Environmental Influences on Seed Quality of Windmillgrass Ecotypes in South Texas

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Seeds

ABSTRACT

Hooded windmillgrass (*Chloris cucullata* Bisch.) and shortspike windmillgrass (*C. subdolichostachya* Muell.) are native grasses with potential for restoration of wildlife habitat. This study was conducted to characterize variability in windmillgrass seed quality as affected by temperature and precipitation. Seed-fill was superior in 2005 with 18% compared with 10 and 5% obtained in 2003 and 2004, respectively. Hooded ecotypes had higher seed-fill with 17% compared with 8% in shortspike ecotypes. No differences were found in seed viability among years, species, or ecotypes. Average seed dormancy was greatest in 2005 and 2003 with 82 and 81%, respectively, compared with 75% for 2004. Shortspike 9085283 (S-283) and 9085260 (S-260) ecotypes showed greater seed dormancy with values of 94 and 89%, respectively, compared to 73 and 62% for Hooded 9085313 (H-313) and 9085301 (H-301), respectively. Seed germination was highest in 2005 (83%), and the lowest (71%) in 2004. The H-313 and H-301 ecotypes showed the greatest seed germination with 86 and 83%, respectively, compared with 69 and 67% obtained by S-283 and S-260, respectively. We concluded that windmillgrasses are well adapted to variable environments and even when variability existed seed quality was acceptable.

The South Texas Plains occupy nearly 9 million hectares of level to rolling terrain with elevations ranging from sea level to 95 m and the annual rainfall ranging from 450 to 750 mm with peaks occurring in May and September (Mutz and Drawe, 1983). Because of the long growing season and the rainfall patterns, this area has a potential to produce high quality forage for livestock, habitat for wildlife, water, recreation, and to serve as a repository for diverse native plant germplasm (Scifres, 1980). However, primarily as a result of continued excessive grazing by domestic livestock and cessation of fires (Brown et al., 1997), undesirable species have increased to the detriment of naturally occurring desirable vegetation, leading to habitat destruction, soil erosion, water pollution, loss of species diversity, and an overall loss of ecosystem function (Saunders et al., 1991; Allen et al., 2005). Therefore, management strategies are needed to rapidly restore the productive capacity and biological diversity of these degraded grasslands. Critically important phases of the grasslands restoration process are the reintroduction and establishment of native species (Corbin and D'Antonio, 2004).

There has been a recent surge of interest in reclaiming South Texas grasslands to native species (Maywald, 2001). Landowners, many public and private conservation groups, as well as highway departments and the seed industry have been involved in this effort (Markwardt, 2005). Direct seeding is the most economical method of revegetating large acreages (Mortlock, 1999, p. 10–25). However, one of the greatest hindrances to this work has been the lack of commercial sources of seed of South Texas native species such as hooded and shortspike windmillgrass species.

Texas A&M University-Kingsville, the Texas Agricultural Experiment Station at Beeville, and the Kika de la Garza Plant Materials Center (PMC) have been working to identify and develop those native species with the greatest potential for use in restoration projects or improvement of wildlife habitats in South Texas. Early work included screening a broad range of grasses for seed production and growth characteristics, in reference to adaptability to reclaimed South Texas grasslands. Lloyd-Reilley et al. (2005) found several promising grasses including plains bristlegrass (*Setaria* spp.), hooded windmillgrass (*Chloris cucullata* Bisch.), shortspike windmillgrass (*C. subdolichostachya* Muell.), and brownseed paspalum (*Paspalum plicatulum* Michx.) ecotypes.

Hooded windmillgrass is a short, warm-season perennial bunchgrass with culms 15 to 60 cm tall that produces multiple seed crops, allowing it to reseed itself and spread; whereas shortspike windmillgrass is a medium-growth strongly stoloniferous warm-season perennial grass with culms 30 to 70 cm. tall (Gould, 1975, p. 1–6; Correll and Johnston, 1996, p. 238–242). Both grasses are native throughout Texas, Oklahoma, New Mexico, and northeast Mexico (Hitchcock,

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Abbreviations: H301, hooded 9085301; H-313, hooded 9085313; PMC, Plant Materials Center; S-260, shortspike 9085260; S-283, shortspike 9085283.

1971; Hatch et al., 1999, p. 105–106), and have potential for planting on highly erodible sites, especially for roadsides and on sites where introduced species are not desired. However, the effects of annual fluctuations in the environment on seed quality of windmillgrass ecotypes including dormancy, viability, seed-fill, and germination rates have received little attention.

Environmental variation has proven important in seed quality of other grass species. Levine and Rees (2004) found that consecutive favorable years were beneficial to quality seed production in grasses. Also, Gimenez-Benavides et al. (2005) suggested that the quality of seed produced might vary greatly within a single species from one population to another, from year to year, and among individuals.

One major life-history process causing plant species to differ in their response to the environment is their seed dormancy and germination biology (Ellner, 1987; Chesson, 1990; Rees and Long, 1992). Baskin and Baskin (2001) mentioned that species possess wide variation in seed viability, seed-fill, germination rates, and germination cues. Thus, dormancy and germination biology are almost certain to be influenced by weather variability that favors or inhibits high quality seed production. Likewise, Boe (2003) stated that both biological and environmental factors could influence seed quality; therefore the temporal variability in the environment needs to be considered when producing seed to develop management guidelines for a successful seed production industry.

Chambers (1989) evaluated the seed viability of Idaho fescue (*Festuca idahoensis* Elmer), and tufted hairgrass [*Deschampsia cespitosa* (L.) Beauv.] as affected by variability within and among years. He found that percent of seed-fill varied greatly from year to year. Also differences in seed viability existed among collection years with values of 83, 4, 43, and 25% for Idaho fescue, and 79, 8, 60, and 46% for tufted hairgrass in 1983, 1984, 1985, and 1986, respectively.

Masters et al. (1993) conducted a study from 1987 through 1990 to evaluate seed production on big bluestem (*Andropogon gerardii* Vitman) and indiangrass [*Sorgastrum nutans* (L.) Nash] and found that germinable seed produced by the grasses was influenced by the rainfall pattern. Seed germination of big bluestem (76 and 82%) and indiangrass (79 and 87%) was high when precipitation was above or near the long-term average during 1987 and 1990. Low seed germination (46%) was obtained in both grasses during 1988 and 1989 when precipitation was below average throughout the entire growing season. Also, they stated that seeds harvested in 1988 were shriveled with no obvious endosperm. They concluded that the adverse effect of precipitation deficit on plant growth and development during the growing season probably accounted for poor seed-fill during 1988 and 1989.

Phaikaew et al. (2001) working on *Paspalum atratum* (Swallen) in a 3-yr trial found that there were variations in seed quality components over the 3 yr of the experiment. Low seed germination and purity in year two was attributed to the heavy rainfall and flooding in that year, which depressed growth of the grass and decreased seed quality when compared with the other years.

This current study evaluated variability in seed-fill, dormancy, viability, and seed germination of two of the most promising ecotypes of hooded and shortspike windmillgrass ecotypes as affected by inter-annual fluctuations of temperature and precipitation in South Texas.

MATERIALS AND METHODS

Hooded and shortspike windmillgrass seeds were collected by hand in 2003, 2004, and 2005 from field plots located at the Kika de la Garza PMC at Kingsville, TX. The seed was harvested in each year during May and June on hooded windmillgrass ecotypes, and during August and September on shortspike windmillgrass ecotypes. Harvested seed was stored in a seed vault with a temperature of 10°C and 50% relative humidity. The seed quality evaluation was conducted in November of the year it was harvested.

The Kika de la Garza PMC is located just outside of Kingsville, TX (27° 33′ N, 97° 52′ W; 16 m elevation). In winter, the average temperature is 14°C, whereas in summer it is 29°C. The mean annual rainfall is 655 mm with long-term rainfall well distributed in the growing season for warm-season grasses. September is the wettest month with 113 mm rainfall, whereas March is the driest month with 23 mm. Humidity is high during most of the year because the prevailing southeasterly winds bring in moist air from the Gulf of México with an average of 90% at dawn and around 60% by mid-afternoon (USDA-SCS, 1992, 1982; USDA-NRCS, 2005). The topography of the PMC is flat. The soils at the PMC are classified as fine, mixed, hyperthermic Vertic Calciustolls (Raymondville clay loam) and moderately crumbly, Calcareous Grumosols (Victoria clay). Raymondville clay loam soils are characterized as moderately well drained, slow surface runoff, low permeability, and the available water holding capacity is moderate (USDA, SCS 1982), whereas Victoria clay soils are dark, calcareous, crumbly soils that crack when dry and swell when wet and take in water slowly (USDA-SCS, 1992).

The studied windmillgrass ecotypes were S-260 from San Patricio County, S-283 from Calhoun County, H-301 from Duval County, and H-313 from Kenedy County. Four replications of 100 seeds of each ecotype were used for determining percent seed-fill. Each seed was checked by palpation to determine if it contained a well-developed caryopsis. The hard caryopsis can be easily felt in mature seed by pressing the seed with the fingers (CIAT 2004).

Viability of seeds (conducted only on seed found to be classified as *filled-seed*) from each ecotype of the three harvest years was evaluated using 1% aqueous solution of tetrazolium (2, 3, 5-triphenyl tetrazolium chloride). Four replications of 100 filled seeds were soaked in distilled water for 18 h, subsequently, the lemma and palea were removed and the caryopsis was bisected longitudinally with a razor blade to expose the main structures of the embryo. As per the Grabe methodology (Grabe 1970), half of each caryopsis was immersed in the tetrazolium solution. After 3 h of dark incubation at 30°C, the caryopsis with completely stained embryos were scored as viable (Association of Official Seed Analysts, 1970).

Seed dormancy (again, only on seed classified as filled-seed) was determined on whole seed. A seed was classified as dormant when it did not germinate after 28 d in the germinator. To determine the percent and rate of germination, a second germination test was made on the naked caryopsis, which was extracted by rubbing the seed by hand on a corrugated rubber mat with a rubber block to remove the lemma and palea from the whole seeds. This test could best be described as a measure of active germination. A South Dakota Seed Blower (Seedburo Equipment Co., Chicago, IL) was used to separate the bare caryopsis from the chaff.

Clear plastic boxes that were 13 by 13 by 3.5 cm, with tight fitting lids, were used to germinate all seeds. The substrate for each container was one sheet of K-24 Kimpack 14-ply cellulose paper and one of blue paper (both are from Anchor Paper Co., St. Paul, MN). The Kimpack blotter paper is designed to be very absorbent and maintain moisture for the seeds. The blue paper improved the contrast with seeds to facilitate counting the seedlings, resulting in more reliable counts (Schleicher and Schuell, 2002). The seeds were moistened with distilled water. Each box, containing 100 randomly selected caryopsis (or whole seed depending on the test), was considered as an experimental unit. Four replications per ecotype from each harvest year were used in the study. Germination conditions were 12 h dark 20°C and 12 h light 30°C. Germination counts were made every day for 28 d. The seeds were considered germinated if both the radicle and coleoptile exceeded the seed in length and the seedling was normal according to the seedling evaluation criteria of the Association of Official Seed Analysts (1992) for comparable grasses. Seedlings were removed as they were counted.

Data were analyzed using a randomized complete block design with a three-way factorial arrangement of treatments with four replicates (Snedecor and Cochran, 1980). The factors evaluated were 3 yr, two species, and two ecotypes. The seed-fill, viability, and germination data were subjected to analysis of variance using the general linear model procedure of the Statistical Analysis System (SAS Institute, 2000). Differences in seed germination and dormancy among species and ecotypes were determined from analysis of change in seed viability in 2003, 2004, and 2005. An arcsine transformation was used on percent germination data before analyses. Differences were considered significant when $P < 0.05$. Mean separations were performed using Duncan's Multiple Range Test ($P < 0.05$). The grass plots were replicated within years, in others words, the seed samples were harvested from the same plots each studied year.

Table 1. Mean monthly temperature and total monthly rainfall for 2003, 2004, 2005, and 30-yr average at Plant Materials Center, Kingsville, TX.

	2003		2004		2005		30-yr avg. (1975–2005)	
Month	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall
	°C	mm	°C	mm	°C	mm	°C	mm
Jan.	12.3	25.50	15.0	50.00	16.1	18.50	14.2	24.14
Feb.	13.8	33.50	14.4	53.50	17.1	75.50	15.3	30.14
Mar.	17.7	32.25	21.5	27.00	19.0	61.50	20.8	47.14
Apr.	22.2	3.00	21.7	230.25	22.5	5.25	22.4	41.79
May	27.4	0.25	24.5	134.00	25.2	47.50	26.3	67.71
June	28.1	81.25	27.9	61.00	27.8	48.50	27.7	81.00
July	28.1	107.00	28.6	31.75	29.4	45.75	28.9	56.39
Aug.	28.8	41.25	29.2	4.50	30.4	6.25	29.9	69.93
Sept.	26.1	268.30	27.2	218.25	29.1	110.75	27.8	153.39
Oct.	25.9	89.50	26.6	18.00	23.3	78.75	25.2	82.61
Nov.	19.8	21.50	19.8	31.25	19.8	125.50	19.6	70.21
Dec.	14.9	14.25	13.9	12.00	14.8	9.00	14.4	29.25
Avg.	22.1		22.5		22.9		22.7	
Total		717.55		871.50		632.75		753.70

RESULTS

Temperatures were similar during the growing season (May to September) of the years in this study (Table 1). On the other hand, the amount and distribution of annual rainfall was markedly different among years (Fig. 1) with total amounts of 717, 871, and 633 mm in 2003, 2004, and 2005, respectively. Total precipitation during the growing season was 498, 449, and 259 mm for years 2003, 2004, 2005, respectively (Table 1). There were differences among years in the rainfall distribution during the growing season. In the first year (2003), the driest months were during seed head formation and pollination of hooded windmillgrass (April and May). But for the total growing season, rainfall was near the average for the location. The second year (2004) was a record high rainfall year. However, this wetter than average rainfall year was made up of a wet spring followed by a dry summer, which coincided with the windmillgrass growing season. In the third year (2005), total rainfall was below the 30 yr average, but moderate rainfall occurred during seed head formation and the growing season.

No interactions among factors were found for percent seed-fill. Percent seed-fill of windmillgrass ecotypes varied greatly from year to year (Table 2). Seed-fill was greater for 2005 compared with 2003 and 2004 with values of 18, 10, and 5%, respectively. Seed-fill of hooded windmillgrass ecotypes was greater than for shortspike windmillgrass ecotypes in 2003 and 2005, but in 2004 the results were similar among all ecotypes. Seed-fill was different between windmillgrass species for the 3 yr average with values of 7, 10, 15, and 18% for S-260, S-283, H-301, and H-313, respectively.

No interactions were significant in seed viability. Seed viability (of filled-seed) was similar among years with average values of 69, 71, and 75% for 2003, 2004, and 2005, respectively. Seed viability of shortspike and hooded windmillgrass was similar with values of 72% and 71%, respectively. Seed viability was similar among windmillgrass ecotypes with values of 76, 66, 75, and 69% for S-260, S-283, H-301, and H-313, respectively. In general, seed viability of windmillgrass ecotypes is maintained among years independent of environmental factors that impact percent seed-fill (Table 2).

No interactions were apparent for seed dormancy. Percent of seed dormancy (of whole, filled seed) varied from year to year (Table 2). Seed dormancy was greater in 2005 and 2003 compared with 2004 with values of 81, 82, and 75%, respectively. Shortspike windmillgrass ecotypes had greater average seed

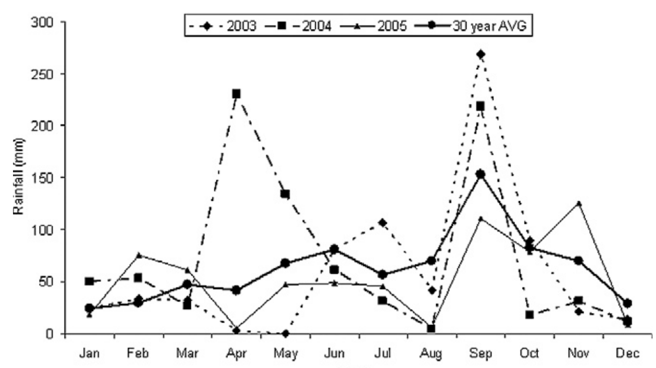

Fig. 1. Total monthly rainfall (mm) during the 3 yr when seeds were collected for the study at the Plant Materials Center, Kingsville, TX.

Table 2. Year effect on percentage seed-fill, viability, dormancy, and seed germination in windmillgrass ecotypes in South Texas (Mean ± SE).

	Seed-fill			Viability			Dormancy			Germination		
Ecotypes	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005
Shortspike-260	5 ± 1.4 b†	4 ± 0.8 c	11 ± 2.6 a	73 ± 8.5 a	75 ± 6.7 a	79 ± 0.8 a	90 ± 2.3 ab	86 ± 2.9 b	92 ± 2.4 a	78 ± 1.6 a	54 ± 3.3 c	69 ± 3.8 b
Shortspike-283	8 ± 1.8 b	4 ± 1.6 c	14 ± 3.7 a	64 ± 6.3 a	66 ± 7.9 a	69 ± 2.2 a	96 ± 1.8 ab	88 ± 1.7 b	97 ± 1.7 a	67 ± 4.2 b	68 ± 3.3 b	73 ± 2.6 a
Hooded-301	12 ± 2.5 b	5 ± 2.2 c	20 ± 2.7 a	72 ± 9.1 a	74 ± 8.5 a	79 ± 3.0 a	63 ± 2.4 a	60 ± 2.1 b	63 ± 3.0 a	84 ± 2.8 b	75 ± 4.2 c	91 ± 2.6 a
Hooded-313	15 ± 2.5 b	8 ± 3.7 c	26 ± 2.5 a	67 ± 6.5 a	68 ± 8.7 a	72 ± 2.1 a	76 ± 4.3 a	69 ± 0.97 b	75 ± 2.2 a	78 ± 4.3 c	86 ± 3.7 b	94 ± 1.6 a

† Values within rows in each response variable followed by different letters are significantly different ($P < 0.05$).

dormancy with 91% compared with 67% for hooded windmillgrass. The H-301 ecotype consistently exhibited the lowest seed dormancy, with an average of 62% compared with 73, 89, and 94% for H-313, S-260, and S-283, respectively.

For seed germination (of naked caryopsis), the interaction between year × species × ecotypes and the two-factor interaction year × species were not significant, but there was a two-factor interaction year × ecotype. The S-260 ecotype had the greatest seed germination with 78% in 2003, with intermediate germination of 69% in 2005, and the lowest value of 54% in 2004. The S-283 ecotype showed the greatest seed germination with 73% in 2005, whereas the seed germinations obtained in 2003 and 2004 were similar with 67 and 68%, respectively. The hooded windmillgrass H-301 ecotype was superior in 2005 with seed germination of 91%, compared with the intermediate germination of 84% obtained in 2003, and the lowest value of 74% obtained in 2004. Ecotype H-313 performed best in 2005 with a 94% seed germination, compared with the intermediate germination of 86% obtained in 2004, and the lowest value of 78% obtained in 2003 (Table 2). Hooded windmillgrass ecotypes were greater in seed germination than that of shortspike windmillgrass ecotypes with germination of 85 and 68%, respectively. In relation to germination rate, most ecotypes germinated rapidly (Fig. 2). Plotted germination curves revealed a minimum period to initiate germination of 3 to 5 d, except S-283, which required 11 d.

DISCUSSION

Previous studies on native grass species from around the world suggest that seed quality may vary greatly within a species from one population to another, from year to year, and among individuals (Biedenbender et al., 2003; Clark et al., 2003; Levine and Rees, 2004). The effects of precipitation on seed quality among different years in windmillgrass ecotypes were similar compared with other research data on other perennial grasses. Lemke et al. (2003), working on 'Pete' and 'Iuka' cultivars of eastern gamagrass [*Tripsacum dactyloides* (L.) L.] during 2000 and 2001, found that year and cultivars had the greatest influence on seed quality. For the year 2000, growing season rainfall was 360 compared with 580 mm that

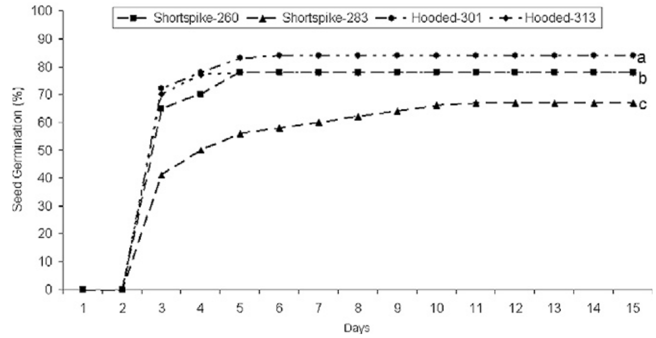

Fig. 2. Germination curves of seeds of windmillgrass ecotypes at 15 d in South Texas.

occurred in 2001, resulting in an increased seed quality of 80% during 2001. They attributed this difference to the age of the stand, the production environment, or a combination of the two. Pete produced higher seed quality (20% more) than Iuka in both years.

The variability observed in seed-fill for windmillgrass ecotypes among years is largely attributable to precipitation pattern. High seed-fill obtained in 2005 from the windmillgrass ecotypes coincided with adequate rainfall during flowering for hooded windmillgrass (April and May) followed by sufficient rainfall during the growing season (May to September). In addition, the 2005 growing season benefited from the high rainfall amounts. In contrast, low seed-fill obtained in 2003 and 2004 could be related to variable rainfall throughout the growing season.

The monthly rainfall for April and May that occurred in 2003 at the PMC in Kingsville was lower than the 30-yr average; these months correspond with inflorescence development of hooded windmillgrass ecotypes and adequate moisture at this stage is critical for a seed crop. On the other hand, 2004 was a record rainfall year but was considered an unfavorable year for seed production because excessive rainfall occurred during seedhead formation, which may have promoted new vegetative tiller growth during anthesis, depressing seedhead development (Hoglind et al., 2001). Another important issue to consider is that the record rainfall in 2004 may have affected pollination due to high temperature and high relative humidity, which may have reduced pollen survival. Clemence and Hebblethwaite (1984) suggested a major cause of the low and variable seed-fill in *Lolium perenne* L. was the competition for assimilates between seedheads and new vegetative tillers. However, Warringa and Kreuzer (1996), working on the same grass species, concluded that competition between growth of new vegetative tillers (after onset of anthesis) and seed for either carbohydrates or nitrogen is not a major cause of reduced and variable seed-fill. In agreement with these results, they recommended that during dry years, soil moisture needs to be maintained to provide less stressful conditions for plant growth and seed production, especially before flowering and at the beginning of the growing season.

The viability of seeds in windmillgrass ecotypes in our study was not affected by environmental conditions among production years, demonstrating the genetic stability of the four ecotypes tested. Such stability of seed viability among windmillgrass ecotypes indicated that they are well adapted to South Texas climate with unpredictable environments.

In Thailand, Gobius et al. (2001) found similar results working with *Brachiaria decumbens* cv. Basilik, *Andropogon gayanus* cv. Kent, and *Digitaria milanjiana* cv. Jarra over 3 yr. They concluded that seed viability was not affected by environmental factors among years where the values ranged from 65 to 82%, 71 to 77%, and 38 to 50% for *Brachiaria decumbens*, *Andropogon gayanus*, and *Digitaria milanjiana*, respectively. In another study (Chambers, 1989), differences in seed viability were found among seeds of Idaho fescue (*Festuca idahoensis* Elmer), and tufted hairgrass [*Deschampsia cespitosa* (L.) Beauv.]. Seed viability averaged over species was 90, 50, 53, and 65% for 4 yr. Years differed from each other, with one exception. These differences were attributed to poor seed development during the undifferentiated years as a result of low soil moisture during the seed formation stage.

Dormancy (in whole seed) was greater in seeds harvested in dry years (2003 and 2005) compared with the wet year (2004). These results agree with the results reported by Steadman et al. (2004) who indicated that seeds from plants of annual ryegrass (*Lolium rigidum* Gaud) grown in reduced moisture conditions lost dormancy faster than seeds from well-watered plants. The variability of seed dormancy characteristics could be interpreted as one of the most important survival strategies for species growing under unpredictable environment conditions (Gutterman, 1994; Kigel, 1995). On the other hand, Briske et al. (2003) suggested, based on traditional conservation biology, that environmental fluctuations are detrimental to plant persistence, because they reduce long-term average growth rates and increase the probability of extinction. In contrast, coexistence models from community ecology suggest that for species with dormancy, environmental fluctuations may be essential for persistence in competitive communities (Pyke and Archer, 1991). In addition, Levine and Rees (2004) used models based on California grasslands to examine the influence of inter-annual fluctuations in the environment on the persistence of rare forbs competing with exotic grasses, and they concluded that yearly fluctuations in climate might be essential for the persistence of rare species in invaded habitats.

The seed of hooded windmillgrass ecotypes had less dormancy than seed of shortspike windmillgrass ecotypes. This is interesting because shortspike windmillgrass is genetically differentiated from hooded windmillgrass (Hitchcock, 1971). Shortspike appears to have evolved to have more dormancy in response to environmental conditions of South Texas, adapting to persistence in an unpredictable environment. Shortspike windmillgrass ecotypes have higher phenotypic plasticity for seed dormancy than hooded windmillgrass ecotypes. Our results indicate that under long-term severe environmental conditions, shortspike windmillgrass ecotypes are at less risk of extinction than are hooded windmillgrass ecotypes because of their stronger seed dormancy.

In introduced populations of fountain grass (*Pennisetum setaceum* Forsk.), Williams et al. (1995) found no evidence for local adaptation across a fluctuating environmental gradient because fountain grass lacked phenotypic plasticity for seed dormancy, which it needed to protect itself from adverse conditions encountered at restoration sites. Poulin et al. (2005), on the same grass species, found no genetic variation within any population or between three geographical areas, a pattern consistent with complete apomixis. This study revealed that variation in establishment success appears unrelated to genetic differences among populations, but the variable invasiveness of fountain grass is caused by differences in the seasonal timing of rainfall among the regions.

In reference to seed germination, variability among years, species, and ecotypes was observed in this study. The first year was very dry during seedhead formation, the second year was characterized by a wet spring and a dry summer, whereas the third year proved favorable to seed production because rainfall occurred during critical plant growth stages (seedhead formation and seed development) in addition to the fact that rainfall in the previous growing season was above average, providing good soil moisture for a vigorous plant coming into the season. Since these two species do not flower at the same time, but often responded the same within a year, it appears that seed quality is influenced by early season rain or the effects of a wet previous season. Variation in germination has been attributed to genetic differentiation among populations in some cases, but variable environmental factors are known to influence germination to a large extent (Via and Lande, 1985; Donohue, 2003).

Gibbens (1991), studying the effects of precipitation patterns on mesa dropseed (*Sporobolus flexuosus* Thurb.) from 1979 to 1987, found that even in relatively wet years there were one or two periods of no growth, whereas periods of rapid growth occurred after a year with high rainfall events, and was highly correlated ($r = 0.98$) with high exertion of seedheads and seed germination. Marone et al. (2000) also reported effects of rainfall patterns on seed germination in grasses, where germination of grass seed increased 36% after an unusually abundant rainfall related to an El Niño Southern Oscillation event. Those assumptions agree with the study conducted by Schwinning and Sala (2004) on arid and semiarid ecosystems, where they found that rainfall events can trigger the germination of different sets of species because when a dry period is interrupted by a sudden rainfall event, all plants are usually not in an optimal state to utilize the pulse of soil moisture, but by the following year they modify their physiological state. For example, the synthesis and storage of more photosynthate, or the growth of new leaves or roots, result in increased seedhead formation and germination rates as a response to hierarchy for ecosystem processes.

CONCLUSIONS

We conclude that windmillgrass ecotypes are well adapted to variable environments and there is sufficient genetic stability to allow selection of genotypes for seed quality in South Texas conditions. The genetic resources evaluated showed a differential response in almost all seed quality components to the effects of precipitation. Seed production of windmillgrass ecotypes may be feasible in the South Texas environment with acceptable levels of seed quality components in all studied ecotypes, considering that both wet and dry years are part of the normal long-term weather pattern in the South Texas region. For commercial seed production, our data suggest that the use of strategic irrigation has the potential to increase the quality of the seed harvested.

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