0	90.6	3.3	4.4	3.8	3.9	4.4	4.3	3.7
KN5-2B	5.0	1.0	0.8	6.0	3.2	5.6	7.0	108.2	117.0	4.2	5.1	5.2	5.0	5.7	3.2	5.2
KN5-2C	4.6	0.8	0.8	5.0	6.4	6.6	6.6	99.0	109.0	3.2	5.0	5.0	4.7	4.6	4.5	4.6
KN5-2D	7.6	1.0	0.6	5.2	3.4	6.2	6.6	90.0	103.6	3.8	5.0	4.6	4.6	5.2	3.6	4.9
KN5-2E	2.8	0.8	1.0	5.0	3.0	5.4	6.0	93.0	83.4	3.9	5.0	4.5	4.6	5.1	4.7	5.0
KN5-3A	6.8	1.0	0.6	5.6	3.2	6.0	6.6	107.2	93.8	3.9	5.2	4.6	4.7	5.3	4.4	5.5
KN5-3D	5.2	1.0	1.0	5.2	2.8	5.6	5.8	101.4	80.6	3.9	4.6	4.1	4.3	4.9	4.6	5.2
KN5-3E	7.4	1.0	0.4	5.2	2.4	5.2	6.6	98.2	110.0	4.0	5.1	4.7	4.7	5.2	4.3	5.0
KN5-4A	7.8	1.0	0.0	5.0	7.3	7.7	7.7	99.7	88.0	3.3	4.7	5.2	4.2	4.1	3.9	4.0
KN5-4B	6.4	1.0	0.8	5.4	2.6	5.2	6.6	110.6	96.2	3.8	4.7	4.6	4.5	5.1	4.9	4.6
KN5-4C	3.8	1.0	0.0	5.4	3.0	5.2	7.4	90.0	106.8	4.6	5.6	5.1	5.2	5.8	4.1	5.3
KN5-4D	2.6	0.8	0.0	5.4	2.8	5.4	6.6	104.6	103.4	4.1	5.4	5.0	5.0	5.7	3.7	5.0
KN5-5A	7.6	1.0	0.8	5.2	2.6	5.4	6.4	109.2	122.6	4.3	5.2	5.3	5.1	5.6	3.2	4.6
KN5-5B	7.4	1.0	1.0	5.0	2.2	5.8	5.8	112.0	107.6	3.8	4.7	4.7	4.5	5.2	3.8	4.8
KN5-5D	7.2	1.0	0.8	5.0	2.8	5.2	6.0	92.6	97.4	4.0	4.7	4.6	4.5	5.1	4.2	5.0
KN5-5E	5.6	1.0	1.0	5.4	3.0	5.6	5.8	98.0	96.0	3.9	4.7	4.3	4.4	4.9	4.3	4.8
KN5-6B	8.0	1.0	0.5	4.2	2.2	4.2	6.0	102.0	91.0	3.9	4.4	4.4	4.2	4.7	4.9	4.3
KN5-6E	2.8	0.8	0.0	4.8	3.4	5.2	7.3	121.0	107.3	3.9	4.9	5.0	4.7	5.3	4.2	4.8
KN5-7B	5.4	1.0	0.4	5.0	1.4	4.8	6.2	96.8	89.6	3.9	4.9	4.2	4.4	5.0	4.5	4.6
KN5-7C	7.0	1.0	0.0	5.6	2.6	4.8	7.8	94.8	116.6	4.8	5.2	5.0	5.0	6.2	3.9	4.9
KN5-7D	7.6	1.0	0.4	5.4	2.6	5.6	6.8	93.8	90.6	3.9	5.0	4.4	4.5	5.4	3.6	4.9
KN5-7E	6.4	1.0	0.8	5.4	2.8	4.8	6.4	97.6	91.0	4.3	4.7	4.7	4.6	5.6	4.1	5.2
KN5-8A	3.0	1.0	0.6	5.2	1.8	5.2	7.0	100.2	109.4	4.0	5.1	4.6	4.6	5.5	3.4	4.9
KN5-8C	2.0	1.0	0.0	5.6	3.4	5.2	6.6	88.0	109.6	4.3	5.5	4.7	4.9	5.7	3.9	4.5
KN5-8D	4.6	1.0	0.8	5.6	1.8	4.8	6.8	101.2	115.4	4.5	5.1	4.8	4.9	5.5	4.2	4.9
KN5-8E	1.8	0.8	0.8	6.0	2.2	4.8	6.8	112.2	90.6	4.3	5.1	4.9	4.9	5.4	4.2	5.0
KN5-9A	4.2	1.0	0.6	5.4	2.2	5.4	6.6	79.4	100.6	4.5	5.0	4.8	4.8	5.4	3.8	5.0
KN5-9B	4.2	1.0	0.0	3.5	6.0	7.0	8.7	115.7	113.0	3.2	4.4	5.0	3.9	4.2	4.6	4.2
KN5-9D	6.0	1.0	1.0	5.0	3.2	5.8	7.0	99.4	91.2	3.3	4.3	4.1	4.0	4.5	5.0	4.6
KN5-9E	4.4	1.0	1.0	5.6	3.4	5.0	7.0	102.0	111.2	4.3	5.0	5.0	4.9	5.5	4.5	4.9
WD1-1	2.0	1.0	0.0	5.3	1.8	5.0	6.0	125.8	82.5	3.9	4.6	4.3	4.3	5.1	3.2	4.1
WD2-1	2.6	0.8	0.0	5.6	3.2	5.0	6.0	96.4	102.2	3.7	4.7	4.3	4.3	4.8	3.7	4.3
WD2-4	1.6	0.6	0.0	5.4	4.2	5.6	6.4	129.0	118.0	3.5	4.9	4.8	4.6	5.3	2.6	4.4
WD3-4	1.8	0.8	0.2	5.0	2.2	6.2	5.8	107.6	83.4	3.9	4.4	4.1	4.2	4.4	3.0	4.0
WD4-4	1.8	0.8	0.0	4.6	5.6	6.0	6.2	104.2	93.0	3.8	4.2	4.3	4.1	4.1	3.7	5.0

WD4-5	1.4	0.4	0.0	5.8	1.2	4.2	4.6	100.4	75.8	3.9	4.8	4.1	4.3	5.0	4.3	4.7
WD5-1	2.8	1.0	0.4	6.0	2.4	5.2	5.6	99.2	84.4	3.3	4.8	4.2	4.2	4.7	4.3	4.0
WD5-4	1.8	0.8	0.0	6.0	2.4	5.0	5.4	100.8	85.2	3.5	4.1	4.1	4.0	4.3	3.9	4.4
WD6-2	1.8	0.8	0.2	5.6	1.6	5.0	6.4	113.2	89.2	4.1	4.5	4.3	4.3	4.8	3.0	4.7
WD6-5	1.8	0.8	0.0	4.8	4.5	6.3	6.5	129.0	118.5	3.9	5.2	5.2	4.6	5.2	2.9	4.5
WD7-1	2.0	1.0	0.0	6.0	1.8	5.0	6.2	109.8	83.0	3.8	4.6	4.1	4.2	4.8	3.7	4.7
WD7-3	1.6	0.6	0.2	6.4	2.4	3.8	4.6	86.4	77.6	4.0	4.1	4.1	4.1	4.4	3.8	4.6
WD7-5	1.8	0.8	0.0	6.0	2.8	6.8	5.0	88.5	65.3	3.5	3.9	3.4	3.6	4.1	3.6	4.1
WD8-4	5.0	1.0	0.2	5.2	2.4	4.6	5.4	95.0	76.2	3.7	4.5	4.1	4.2	5.0	3.5	4.3
WD9-4	2.8	1.0	0.2	5.6	2.8	5.6	4.8	111.4	74.4	3.7	4.0	4.0	3.9	4.1	3.9	4.5
WD10-2	2.6	0.6	0.4	5.8	2.0	4.8	5.6	118.4	72.6	3.5	4.2	3.5	3.7	4.2	3.4	4.7
WD10-3	2.0	1.0	0.0	5.0	1.8	5.4	4.4	92.4	70.2	3.9	4.3	4.1	4.1	4.4	3.6	4.4
WD10-4	2.0	1.0	0.0	5.3	2.3	5.5	5.5	84.8	78.3	3.3	5.1	4.1	3.7	4.7	3.9	4.5
WD11-1	1.8	0.8	0.0	5.0	1.6	4.4	5.6	103.6	72.2	3.2	3.9	4.3	3.9	4.2	4.0	4.3
WD12-2	1.6	0.6	0.0	5.6	2.0	5.8	5.6	105.0	72.2	3.3	4.2	4.0	4.0	4.3	4.1	4.0
WD12-4	1.8	0.8	0.2	5.0	3.0	4.4	4.8	96.4	74.4	4.3	4.4	4.9	4.6	5.2	4.0	3.9
WD13-4	1.8	0.8	0.2	5.6	1.4	4.6	6.6	101.8	98.0	3.9	4.5	4.5	4.4	5.1	3.5	4.7
WD14-2	2.8	1.0	0.0	5.4	2.4	4.6	5.2	116.8	97.2	3.7	4.3	4.4	4.3	5.0	3.1	4.5
WD14-5	2.0	1.0	0.0	5.5	1.3	4.3	6.8	103.5	99.0	4.3	4.4	4.3	4.4	5.3	2.8	4.0
WD15-1	1.4	0.4	0.0	5.6	1.4	4.2	5.8	121.6	85.8	4.0	4.3	3.7	4.0	4.5	3.5	4.7
WD15-5	3.0	1.0	0.0	5.0	6.6	6.0	6.2	103.8	86.8	3.5	4.2	4.1	4.0	3.9	3.5	4.9
WD16-2	2.4	0.8	0.0	5.6	3.2	5.2	5.6	108.4	84.0	3.5	4.3	3.9	4.0	4.3	3.3	4.7
WD16-3	1.6	0.6	0.0	5.6	2.0	5.0	5.0	118.8	76.6	3.9	4.3	3.5	3.8	4.4	3.3	4.7
WD16-5	2.4	0.6	0.0	5.8	2.0	4.4	6.0	100.5	84.8	3.5	4.0	3.8	3.9	4.3	4.0	4.5
WD17-1	2.0	1.0	0.0	6.0	2.2	5.2	6.0	108.2	87.6	4.3	4.8	4.7	4.6	5.2	3.0	4.7
WD17-5	2.0	1.0	0.0	5.6	2.6	5.4	6.2	128.2	93.8	4.0	4.7	3.8	4.1	4.7	3.0	4.8
LSD(0.05)	2.5	0.3	0.5	0.7	1.6	1.0	1.7	25.2	34.4	0.6	0.7	0.8	0.5	0.5	0.8	0.6

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† Rust severity was rated on 8/30/2007 using a 1-9 scale (9 = least symptoms). Rust incidence was rated on 8/30/07 and 9/24/09 as 0 = no infection, 1 = infection.

‡ These traits were measured on a 1-9 scale (9 = best rating for each respective trait)

§ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size (9 = fewest inflorescences). Straw persistence was visually rated on a 1-9 scaled as the proportion of straw and debris present two weeks after inflorescence rating, after mowing (9 = least amount of straw and/or debris).

¶ Lateral spread (mm) was measured as the diameter of the crown at its widest point at a height of 4 cm. Vertical re-growth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing at 6.4 cm.

APPENDIX E

Means separation analysis of turf quality characteristics of native prairie junegrass genotypes grown in low input conditions and mowed weekly from 2007-2009 at Becker, MN. (KC-Colorado, KN-Nebraska, and WD-Minnesota).

Genotype	Rust Severity 2007†	Rust incidence 2007†	Rust incidence 2009†	Fall color‡	Inflorescence emergence§	Straw persistence§	Spring green-up‡	Vertical re-growth¶	Lateral spread¶	Turf Quality 2007‡	Turf Quality 2008‡	Turf Quality 2009‡	Average TQ (2007-09)	Density‡	Mowing Quality‡	Color‡
KC1-1B	1.0	0.0	1.0	6.6	3.0	6.4	3.7	74.3	74.7	4.2	4.9	4.5	4.3	5.1	5.7	5.1
KC1-1C	1.0	0.0	0.8	6.8	3.4	5.4	3.8	64.8	87.5	4.5	3.7	4.0	4.1	4.8	5.3	4.5
KC1-1D	1.0	0.0	0.8	6.4	5.5	6.0	3.8	66.6	67.6	3.6	3.4	4.4	4.0	4.7	5.7	4.8
KC1-2A	1.0	0.0	0.5	7.3	2.8	6.3	3.8	67.0	82.3	3.5	4.0	4.9	3.9	4.9	5.0	5.0
KC1-2D	1.0	0.0	0.8	6.2	1.8	5.6	3.0	73.5	37.5	5.2	4.7	3.1	4.1	5.2	6.0	4.9
KC1-3A	1.0	0.0	0.8	6.0	2.2	4.2	3.0	62.0	46.6	5.2	3.8	3.6	4.0	5.3	4.9	4.7
KC1-3B	1.0	0.0	0.3	6.0	3.0	6.3	1.3	57.0	19.7	4.2	3.8	3.0	3.7	4.4	5.3	5.0
KC1-3C	1.0	0.0	0.3	5.8	1.2	4.8	3.5	60.0	30.3	3.5	4.1	1.8	3.0	4.6	5.2	5.1
KC1-5B	1.0	0.0	1.0	6.3	5.5	6.3	3.8	56.8	51.5	3.6	2.7	3.9	3.3	4.5	5.4	4.1
KC1-5C	1.0	0.0	1.0	6.8	4.8	6.0	2.3	66.8	62.3	3.5	3.3	4.0	3.7	4.0	3.8	4.8
KC1-7A	1.0	0.0	0.8	7.0	3.2	7.0	4.0	78.6	59.0	4.6	4.4	4.8	4.6	5.7	6.0	4.9
KC1-7B	1.0	0.0	1.0	6.4	4.2	7.2	3.8	65.8	75.8	3.8	4.5	4.8	4.3	5.0	5.1	4.6
KC1-8A	2.0	0.2	0.7	6.2	4.4	6.8	3.0	69.0	77.7	4.2	4.1	4.3	4.1	4.7	6.1	4.9
KC1-8B	1.0	0.0	1.0	6.3	4.3	4.7	3.0	77.5	60.0	4.1	3.3	4.2	3.8	4.6	6.1	4.3
KC1-8C	1.0	0.0	1.0	6.5	2.3	5.8	4.5	58.8	89.5	3.8	4.0	4.7	4.3	4.9	4.9	4.9
KC1-9A	1.0	0.0	1.0	6.5	6.3	6.8	2.5	54.0	53.3	2.8	2.6	3.8	3.4	3.8	5.5	4.9
KC1-9B	1.0	0.0	0.0	6.2	1.4	5.6	4.8	73.4	84.4	4.7	4.4	5.3	4.9	6.0	5.8	4.7
KC1-9C	1.2	0.2	0.8	6.4	1.8	5.8	3.0	69.6	52.4	4.4	4.0	3.5	3.8	5.2	5.3	5.5
KC1-10A	1.0	0.0	0.8	6.8	4.0	6.5	4.5	62.5	60.8	3.8	4.6	4.8	4.5	5.4	4.7	5.1
KC1-10B	1.0	0.0	1.0	5.6	1.2	5.4	3.0	76.0	52.8	4.4	3.8	3.5	3.8	5.2	5.8	4.9
KC1-10C	1.0	0.0	0.3	6.5	3.5	6.8	4.8	73.8	87.0	3.7	4.9	5.8	5.1	5.6	5.3	4.7
KC1-11A	1.0	0.0	0.2	7.2	4.0	6.0	5.4	69.2	91.2	3.5	4.8	4.7	4.4	5.1	5.8	5.1
KC1-12A	1.0	0.0	0.5	7.0	2.2	5.2	2.0	65.0	48.5	3.8	4.6	3.1	3.9	4.8	4.8	5.2

KC1-12B	1.0	0.0	1.0	6.6	8.0	6.2	2.5	56.5	67.5	3.3	3.1	2.9	3.2	4.2	4.9	3.7
KC1-12C	1.0	0.0	0.8	6.8	2.2	6.4	3.8	58.4	72.4	4.4	4.0	4.6	4.4	5.2	6.0	4.9
KC1-13A	1.0	0.0	1.0	6.0	5.3	6.0	3.0	58.0	46.7	3.6	2.9	3.8	3.4	3.9	6.3	3.8
KC1-13B	1.0	0.0	0.0	6.3	9.0	7.3	3.0	57.0	19.0	3.1	3.1	1.8	3.0	3.2	4.2	4.4
KC1-13C	2.2	0.2	1.0	5.6	7.8	5.6	3.3	66.0	61.8	3.6	3.4	3.8	3.6	4.8	5.8	4.1
KC1-14A	1.0	0.0	0.0	6.4	6.0	6.4	2.0	0.0	0.0	4.0	5.0	1.0	4.2	5.4	5.7	4.6
KC1-14C	1.2	0.2	0.6	6.2	4.4	5.6	3.4	73.2	57.2	4.6	3.8	4.2	4.2	5.5	5.9	4.7
KC1-15A	1.0	0.0	0.5	7.0	2.8	6.0	5.3	71.3	117.8	4.5	4.4	6.1	5.4	5.5	5.7	4.0
KC3-1B	1.0	0.0	0.3	5.5	4.0	5.8	3.7	66.3	59.7	3.3	3.5	4.0	3.2	4.5	5.1	4.6
KC3-2A	1.0	0.0	0.2	6.4	2.0	5.8	5.4	75.0	94.6	4.5	4.6	5.0	4.8	5.8	5.1	5.3
KC3-2B	1.0	0.0	0.4	6.6	3.2	5.6	5.4	79.6	91.2	4.6	4.5	4.5	4.5	5.5	4.9	5.4
KC3-3A	1.0	0.0	0.6	6.8	2.4	4.4	2.6	69.0	55.8	4.4	3.7	3.0	3.5	4.9	5.6	5.4
KC3-6A	1.0	0.0	0.6	6.8	5.4	6.4	5.2	74.8	100.4	4.0	4.9	4.6	4.5	5.2	4.9	4.9
KC3-7A	1.0	0.0	0.4	7.0	2.6	5.8	4.6	73.6	72.0	3.7	3.7	4.1	3.9	4.7	5.3	5.3
KC3-8A	1.0	0.0	0.6	7.0	2.2	5.8	5.2	76.6	89.2	3.8	4.8	4.2	4.2	5.2	5.7	5.3
KC3-8B	1.0	0.0	0.8	6.5	3.3	5.5	4.5	93.0	82.3	3.7	3.9	5.1	4.4	5.2	4.7	4.9
KC3-9B	1.0	0.0	0.0	6.8	3.4	5.6	3.6	68.6	62.6	4.1	4.0	3.9	4.0	4.9	5.3	5.1
KC3-10A	1.0	0.0	1.0	6.2	3.2	6.0	4.3	71.2	79.4	4.2	3.9	4.1	4.1	5.3	4.9	5.3
KC3-11A	1.0	0.0	0.8	6.8	3.2	4.8	4.0	61.3	66.3	4.4	4.2	3.7	4.0	5.3	5.4	5.3
KC3-11B	2.2	0.2	0.6	7.0	1.4	4.6	4.4	64.2	83.8	4.4	3.9	4.1	4.1	5.0	6.1	5.0
KC3-12A	1.2	0.2	0.8	6.6	4.0	5.2	2.6	66.3	53.8	4.4	3.7	4.3	4.0	5.0	5.9	4.7
KC3-12B	1.0	0.0	0.3	6.6	1.8	3.8	5.0	61.8	78.0	3.5	3.8	4.9	4.1	4.6	4.2	5.2
KC3-13B	1.0	0.0	1.0	7.5	1.8	6.0	3.0	68.5	76.0	4.6	4.3	4.4	4.4	5.1	4.8	6.3
KC3-14A	1.0	0.0	0.0	7.4	1.8	5.8	4.5	78.8	63.0	3.8	3.5	3.7	3.5	4.9	4.6	5.3
KC3-14B	1.0	0.0	0.8	6.6	3.6	5.4	3.3	66.3	54.0	4.8	4.2	3.3	4.0	5.1	5.4	4.9
KC3-15A	1.0	0.0	0.5	5.5	3.0	6.5	4.0	74.0	72.8	3.8	3.2	4.8	4.1	4.2	4.7	4.8
KC3-15B	1.0	0.0	0.0	6.3	3.3	5.5	3.8	74.0	56.3	3.3	3.4	3.3	3.0	4.9	5.1	5.0
KC3-16A	1.0	0.0	0.2	6.6	1.4	5.8	3.8	74.3	71.5	4.3	3.8	3.3	3.7	4.9	5.4	4.7
KC3-16B	1.0	0.0	0.3	5.4	5.0	4.4	3.8	59.8	49.4	4.0	3.5	3.9	3.9	5.1	4.5	4.3
KC3-16C	1.0	0.0	0.2	6.6	2.2	5.6	4.8	79.2	69.8	4.1	4.4	4.6	4.4	4.9	4.7	5.2
KC3-17A	1.0	0.0	0.4	6.2	2.8	5.6	4.8	73.6	92.0	3.9	4.1	5.2	4.6	5.0	5.5	4.9
KC3-17B	1.0	0.0	0.8	6.6	1.8	5.4	3.2	71.3	78.5	4.1	3.7	3.8	3.9	5.3	5.4	4.9
KC3-18A	1.0	0.0	0.8	6.6	1.4	5.2	5.2	87.0	95.4	4.7	4.8	5.8	5.3	6.4	4.7	5.8
KC3-18B	2.6	0.4	0.8	5.0	5.0	6.0	4.0	68.0	76.0	3.8	3.5	3.5	3.7	4.3	5.8	4.7
KC3-19A	1.0	0.0	1.0	6.8	1.2	5.8	3.0	63.5	36.8	3.8	4.1	3.1	3.7	5.0	5.3	5.6
KC3-19B	1.0	0.0	0.6	6.0	3.4	6.0	3.0	69.6	53.0	3.8	3.1	2.9	3.2	4.5	5.9	5.5

KC3-20A	2.5	0.3	0.7	6.7	3.8	6.5	3.7	77.7	69.0	3.6	3.9	3.1	3.6	4.2	4.5	4.9
KC3-20B	1.0	0.0	0.2	6.8	4.6	6.0	4.2	79.6	73.0	4.2	4.1	4.4	4.2	4.9	5.1	5.4
KC4-2A	1.0	0.0	1.0	5.6	4.4	5.0	1.5	60.0	25.5	4.7	4.5	2.9	4.2	4.6	4.7	5.7
KC4-2B	1.2	0.2	0.8	6.0	2.2	5.2	3.0	58.3	41.5	4.1	4.7	2.7	3.6	4.7	5.8	5.4
KC4-3A	1.0	0.0	1.0	6.0	7.2	5.6	6.0	85.0	80.0	3.8	4.6	3.3	4.3	4.8	5.0	4.5
KC4-4A	1.0	0.0	0.5	7.0	3.0	5.0	2.3	78.8	35.8	3.8	3.7	2.4	3.2	4.6	5.2	4.8
KC4-4B	1.0	0.0	1.0	6.2	2.8	5.4	2.7	79.7	27.0	3.9	4.9	2.4	3.5	4.7	4.7	5.2
KC4-5A	1.0	0.0	0.0	6.2	6.4	6.0	3.0	73.0	156.0	4.1	4.6	2.9	4.2	5.6	6.6	4.3
KC4-5B	1.0	0.0	1.0	4.6	5.4	5.2	2.8	71.8	61.5	4.1	2.8	4.0	3.6	4.3	6.0	4.9
KC4-7A	1.0	0.0	1.0	6.2	3.0	4.4	2.7	77.3	43.3	4.3	3.7	4.0	3.9	4.5	5.7	5.5
KC4-8A	1.0	0.0	1.0	7.0	2.0	3.4	2.2	62.8	37.2	4.5	3.7	2.3	3.1	5.0	5.7	5.3
KC4-8B	1.0	0.0	0.0	6.6	6.6	5.8	7.0	65.0	35.0	4.2	5.2	3.1	4.5	5.1	5.2	4.6
KC4-9A	1.0	0.0	0.0	7.2	2.4	5.4	0.0	0.0	0.0	3.8	5.3	--	4.3	4.9	4.7	5.1
KC4-9B	1.0	0.0	1.0	6.4	1.2	5.2	3.7	83.7	60.0	4.5	5.3	3.6	4.4	5.8	5.4	5.9
KC4-10A	1.0	0.0	0.4	6.0	2.2	5.4	5.8	79.2	98.4	4.7	5.0	5.9	5.4	6.4	5.3	5.1
KC4-10B	1.0	0.0	1.0	6.2	1.8	4.8	3.3	67.0	29.7	4.2	4.5	2.8	3.9	5.4	5.3	5.3
KC4-11B	5.4	0.6	1.0	4.6	7.7	6.3	2.5	65.0	61.0	3.5	2.3	2.8	3.0	4.2	6.3	3.9
KC4-13A	6.4	0.8	0.0	4.3	6.5	6.0	2.0	0.0	0.0	2.6	2.2	1.0	2.4	3.9	5.4	3.2
KC4-14A	1.0	0.0	1.0	6.5	4.3	5.5	3.0	67.0	45.0	3.7	4.4	3.1	3.7	4.3	5.5	5.1
KC4-14B	1.2	0.2	1.0	5.8	1.6	4.8	2.3	80.7	43.3	4.1	3.9	3.1	3.7	4.9	5.7	5.5
KC4-15A	1.0	0.0	0.5	5.6	2.4	5.0	3.0	68.0	49.0	4.4	4.6	4.3	4.4	5.0	5.8	5.8
KC4-15B	1.0	0.0	0.8	7.0	2.6	5.2	2.6	76.6	59.0	4.9	3.8	2.9	3.6	4.9	5.8	5.6
KC4-16A	1.0	0.0	0.8	6.2	1.2	4.0	4.0	79.3	56.3	4.1	3.6	3.6	3.8	4.8	5.5	5.1
KC4-16B	1.0	0.0	0.6	6.6	1.0	5.2	1.8	72.2	36.0	4.3	4.8	2.8	3.6	5.1	5.2	5.3
KC4-19A	1.0	0.0	0.7	6.5	3.0	4.5	4.0	70.0	55.7	4.0	4.1	4.3	4.0	5.4	5.0	5.5
KC4-20A	1.0	0.0	0.4	6.2	1.8	5.6	3.6	73.0	45.8	4.3	3.5	3.7	3.8	4.9	4.8	5.3
KC4-21A	1.0	0.0	0.3	6.4	2.8	5.2	4.3	66.0	86.5	3.8	3.5	4.3	3.8	4.4	5.4	5.4
KC4-24A	1.8	0.2	0.8	6.8	2.4	5.0	3.4	74.2	95.6	4.9	4.0	4.1	4.3	5.2	5.4	5.0
KC4-24B	1.0	0.0	0.8	6.6	1.6	5.0	2.8	67.3	37.3	3.6	3.3	3.2	3.3	4.6	5.7	4.9
KC4-26A	1.0	0.0	0.0	6.4	1.4	4.0	4.8	85.0	65.3	4.1	4.1	4.1	4.1	5.2	5.9	5.4
KC4-27A	1.0	0.0	0.0	5.4	9.0	7.0	2.0	0.0	0.0	4.1	2.8	2.5	3.7	3.8	5.6	4.6
KC5-1A	1.0	0.0	0.0	5.0	4.0	5.6	5.0	73.4	68.2	3.8	3.9	4.1	4.0	4.7	4.6	5.3
KC5-1B	1.2	0.2	0.8	6.4	1.8	6.2	4.0	75.4	82.8	4.1	4.3	4.3	4.3	5.7	5.4	4.9
KC5-1D	1.0	0.0	0.0	6.4	2.6	6.4	4.8	91.4	87.8	3.9	4.4	4.2	4.2	5.0	4.8	5.6
KC5-1E	1.0	0.0	0.0	6.4	1.6	5.2	4.8	83.5	87.8	3.8	4.0	4.6	4.0	5.1	5.4	4.9
KC5-1F	1.0	0.0	0.8	6.6	2.0	5.0	3.6	74.0	61.0	4.5	3.3	4.0	3.9	5.2	5.5	4.9

KC5-1G	1.0	0.0	0.2	6.6	2.8	6.4	5.0	70.6	68.0	3.4	4.4	4.1	4.0	4.5	4.4	5.0
KC5-1H	1.0	0.0	0.6	6.8	1.8	5.2	3.2	69.8	71.4	4.3	3.4	4.0	3.9	5.0	5.4	5.1
KC5-2A	4.2	0.4	0.6	6.6	5.0	6.4	2.6	61.0	48.4	4.0	3.3	2.7	3.3	4.5	5.3	4.5
KC5-2C	3.8	0.4	0.0	4.0	7.7	8.3	0.0	0.0	0.0	3.2	1.8	--	2.8	2.9	6.9	3.7
KC5-2E	1.0	0.0	0.8	6.0	3.8	6.2	2.0	64.3	43.5	4.5	4.1	2.0	3.5	5.0	5.5	5.3
KC5-2F	1.0	0.0	1.0	6.0	1.5	6.0	2.0	77.0	32.0	4.0	3.8	2.1	3.6	4.7	5.0	4.1
KC5-2H	1.0	0.0	0.8	6.4	2.2	5.6	3.3	60.2	54.2	5.1	3.8	3.7	4.0	5.1	5.8	4.9
KC5-3A	1.0	0.0	0.8	6.0	3.2	6.4	1.8	64.5	44.0	3.8	3.7	3.1	3.3	4.1	5.7	5.1
KC5-3B	1.0	0.0	1.0	6.0	2.8	5.2	4.8	73.5	65.3	4.5	3.6	4.0	3.9	5.5	5.4	4.9
KC5-3C	2.6	0.4	0.5	5.4	6.2	6.8	2.0	59.0	22.0	3.9	3.7	2.1	3.4	4.5	5.8	4.2
KC5-3E	1.6	0.2	0.8	4.6	4.4	5.8	2.8	69.6	32.6	3.9	3.9	3.4	3.7	4.1	5.8	4.3
KC5-3G	1.0	0.0	0.8	6.4	2.4	5.2	2.5	71.8	30.0	3.8	4.2	2.7	3.4	4.7	5.7	5.5
KC5-4A	1.0	0.0	1.0	6.8	2.8	4.8	2.5	65.8	43.3	4.9	4.5	3.6	4.2	5.5	5.5	5.1
KC5-4B	1.0	0.0	1.0	5.6	3.0	4.8	2.3	63.3	47.7	4.0	4.0	2.9	3.5	4.7	6.3	5.1
KC5-4D	2.0	0.2	1.0	6.6	3.0	6.0	3.0	76.0	57.0	3.5	5.0	3.1	3.9	4.5	4.5	5.6
KC5-4E	2.0	0.2	1.0	6.0	2.6	5.4	3.0	63.5	45.8	4.1	4.4	3.8	4.1	5.0	5.4	5.3
KC5-4G	1.0	0.0	0.0	5.8	3.2	5.8	0.0	50.0	0.0	4.2	4.7	1.0	4.3	5.1	6.5	5.0
KC5-4H	2.2	0.2	0.8	5.8	2.8	4.8	2.3	51.8	46.3	4.6	4.2	2.7	3.8	4.8	5.2	5.3
KC5-5A	1.0	0.0	0.0	6.0	3.6	6.8	4.4	72.8	68.6	3.6	3.7	3.6	3.7	4.5	5.1	4.7
KC5-5B	1.0	0.0	0.7	5.4	3.8	6.0	2.3	54.3	34.3	3.6	3.8	2.3	3.3	4.3	5.9	5.1
KC5-5C	3.2	0.4	1.0	6.2	4.8	6.6	4.3	67.3	71.0	3.5	4.1	4.5	4.1	4.4	4.8	5.2
KC5-5D	1.0	0.0	0.2	6.8	5.2	5.8	4.4	73.0	81.8	5.0	4.3	4.8	4.7	5.6	5.1	5.0
KC5-5F	1.3	0.3	0.3	5.5	6.0	7.0	4.0	74.3	80.8	3.5	3.5	4.6	4.1	4.7	5.4	4.8
KC5-5G	1.0	0.0	0.0	6.0	4.0	6.8	4.5	61.8	98.3	3.9	4.4	4.4	4.5	4.3	5.3	5.2
KC5-6A	1.2	0.2	0.5	6.0	2.2	3.8	2.3	60.5	42.0	4.1	3.7	2.6	3.3	4.8	5.4	4.9
KN1-1A	1.0	0.0	1.0	6.6	3.5	4.8	5.4	61.2	94.2	4.2	4.5	5.4	4.9	5.6	4.6	5.5
KN1-1B	1.0	0.0	0.8	7.2	1.8	5.4	4.5	75.0	101.5	3.4	3.9	4.4	3.9	4.5	5.1	4.8
KN1-2A	1.0	0.0	0.8	6.0	2.0	5.3	3.8	69.5	69.3	3.4	4.1	3.9	3.5	5.4	5.4	5.3
KN1-2B	1.0	0.0	0.8	6.4	1.8	5.8	4.0	77.5	82.3	4.2	3.9	3.8	4.0	5.1	5.1	5.1
KN1-3A	1.0	0.0	0.2	5.6	3.4	5.6	5.4	75.8	104.0	3.9	4.5	4.8	4.5	5.1	4.7	5.6
KN1-3B	1.0	0.0	0.0	6.0	2.5	6.0	5.5	82.5	97.5	3.3	4.4	4.9	4.4	4.7	4.2	5.6
KN1-3C	1.0	0.0	0.0	6.4	2.6	5.4	4.6	78.6	88.8	4.1	4.4	4.7	4.5	5.4	4.8	5.5
KN1-4A	1.0	0.0	0.0	6.6	2.4	6.6	3.7	66.7	42.7	3.4	4.6	3.9	3.8	4.3	5.0	5.1
KN1-4B	1.0	0.0	0.8	6.2	3.6	6.0	4.6	84.8	107.4	3.8	3.8	4.3	4.0	5.0	4.8	4.6
KN1-5A	1.0	0.0	0.8	6.4	1.0	6.4	3.8	75.3	86.3	3.7	3.8	4.0	3.9	5.2	4.8	5.0
KN1-6B	1.0	0.0	1.0	6.4	1.2	5.2	4.7	70.7	70.0	4.3	4.6	4.2	4.3	5.7	5.8	5.4

KN1-7A	1.0	0.0	0.2	6.8	5.4	5.8	3.6	76.8	102.8	4.0	3.7	3.9	3.9	5.0	4.3	4.6
KN1-7B	1.0	0.0	0.8	6.4	7.0	6.0	4.0	72.4	109.8	3.8	3.7	4.3	4.0	5.0	4.9	4.8
KN1-7C	1.0	0.0	0.6	6.4	3.6	5.6	4.6	74.4	97.2	4.1	4.0	3.7	3.9	5.2	5.1	4.9
KN1-8A	1.0	0.0	0.6	6.0	3.4	5.8	4.4	68.2	52.8	3.4	3.8	3.8	3.7	4.8	5.1	5.0
KN1-8B	1.0	0.0	0.4	6.0	4.2	5.8	4.2	81.6	80.6	3.7	3.9	4.3	4.0	5.1	4.4	4.7
KN1-9A	1.8	0.2	0.4	6.2	4.0	5.2	3.8	66.4	69.6	3.7	3.3	3.7	3.6	4.4	5.5	5.0
KN1-10B	1.0	0.0	0.6	6.0	2.6	6.0	3.0	80.0	43.0	3.9	5.1	3.2	3.7	5.3	4.9	5.5
KN1-11A	1.0	0.0	0.8	6.4	3.8	5.2	3.4	75.2	72.4	4.0	3.3	3.5	3.5	5.1	4.6	4.9
KN1-11B	2.0	0.2	0.0	6.0	1.8	5.4	4.8	76.3	77.0	4.5	4.6	4.0	4.4	5.9	4.4	5.1
KN1-12A	1.0	0.0	1.0	6.8	3.6	5.2	2.3	51.3	21.7	2.7	3.2	1.9	2.6	3.2	4.0	4.8
KN1-12B	1.0	0.0	0.3	6.8	4.8	6.3	2.7	73.7	56.0	3.2	4.0	2.8	2.9	4.0	4.8	5.3
KN1-13A	1.0	0.0	0.6	5.4	1.4	5.0	6.4	86.2	119.0	4.2	4.3	5.5	4.9	5.5	4.4	4.4
KN1-13C	1.0	0.0	0.2	6.0	3.0	5.2	3.0	64.2	48.2	3.2	3.0	2.8	3.0	3.8	4.7	4.9
KN1-14B	1.0	0.0	0.8	7.0	2.0	6.6	3.0	73.0	70.8	4.4	4.5	4.1	4.3	5.4	5.0	5.6
KN1-14C	1.0	0.0	0.8	6.6	1.8	6.0	5.2	72.4	96.8	4.3	4.8	4.7	4.6	5.3	5.2	5.3
KN1-15A	1.0	0.0	0.7	6.4	1.6	5.2	3.5	66.5	31.5	3.7	3.4	2.6	3.2	4.1	5.2	4.3
KN1-16A	1.0	0.0	1.0	6.0	2.0	5.8	3.0	76.0	78.7	4.3	3.6	3.4	3.7	5.1	4.9	5.2
KN1-16B	1.0	0.0	0.0	6.2	1.4	5.8	6.0	78.6	118.8	3.9	4.5	5.1	4.6	5.4	4.1	5.5
KN1-17B	1.8	0.2	0.5	6.3	2.8	5.8	3.8	73.3	70.8	4.5	4.5	4.5	4.5	5.6	4.9	5.4
KN2-1A	1.0	0.0	0.8	6.2	2.2	4.6	3.6	69.0	64.6	3.8	3.4	3.8	3.7	4.8	6.0	5.0
KN2-1B	1.0	0.0	0.3	7.3	3.7	3.0	2.7	82.0	57.7	3.2	3.5	3.3	2.9	3.9	5.4	4.6
KN2-2A	1.0	0.0	0.3	7.4	1.4	5.0	3.8	68.3	62.5	4.5	3.9	3.0	3.7	5.0	4.9	5.4
KN2-2B	1.0	0.0	0.8	6.0	3.8	5.4	3.4	82.2	54.0	4.0	3.4	3.4	3.6	4.9	4.5	5.0
KN2-3A	1.0	0.0	0.7	6.6	2.0	5.0	1.7	63.3	32.0	3.4	3.4	2.4	3.1	4.0	4.1	4.6
KN2-4B	1.0	0.0	0.4	6.6	2.8	5.2	3.6	59.2	59.4	4.3	3.9	3.2	3.6	4.9	5.5	5.2
KN2-5A	1.0	0.0	0.8	6.4	2.6	5.2	3.8	75.0	74.4	4.4	3.9	3.8	4.1	5.8	5.2	4.9
KN2-5B	1.0	0.0	0.0	6.6	1.0	5.4	4.0	76.8	80.3	3.5	3.9	3.0	3.5	4.6	4.6	5.1
KN2-6A	1.0	0.0	0.0	6.4	3.2	5.0	4.4	85.0	74.0	3.8	4.3	3.9	4.0	4.9	4.8	4.9
KN2-7A	1.0	0.0	0.5	6.6	2.2	5.4	1.8	67.0	31.3	3.6	4.0	2.3	3.1	4.9	5.6	4.7
KN2-7B	1.0	0.0	0.8	6.4	3.0	5.6	2.2	71.5	42.5	3.4	3.3	2.0	2.8	4.3	4.1	4.9
KN2-8A	2.4	0.2	0.6	6.6	1.6	5.0	3.0	58.0	26.0	3.5	3.3	2.2	2.8	4.1	5.3	5.3
KN2-8B	1.0	0.0	0.4	6.2	1.6	5.0	3.2	60.4	60.2	4.5	3.7	3.4	3.8	4.9	5.6	5.3
KN2-9A	1.0	0.0	0.8	6.6	2.4	5.6	5.0	76.0	82.6	4.1	4.8	4.6	4.5	5.6	5.1	5.7
KN2-9B	1.0	0.0	0.8	6.8	1.2	5.0	4.0	69.2	54.0	3.9	3.9	3.1	3.5	5.0	5.3	5.5
KN2-11A	2.0	0.2	0.5	5.6	1.6	5.6	4.0	69.8	53.5	3.5	3.6	3.7	3.5	4.6	4.4	4.7
KN2-11B	1.0	0.0	1.0	5.6	2.0	5.5	4.5	76.0	89.3	4.3	4.3	4.4	4.2	5.7	4.9	4.8

KN2-12A	1.2	0.2	1.0	6.4	2.5	6.0	2.5	68.6	57.8	3.7	3.6	3.6	3.6	4.2	5.1	5.0
KN2-15B	1.0	0.0	0.3	7.2	3.4	5.2	3.7	51.0	39.0	4.2	3.9	3.4	3.9	4.9	3.9	5.3
KN2-16A	2.0	0.2	0.3	5.0	3.7	5.3	3.7	67.0	54.7	2.8	2.3	3.3	2.9	3.2	5.4	4.8
KN2-16B	1.0	0.0	0.5	6.0	3.0	6.5	2.8	65.5	55.3	3.7	3.0	3.0	3.3	4.5	4.9	4.9
KN2-17A	1.0	0.0	1.0	5.8	6.4	6.0	2.5	67.5	46.3	4.1	3.3	3.0	3.5	4.3	5.6	4.7
KN2-17B	2.0	0.2	1.0	4.5	9.0	4.0	2.5	43.0	35.0	2.6	2.8	3.8	2.7	3.2	3.2	3.2
KN2-18A	1.4	0.2	0.8	5.6	3.4	4.6	4.8	68.8	65.0	3.7	3.2	4.3	3.7	4.7	5.5	4.6
KN2-19B	1.0	0.0	0.6	5.4	2.8	5.6	3.0	66.2	21.4	3.4	2.9	2.1	2.6	3.5	5.8	4.7
KN2-20A	2.4	0.2	0.0	4.5	1.7	4.3	3.0	62.0	40.5	3.4	3.6	2.3	3.1	4.0	6.1	4.4
KN2-20B	1.0	0.0	0.6	6.4	4.8	5.4	2.8	74.2	42.8	3.4	3.3	2.8	3.1	4.4	5.9	5.1
KN2-21A	1.0	0.0	0.8	6.4	2.6	5.6	2.6	80.0	55.6	3.5	3.6	2.9	3.2	4.8	5.6	5.3
KN2-22A	1.0	0.0	0.6	6.8	3.0	5.6	3.0	79.6	65.2	4.0	3.7	3.4	3.6	4.8	4.9	5.2
KN2-22B	1.0	0.0	0.6	7.4	5.0	6.2	4.0	66.6	86.2	3.7	3.8	4.0	3.8	5.0	5.8	5.3
KN3-2A	2.0	0.2	0.5	6.4	3.8	5.4	2.8	68.3	54.3	4.3	3.2	3.3	3.5	5.1	5.1	5.0
KN3-2B	1.0	0.0	0.8	6.8	2.2	4.6	4.0	64.8	43.4	5.0	4.4	3.7	4.2	5.3	4.5	5.4
KN3-3A	1.2	0.2	1.0	7.2	1.8	5.0	2.7	64.0	26.7	4.2	5.7	2.5	4.0	5.2	5.0	5.1
KN3-3B	1.0	0.0	0.3	6.8	2.4	4.2	4.2	74.5	58.3	3.7	3.7	3.5	3.6	4.7	5.2	4.9
KN3-4A	1.0	0.0	0.2	6.4	2.6	4.6	4.2	71.6	74.8	3.5	3.2	3.7	3.5	4.7	4.5	4.7
KN3-4B	1.0	0.0	0.2	5.8	2.0	4.2	5.8	80.0	96.2	4.1	4.3	5.4	4.8	5.6	5.2	5.1
KN3-5A	1.0	0.0	1.0	7.0	1.5	4.0	3.7	68.0	61.7	4.3	3.6	2.9	3.7	5.4	5.8	5.0
KN3-6B	1.0	0.0	0.8	6.4	1.6	3.6	1.8	74.0	42.5	4.0	4.1	2.4	3.3	5.1	4.8	5.0
KN3-6C	1.0	0.0	0.8	6.4	3.2	4.6	4.2	71.3	63.0	4.0	3.9	4.0	4.2	5.1	5.1	5.1
KN3-7A	1.0	0.0	0.4	6.2	3.4	4.2	5.4	66.4	84.2	3.7	4.0	4.7	4.3	5.1	5.5	4.9
KN3-7B	1.0	0.0	0.6	6.2	1.4	5.0	5.2	73.6	67.8	3.9	3.7	4.1	4.0	4.8	5.9	5.3
KN3-8A	1.0	0.0	0.8	6.6	3.6	3.8	3.5	63.8	61.8	4.1	4.0	3.3	3.7	5.1	5.6	4.8
KN3-9B	1.0	0.0	0.5	7.0	3.0	4.0	2.0	56.0	33.3	4.3	4.2	2.1	3.5	4.9	5.1	5.0
KN3-10A	1.0	0.0	0.0	6.2	3.0	4.4	4.2	70.2	68.8	3.7	3.6	3.8	3.7	4.7	5.8	4.5
KN3-10B	2.0	0.2	1.0	6.0	2.8	4.6	2.5	61.0	25.0	3.6	5.1	3.3	4.0	4.6	5.3	4.6
KN3-11A	1.0	0.0	0.0	6.4	1.4	5.0	7.0	86.0	89.0	3.7	5.0	5.5	4.2	4.9	6.1	5.4
KN3-11B	1.0	0.0	0.8	6.8	2.8	4.3	2.8	55.8	54.0	4.4	4.1	3.1	3.3	5.3	6.2	5.8
KN3-12A	1.0	0.0	1.0	6.0	4.8	6.0	3.4	68.4	50.8	3.5	3.7	3.1	3.3	4.3	4.9	5.0
KN3-12B	1.0	0.0	0.0	6.6	2.6	5.8	5.4	71.0	88.0	3.7	4.2	4.6	4.3	5.0	5.2	4.6
KN3-12C	1.0	0.0	0.6	6.6	1.4	5.8	3.6	73.8	54.4	3.9	4.3	2.9	3.5	4.9	4.8	5.0
KN3-13B	1.0	0.0	1.0	6.2	1.6	4.6	2.8	54.4	48.2	4.6	3.3	3.5	3.7	5.0	5.3	4.9
KN3-14A	1.0	0.0	0.2	6.4	3.0	5.4	4.0	67.2	70.8	4.2	4.0	3.4	3.8	4.8	5.7	5.3
KN3-15B	1.0	0.0	1.0	6.0	4.0	5.4	1.7	66.5	44.5	4.0	4.9	1.9	3.7	4.5	5.1	5.1

KN3-16A	1.0	0.0	0.2	7.4	3.6	4.2	4.8	58.8	67.2	3.8	3.2	3.9	3.7	4.4	4.6	5.3
KN3-16B	1.0	0.0	0.4	6.8	2.2	5.8	4.0	79.2	77.2	4.0	4.1	4.0	4.0	5.0	4.8	5.7
KN3-17A	1.0	0.0	0.8	6.6	2.2	5.4	4.2	75.8	67.8	4.0	4.2	4.3	4.2	5.2	5.1	4.7
KN3-17B	1.0	0.0	0.5	6.8	4.4	5.4	5.0	64.0	35.3	3.5	3.8	2.4	3.3	4.6	5.5	5.0
KN3-18A	1.0	0.0	1.0	6.8	2.2	4.6	2.0	73.0	62.0	4.9	4.8	3.1	4.6	5.7	5.5	5.1
KN3-19A	1.0	0.0	0.6	6.4	2.6	6.2	4.8	83.2	77.0	4.3	4.2	4.8	4.5	5.5	4.4	5.1
KN3-19B	1.0	0.0	1.0	6.4	3.0	4.8	3.2	69.4	48.2	3.9	4.0	3.1	3.5	4.6	5.4	5.2
KN4-1A	1.0	0.0	0.3	6.8	1.0	5.3	5.5	63.0	87.8	3.9	4.4	4.3	4.3	5.0	5.3	4.8
KN4-1B	1.0	0.0	0.0	6.8	1.0	3.8	5.2	69.6	88.2	4.5	4.0	4.2	4.2	5.4	5.3	4.5
KN4-1C	1.0	0.0	0.8	6.4	2.8	6.0	4.0	62.6	75.4	3.8	4.0	3.9	3.9	5.3	5.6	4.7
KN4-1D	1.0	0.0	0.0	6.4	2.4	5.8	5.8	82.0	77.6	3.5	4.5	4.6	4.3	5.3	4.1	4.7
KN4-3A	1.0	0.0	0.7	5.8	4.8	5.5	4.3	72.3	48.3	2.8	2.3	3.9	2.8	3.4	5.4	4.8
KN4-3B	5.2	0.6	0.7	4.4	5.0	6.5	3.7	65.3	47.0	2.8	2.8	3.4	2.8	3.0	5.6	3.8
KN4-4B	2.0	0.2	1.0	6.4	3.5	3.3	2.6	64.4	27.8	3.9	3.1	3.4	3.4	4.1	5.4	4.9
KN4-4C	1.0	0.0	0.6	6.8	1.6	4.8	5.2	68.8	86.2	3.7	4.4	4.9	4.5	4.9	5.3	4.7
KN4-5A	1.0	0.0	0.2	5.8	2.4	5.4	5.6	72.4	89.8	4.2	4.1	4.7	4.4	5.1	6.1	4.9
KN4-5C	1.0	0.0	0.7	7.0	3.0	5.6	3.5	49.7	86.7	4.2	4.1	3.2	3.8	4.8	5.0	4.9
KN4-6A	1.0	0.0	0.0	6.8	1.6	5.2	5.0	72.0	84.6	4.4	4.4	4.5	4.5	5.4	5.1	4.9
KN4-6B	1.2	0.2	0.8	4.8	1.0	4.8	5.8	76.3	85.3	3.6	4.2	4.8	4.0	5.0	4.9	4.4
KN4-6C	1.0	0.0	0.0	7.0	1.6	6.0	6.0	77.2	78.4	4.2	4.8	4.6	4.5	5.6	5.4	5.2
KN4-7B	1.0	0.0	0.0	6.5	3.0	4.0	5.0	68.5	64.5	3.9	3.8	3.9	3.5	5.1	5.9	5.0
KN4-7C	1.0	0.0	0.0	7.3	2.0	5.0	3.8	55.0	31.4	3.2	3.1	2.9	3.0	4.0	6.2	5.3
KN4-8A	1.0	0.0	0.6	7.0	3.0	6.8	2.5	71.0	28.8	3.2	2.9	2.4	2.8	3.7	5.6	4.8
KN4-8C	1.6	0.2	0.5	5.8	2.8	5.0	5.3	74.5	66.5	3.4	3.8	4.7	4.1	4.9	5.1	4.6
KN4-9A	1.0	0.0	0.3	5.8	2.3	5.3	6.0	74.0	59.7	3.3	3.2	3.3	3.3	4.0	5.5	4.3
KN4-9B	1.0	0.0	0.8	6.8	3.2	5.4	4.2	65.0	49.2	4.0	3.4	3.8	3.8	4.8	5.4	4.9
KN4-9D	1.0	0.0	0.0	7.0	1.6	5.8	5.6	71.0	75.8	4.0	3.9	4.6	4.3	4.9	4.8	4.9
KN4-11B	1.0	0.0	0.0	6.2	3.0	7.0	5.8	72.6	91.8	3.8	5.7	5.6	5.2	5.4	4.7	5.3
KN4-11C	1.0	0.0	0.6	6.8	1.6	5.0	6.2	81.2	111.6	5.1	4.8	5.5	5.2	6.0	4.9	5.1
KN4-12A	1.0	0.0	0.5	6.0	4.4	4.8	3.8	60.0	47.0	3.9	3.4	3.5	3.7	4.2	6.1	4.9
KN4-12C	1.0	0.0	0.0	6.2	2.2	5.0	5.4	78.0	84.0	4.0	4.3	4.6	4.4	5.1	4.9	4.7
KN4-13A	1.0	0.0	0.7	5.6	3.8	4.8	4.0	82.7	69.7	3.2	4.1	4.0	3.7	4.3	3.6	4.9
KN4-13B	1.0	0.0	0.6	6.8	1.4	4.8	3.6	76.0	59.8	3.9	3.5	3.3	3.6	5.0	5.2	5.0
KN4-15A	1.0	0.0	0.0	6.0	1.0	5.0	5.3	74.3	66.3	3.6	4.5	4.7	4.4	5.2	4.2	4.8
KN4-15B	1.0	0.0	0.0	6.2	1.8	5.2	4.4	66.8	83.8	4.9	4.4	4.2	4.4	5.5	4.6	5.0
KN4-15C	1.0	0.0	0.8	5.8	3.8	6.6	4.2	77.6	67.0	3.6	3.7	4.4	4.0	4.7	5.1	4.9

KN4-16B	1.0	0.0	0.3	7.0	2.5	4.5	2.3	69.7	46.0	3.3	2.9	2.3	2.8	4.1	3.9	3.8
KN5-2B	1.0	0.0	1.0	6.8	2.2	6.0	4.8	75.3	99.3	4.4	4.1	5.0	4.4	5.4	4.5	5.7
KN5-2C	3.2	0.4	1.0	4.4	4.0	5.0	5.3	71.3	44.5	3.2	2.9	4.9	3.7	4.0	5.3	4.5
KN5-2D	1.0	0.0	1.0	6.5	3.3	6.0	3.0	75.5	52.0	3.7	5.8	2.9	4.1	5.0	5.1	5.0
KN5-2E	1.0	0.0	0.4	6.4	5.0	6.2	2.8	73.6	58.4	4.2	3.9	3.4	3.7	4.8	5.1	5.2
KN5-3A	1.2	0.2	0.5	6.4	3.0	6.0	3.5	79.0	82.8	3.8	3.5	3.6	3.6	4.7	4.6	5.2
KN5-3D	1.0	0.0	0.7	6.8	3.2	5.8	2.3	71.3	41.7	3.9	4.2	3.0	3.6	4.5	5.5	5.4
KN5-3E	1.2	0.2	0.7	6.8	3.8	5.8	3.3	75.3	38.3	3.5	4.2	3.2	3.5	4.0	5.7	4.9
KN5-4A	5.6	0.6	0.0	5.0	0.0	0.0	0.0	0.0	0.0	2.2	1.0	--	2.2	3.2	3.5	3.3
KN5-4B	2.2	0.4	0.0	5.8	4.8	5.8	2.0	0.0	0.0	2.8	3.3	1.0	3.0	3.5	5.1	4.5
KN5-4C	2.0	0.2	0.2	6.2	4.0	6.2	5.6	74.8	74.2	3.8	4.3	4.5	4.3	5.1	3.9	5.6
KN5-4D	1.0	0.0	0.2	6.2	2.2	5.6	5.4	88.4	93.0	4.2	4.5	4.9	4.6	5.6	4.6	5.5
KN5-5A	1.0	0.0	0.8	6.0	2.0	5.7	4.8	93.7	70.3	3.9	4.5	4.5	4.4	5.2	4.2	5.7
KN5-5B	1.0	0.0	1.0	6.4	3.0	5.4	2.0	76.8	46.0	3.8	4.8	3.1	3.7	4.9	4.9	5.1
KN5-5D	1.0	0.0	0.6	6.4	2.4	5.6	3.5	72.2	45.6	4.1	3.8	4.3	4.1	4.9	5.7	5.3
KN5-5E	1.0	0.0	0.5	5.6	2.6	6.0	1.5	64.0	38.0	3.5	4.1	1.8	3.5	4.8	5.9	4.5
KN5-6B	1.0	0.0	0.5	6.8	2.4	6.0	1.7	62.5	23.0	4.4	3.7	1.5	3.6	5.0	6.4	5.0
KN5-6E	1.0	0.0	0.0	6.5	2.0	5.8	5.3	72.3	83.8	3.6	5.0	4.6	3.9	5.6	5.1	5.1
KN5-7B	1.0	0.0	0.7	6.8	4.2	5.0	3.0	88.0	61.7	4.3	3.2	3.4	3.5	4.8	5.4	4.5
KN5-7C	1.0	0.0	0.4	6.4	2.0	4.4	3.6	85.6	51.4	4.8	3.6	4.3	4.2	5.7	5.0	4.8
KN5-7D	1.0	0.0	0.8	6.4	2.4	4.8	4.4	69.6	86.2	4.2	3.8	4.4	4.2	5.4	5.2	5.1
KN5-7E	1.0	0.0	0.8	6.6	3.6	5.6	4.4	73.4	59.2	4.2	4.0	3.9	4.0	5.2	4.3	4.9
KN5-8A	1.0	0.0	0.4	7.0	4.2	5.4	5.6	75.0	107.0	4.2	4.7	5.0	4.7	5.4	4.5	5.3
KN5-8C	1.0	0.0	0.2	6.8	3.8	6.2	4.4	78.6	95.4	4.0	4.9	5.1	4.8	5.5	4.9	5.1
KN5-8D	1.0	0.0	0.8	6.8	2.8	5.6	5.0	71.2	90.8	4.8	4.3	5.6	5.1	5.9	5.3	5.2
KN5-8E	1.0	0.0	0.4	7.2	2.8	6.2	4.6	76.6	64.8	3.3	3.9	3.8	3.7	4.0	4.1	5.0
KN5-9A	2.6	0.4	0.5	6.0	4.4	5.0	3.0	60.3	34.3	4.0	4.1	2.6	3.5	4.5	5.2	5.1
KN5-9B	3.2	0.4	0.8	6.5	3.8	5.8	5.0	79.0	74.0	3.3	3.7	4.7	3.8	4.9	4.7	4.1
KN5-9D	1.0	0.0	0.0	4.8	3.0	6.0	6.0	89.0	66.0	2.9	3.8	2.6	3.1	3.8	4.8	4.4
KN5-9E	1.0	0.0	0.8	6.4	3.4	5.4	2.0	65.6	36.2	4.0	4.1	2.9	3.4	4.9	4.9	4.5
WD1-1	1.0	0.0	0.2	6.0	6.0	6.4	4.8	106.0	71.6	3.5	4.1	4.0	3.9	4.8	3.9	4.7
WD2-1	1.0	0.0	0.0	6.2	6.2	6.6	5.0	88.3	73.0	3.0	3.3	3.5	3.3	4.2	4.7	4.8
WD2-4	1.0	0.0	0.0	6.0	7.6	5.4	6.2	94.0	88.8	3.6	4.5	4.5	4.3	5.2	3.1	5.1
WD3-4	1.0	0.0	0.0	6.0	3.3	5.3	6.5	96.8	80.5	3.8	3.9	3.7	3.8	4.9	3.5	5.2
WD4-4	1.0	0.0	0.0	6.4	4.6	5.4	4.8	86.6	95.2	3.7	4.2	5.1	4.5	5.3	4.0	5.1
WD4-5	1.0	0.0	0.0	6.4	4.6	4.6	4.3	87.5	51.0	3.4	3.7	3.8	3.6	4.6	4.2	5.5

WD5-1	1.0	0.0	0.0	6.2	3.8	6.0	5.0	96.5	85.5	3.1	3.2	3.7	3.2	4.1	4.9	5.4
WD5-4	1.0	0.0	0.3	5.2	5.3	6.0	2.0	83.3	55.0	3.4	3.0	2.4	3.0	3.7	4.3	5.2
WD6-2	1.0	0.0	0.0	6.0	4.8	4.8	3.0	90.0	32.0	4.0	3.7	2.3	3.4	5.3	4.5	5.0
WD6-5	1.0	0.0	0.2	6.0	3.4	6.0	5.8	92.8	88.6	4.0	4.3	4.7	4.4	5.5	3.5	4.9
WD7-1	1.0	0.0	0.2	6.2	4.8	5.0	4.8	85.8	84.6	3.6	3.6	3.6	3.6	4.7	4.7	5.1
WD7-3	1.0	0.0	0.0	6.6	3.5	4.6	4.3	71.5	76.3	3.5	3.7	3.9	3.6	4.8	4.7	4.7
WD7-5	1.0	0.0	0.0	6.0	4.8	4.8	3.2	78.6	50.4	3.3	3.2	2.5	2.9	4.8	4.1	4.9
WD8-4	1.0	0.0	0.8	6.4	2.8	5.4	4.0	91.0	59.8	3.2	3.4	3.9	3.6	4.7	3.8	4.6
WD9-4	1.0	0.0	0.2	6.4	2.8	4.8	3.4	74.0	56.0	4.2	3.5	3.0	3.5	4.9	3.9	4.9
WD10-2	1.0	0.0	0.5	5.7	4.3	5.7	4.0	82.5	47.0	3.2	3.5	3.4	3.3	4.6	5.1	4.7
WD10-3	1.0	0.0	0.2	6.0	3.8	5.0	4.4	85.8	64.6	3.8	3.6	3.9	3.8	4.8	4.3	5.3
WD10-4	1.0	0.0	0.0	6.0	4.4	4.8	5.8	94.6	87.2	4.1	4.4	4.1	4.2	5.5	4.4	5.1
WD11-1	1.0	0.0	0.2	6.0	3.0	4.2	4.6	81.6	76.8	3.7	3.9	3.7	3.8	5.1	4.3	4.7
WD12-2	1.0	0.0	0.2	6.0	4.3	4.0	5.2	76.2	70.2	3.3	3.3	3.6	3.4	4.7	4.8	4.7
WD12-4	1.0	0.0	0.3	6.0	7.0	7.3	4.3	91.3	52.0	3.1	3.4	3.2	3.2	4.1	5.5	3.8
WD13-4	1.0	0.0	0.3	5.5	4.5	6.0	5.5	78.5	84.8	3.3	3.8	3.9	3.6	4.0	4.5	5.1
WD14-2	1.0	0.0	0.2	5.8	2.2	5.0	4.4	94.8	89.8	3.9	3.9	4.0	4.0	5.1	4.2	5.1
WD14-5	1.0	0.0	0.0	4.8	5.4	5.0	4.4	88.0	84.6	3.5	3.4	4.4	3.9	5.1	3.2	4.7
WD15-1	1.0	0.0	0.0	6.4	3.8	4.4	3.3	86.0	63.7	3.6	3.6	3.3	3.5	4.7	5.3	4.9
WD15-5	1.0	0.0	0.0	5.6	6.2	5.2	4.2	85.8	74.8	3.9	4.0	3.7	3.8	4.6	4.3	5.3
WD16-2	1.0	0.0	0.0	6.4	3.6	4.4	3.8	92.0	81.3	3.7	3.7	3.7	3.8	4.9	3.7	5.3
WD16-3	1.0	0.0	0.2	6.6	5.4	5.0	4.8	82.0	51.4	4.0	3.3	2.8	3.2	4.5	4.2	4.9
WD16-5	1.0	0.0	0.0	6.6	5.6	4.6	4.5	89.0	66.8	3.4	4.2	3.8	3.8	4.9	4.3	5.2
WD17-1	1.0	0.0	0.0	6.2	4.8	4.8	5.0	90.4	84.6	4.1	4.0	4.1	4.0	5.2	4.1	4.8
WD17-5	1.0	0.0	0.6	6.2	3.4	5.4	4.0	75.6	73.2	3.6	3.3	3.4	3.4	5.1	4.3	5.2
LSD(0.05)	1.2	0.2	0.6	1.3	2.7	1.4	2.1	20.3	38.6	0.9	1.1	1.5	0.9	1.0	1.4	0.7

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† Rust severity was rated on 8/30/2007 using a 1-9 scale (9 = least symptoms). Rust incidence was rated on 8/30/07 and 9/24/09 as 0 = no infection, 1 = infection.

‡ These traits were measured on a 1-9 scale (9 = best rating for each respective trait)

§ Inflorescence emergence was rated as the proportion of inflorescences observed in relation to plant size (9 = fewest inflorescences). Straw persistence was visually rated on a 1-9 scaled as the proportion of straw and debris present two weeks after inflorescence rating, after mowing (9 = least amount of straw and/or debris).

¶ Lateral spread (mm) was measured as the diameter of the crown at its widest point at a height of 4 cm. Vertical re-growth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing at 6.4 cm.