July 2003

Establishment and Seedling Growth of Big Bluestem and Switchgrass Populations Divergently Selected for Seedling Tiller Number

Alexander J. Smart
South Dakota State Univ., Brookings, SD

Lowell E. Moser
University of Nebraska - Lincoln, lmoser1@unl.edu

Kenneth P. Vogel
USDA-ARS

Establishment and Seedling Growth of Big Bluestem and Switchgrass Populations Divergently Selected for Seedling Tiller Number

Alexander J. Smart,* Lowell E. Moser, and Kenneth P. Vogel

ABSTRACT

Selection at the seedling stage in grass breeding would be extremely useful if seedling traits are correlated to desired agronomic traits. The objective of this study was to evaluate seedling morphological development, plant growth, and field establishment of big bluestem (*Andropogon gerardii* Vitman) and switchgrass (*Panicum virgatum* L.) populations that were developed by divergent selection for seedling tiller number while selecting for high shoot weight. Six populations were evaluated: (i) 'Pawnee' big bluestem base, (ii) 'Pathfinder' switchgrass base, (iii) big bluestem multiple tiller, (iv) big bluestem single tiller, (v) switchgrass multiple tiller, and (vi) switchgrass single tiller. Field plots were seeded in spring 1999 and 2000 in a Kennebec silt loam (fine-silty, mixed, superactive, mesic Cumulic Hapludolls). Plants were excavated and evaluated during the growing season for shoot weight, root weight, and morphological stage of shoot and root systems. There were no major population differences in shoot weight, root weight, and morphological root stage. Shoot stage was higher for multiple tiller populations than single tiller populations 6 wk after emergence. Stand counts for all populations exceeded 10 seedlings per linear m of row, which is considered an acceptable stand density, and there were no consistent differences among populations. Populations divergently selected for seedling tiller number did not differ in ability to become established under field conditions because root systems apparently were not altered by the selection for seedling tiller number and weight. These results suggest that selection for high shoot weight did not improve seedling vigor in the field.

SEEDLING ESTABLISHMENT is a major limitation for incorporating improved cultivars of native warm-season grasses into a forage system. Lack of successful establishment of perennial forage grasses has been attributed to inadequate surface moisture (Newman and Moser, 1988b), weed competition (McCarty et al., 1967; Martin et al., 1982), excessive planting depth (Carren et al., 1987; Newman and Moser, 1988a), and low seedling vigor (Hyder et al., 1971; Berdahl and Barker, 1984).

Seedling vigor is a conceptual term and cannot be directly measured, but traits associated with seedling emergence or establishment success can be determined. Seed size (Kneebone, 1972), coleoptile length (Berdahl and Barker, 1984), water uptake (Nason et al., 1987), and shoot weight (Glewen and Vogel, 1984) have been used as indicators of seedling vigor.

Whalley et al. (1966) described three stages of seedling growth: heterotrophic, transitional, and autotrophic. Seedling growth in the heterotrophic stage includes all physiological processes before initiation of photosynthesis. The autotrophic stage includes seedling growth after all endosperm reserves have been depleted and is completely dependent on photosynthesis. The transitional stage, that period of flux between the two stages, is when seedling failure is most likely. A selection criterion that theoretically integrates all the physiological processes associated with seedling growth is seedling shoot weight at a given date or stage after seeding.

Tiller development of seedlings also may affect seedling vigor by affecting the source–sink relationship of photosynthate used for growth. In tall fescue (*Festuca arundinacea* Schreb.), seedlings that had more tillers and low leaf elongation rate produced 34% less root mass than seedlings that had fewer tillers and high leaf elongation rate (Skinner and Nelson, 1994). Song et al. (1990) reported that tall fescue seedlings with fewer tillers produced longer roots than seedlings that had more tillers when grown in a hydroponic solution with different N levels. Previous greenhouse studies have reported that big bluestem and switchgrass populations, developed by divergent selection for seedling tiller number while selecting for high shoot weight in 6- to 8-wk-old seedlings, differed in mean seedling tiller number and seedling shoot weight (Smart, 2001). After two cycles of selection, single-tiller populations had greater shoot weight than multiple tiller populations or base populations (Smart, 2001).

The objective of this field study was to evaluate seedling growth rate, morphological development, and establishment of big bluestem and switchgrass populations (Smart, 2001) that differed in seedling tiller number and weight at 6 to 8 wk after planting. This experiment was conducted to test the hypothesis that divergent populations of big bluestem and switchgrass selected for seedling mass and seedling tiller number at 6- to 8-wk of age in the greenhouse differ in seedling growth rate, morphological development, and establishment success in the field.

MATERIALS AND METHODS

Two field experiments were conducted in 1999 and 2000 at the University of Nebraska Havelock Agronomy Farm in Lincoln, NE. The soil was a Kennebec silt loam (fine-silty, mixed, superactive, mesic Cumulic Hapludolls). Rainfall and temperature data were obtained from the University of Nebraska-Lincoln Havelock Agronomy Farm monitoring station (High Plains Regional Climate Center, 2000).

A.J. Smart, South Dakota State Univ., Dep. of Animal and Range Sci., Box 2170, Brookings, SD, 57007; L.E. Moser, Agronomy and Horticulture Dep., 279 Plant Sci., P.O. Box 830915, and K.P. Vogel, USDA-ARS, 344 Keim Hall, P.O. Box 830937, Univ. of Nebraska, Lincoln, NE 68583. A contribution of the University of Nebraska Agricultural Research Division, Lincoln, NE 68583. Journal Series No. 13875. Received 14 Oct. 2002. *Corresponding author (alexander_smart@sdstate.edu).

Published in Crop Sci. 43:1434–1440 (2003).

Abbreviations: BMT, big bluestem high seedling weight, multiple tiller Cycle 2; BST, big bluestem high seedling weight, single tiller Cycle 2; MSCR, mean stage count root; MSCS, mean stage count shoot; SMT, switchgrass high seedling weight, multiple tiller Cycle 2; SST, switchgrass high seedling weight, single tiller Cycle 2.

Six populations were evaluated: (i) 'Pawnee' big bluestem base, (ii) 'Pathfinder' switchgrass base, (iii) big bluestem high seedling weight, multiple tiller Cycle 2 (BMT), (iv) big bluestem high seedling weight, single tiller Cycle 2 (BST), (v) switchgrass high seedling weight, multiple tiller Cycle 2 (SMT), and (vi) switchgrass high seedling weight, single tiller Cycle 2 (SST). The Pawnee big bluestem and Pathfinder switchgrass populations had gone through three cycles of selection for high seedling fresh shoot weight at 4 wk of age (Sebolai, 1989). The single and multiple tiller populations were developed by two additional cycles of divergent selection for seedling tiller number while selecting for high shoot weight (Smart, 2001).

Isolated breeding populations of the base, single tiller Cycle 1, multiple tiller Cycle 1, single tiller Cycle 2, and multiple tiller Cycle 2 populations of big bluestem and switchgrass were established in 1996 and 1997 at the Agricultural Research Development Center near Mead, NE (Smart, 2001). This was done so that seed of all entries was produced in the same year. Populations were kept weed free by rototilling and a single postemergence application of atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 2.24 kg a.i. ha^{-1}.

Seed was bulk harvested from each population for big bluestem and switchgrass in late September 1998 and 1999. Seed was cleaned and processed before use in field experiments. Big bluestem seed for Exp. I and II was from the production years of 1998 and 1999, respectively, because there was insufficient 1998 seed to be used in Exp. II. Switchgrass seed used for both experiments was from the production year of 1998, because 1999 seed was not available.

The experimental design was a randomized complete block with five replications in Exp. I (1999) and six replications in Exp. II (2000). Treatments were arranged as a 2 by 3 factorial consisting of two species (big bluestem and switchgrass) and three populations (base, multiple tiller Cycle 2, and single tiller Cycle 2). The experimental unit was a 4- by 1.05-m plot seeded at a rate of 100 pure live seed m^{-1} in seven rows with row spacing of 0.15 m. The reason for the high seeding rate was to make sure there were enough seedlings for the destructive harvests and stand count measurements since field-plot space was limited. The treatments were seeded no-till into the field with a no-till plot drill (Hege Inc., Waldenburg, Germany). Planting dates were 3 May 1999 for Exp. I and 14 Apr. 2000 for Exp. II.

The field used in Exp. I was planted to soybean [*Glycine max* (L.) Merr.] in 1998. In 1999, treatments were no-tilled directly into the soybean stubble. The field used in Exp. II was planted to corn (*Zea mays* L. subsp. *mays*) in 1999. The field was disked twice and treatments were seeded with the same no-till drill in 2000. Weeds were controlled by hand-weeding and a single preemergence application of atrazine at 2.24 kg a.i. ha^{-1} after planting in both experiments.

Sampling began when seedlings were distinguishable in a row and pursuant sampling dates occurred every 2 wk for a 60-d period. The sampling unit was a group of 25 seedlings excavated from the experimental unit from a random section of a single row within the plot. The seedlings were hand-excavated to a depth of 20 cm with a spade. Most of the soil was removed from the seedling roots in the field and the roots were washed in the lab to remove remaining soil. Nearly all of the root mass was recovered with this technique. Samples were stored in plastic bags at 5°C until morphological staging and plant component weight were determined. Seedling morphology was quantified as to mean stage count shoot (MSCS) and mean stage count root (MSCR) (Moser et al., 1993). Mean stage count equals the growth stage index value multiplied by the number of seedlings in that stage and summed across all stages from 1 to 8 and divided by the total number of seedlings. Dry shoot and root weight were measured by drying the plant samples in a forced-air oven at 60°C for 72 h. Stand counts were taken at emergence (19 May 1999 and 5 May 2000) and after plants were well established (11 July 1999 and 29 May 2000) in all plots from two, 0.5-m long samples randomly selected within the middle three rows of the drill pass.

Analysis of variance was performed on all variables within a common sampling date using PROC GLM (SAS, 1999), and mean differences were considered statistically significant at the $\alpha = 0.05$ level. Shoot weight, root weight, MSCS, MSCR, and stand counts were analyzed separately by experiment because planting dates and sampling dates were not the same for each experiment. Residuals were analyzed using PROC UNIVARIATE (SAS, 1999) to verify that the assumptions of analysis of variance were not violated. Sources of variation were blocks, species, population, and species × population interaction. Repeated measures analyses were conducted on shoot weight, root weight, MSCS, and MSCR. Because the trends across time followed an exponential growth model, analyzing the natural logs of these variables linearized the model. The analyses were computed using PROC MIXED (SAS, 1999) with a compound symmetry model that adequately accounted for error correlation during the four sampling dates.

RESULTS AND DISCUSSION

Climatological Summary

In Exp. I, rainfall was evenly distributed in May, but the first week of June was relatively dry (Fig. 1). In Exp. II, March and April were very dry, so each plot was irrigated with approximately 10 mm of water on 3 May and 5 May. Other than a rainfall event on 26 May (16 mm), dry conditions prevailed until mid-June. Daily high temperatures were generally higher in Exp. II than in Exp. I.

Shoot and Root Weight

By comparing mean squares, differences between species accounted for most of the variation in shoot weight in both experiments across all sampling dates (Table 1). There were minor differences in shoot weight among populations at the second and third sampling date in Exp. I, but none at any sampling date in Exp. II. The species × population interaction effect accounted for very little of the total variation at any sampling date in Exp. I, and only 27% of the variation at the second sampling date in Exp. II. Big bluestem populations were not different in growth rate of shoots in either experiment as measured by log × shoot weight across the four sampling dates (Table 2). Switchgrass base and SST populations were greater in shoot growth rate than SMT population in 1999, but not in 2000 (Table 2). It is unclear why the SMT population had such low shoot and root weight in 1999, but not in 2000.

In previous greenhouse experiments, single tiller Cycle 2 populations of big bluestem and switchgrass had greater fresh shoot weight than other populations (Smart, 2001). In the current study, these populations did not differ greatly in shoot weight under environmentally variable field conditions. These results suggest that se-

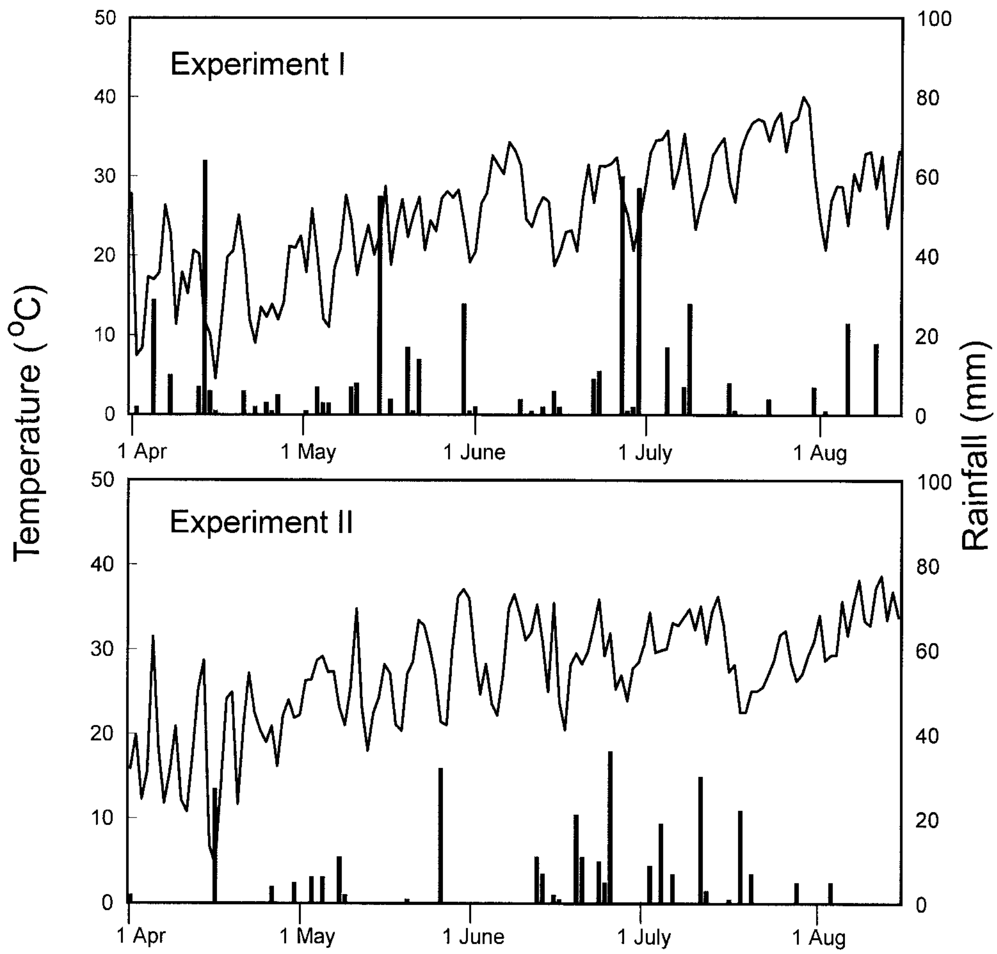

Fig. 1. Daily high temperature (°C; lines) and precipitation (mm; solid bars) at the University of Nebraska-Lincoln Havelock Agronomy Farm in 1999 (Exp. I) and 2000 (Exp. II) (High Plains Regional Climate Center, 2000).

lection for high shoot weight did not improve seedling vigor in the field.

Root weight was not significantly different among populations at any sampling date in Exp. I or Exp. II (Table 3). These results differed from Skinner and Nelson (1994), who reported less root mass in high tillering tall fescue seedlings. The tall fescue seedlings were specific genotypes differing in tiller number, while the seedlings compared in this study were from populations differing in seedling tiller number; thus differences would not be expected to be as great as for two contrasting genotypes. Nearly all of the variation in root growth

Table 1. Shoot weight of big bluestem and switchgrass populations developed by divergent selection for seedling tiller number while selecting for high shoot weight in field trials at Lincoln, NE, in 1999 and 2000.

		Exp. I (1999)				Exp. II (2000)			
Species	**Population†**	**19 May**	**4 June**	**18 June**	**2 July**	**8 May**	**22 May**	**5 June**	**19 June**
		mg per plant							
Big bluestem	**Base**	4	8	37	228	3	7	38	165
	BMT	3	8	43	289	3	6	34	192
	BST	4	9	64	208	4	9	42	177
Switchgrass	**Base**	2	6	27	123	2	6	26	98
	SMT	2	4	13	22	2	5	25	98
	SST	2	7	30	94	2	4	17	79
Coefficient of variation, %		18	21	43	30	17	24	29	35
Source of variation		Mean squares							
Species (S)		22.2**	49**	3 522**	169 370**	12**	52**	1 759**	52 431**
Population (P)		0.7	9	879*	1 430	3	4	28	770
S × P		0.09	3	303	18 136**	7*	16**	194	670
MSE		0.21	2	214	2 200	0.2	2	69	2 570

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† BMT and BST are big bluestem multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively, and SMT and SST are switchgrass multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively.

Table 2. Intercept and slope of repeated measures analysis of log × shoot weight and log × root weight across four sampling dates in 1999 and 2000 of populations developed by two cycles of divergent selection for seedling tiller number while selecting for high shoot weight in big bluestem and switchgrass.

		Exp. I (1999)				Exp. II (2000)			
Species	Population†	Intercept	Slope†	r^2	SE‡	Intercept	Slope	r^2	SE
		log × shoot weight, mg							
Big bluestem	Base	−4.0	1.4	0.95	0.09	−3.9	1.4	0.95	0.06
	BMT	−4.1	1.5	0.96	0.08	−4.1	1.4	0.95	0.06
	BST	−3.7	1.4	0.95	0.08	−3.7	1.3	0.96	0.06
Switchgrass	Base	−4.3	1.3a§	0.84	0.09	−4.0	1.2	0.94	0.06
	SMT	−3.9	0.9b	0.90	0.08	−4.3	1.3	0.92	0.07
	SST	−4.1	1.3a	0.93	0.08	−4.4	1.3	0.94	0.07
		log × root weight, mg							
Big bluestem	Base	−6.8	1.8	0.91	0.16	−6.0	1.6	0.93	0.12
	BMT	−6.4	1.7	0.93	0.15	−6.6	1.7	0.92	0.12
	BST	−5.9	1.6	0.86	0.15	−6.1	1.6	0.92	0.12
Switchgrass	Base	−6.6	1.2a	0.67	0.17	−7.0	1.6	0.89	0.12
	SMT	−6.2	0.7b	0.42	0.15	−7.3	1.6	0.82	0.12
	SST	−7.1	1.5a	0.87	0.16	−7.1	1.5	0.87	0.13

† BMT and BST are big bluestem multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively, and SMT and SST are switchgrass multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively.
‡ Standard error of estimate of slope.
§ Slopes without letters or followed by similar letters within a column and species are not significantly different from each other at $P = 0.05$.

was a result of the species effect across all sampling dates in both years (Table 3). Big bluestem populations were similar in root growth rates as measured by log × root weight across the four sampling dates in 1999 and 2000 (Table 2). In 1999, SMT population had a lower growth rate than switchgrass base or SST populations, but were similar in 2000 (Table 2). Big bluestem seedlings had greater root weight than switchgrass seedlings, which was similar to findings by O'Brien (2000) and Watson (1997), and may be a reason why big bluestem stand counts were higher than switchgrass. Lack of difference among populations in root weight suggests that selection for seedling tiller number and high seedling shoot weight in the greenhouse did not alter root growth. Selection for aboveground traits, such as seedling tiller number and shoot weight, may not improve establishment in the field because root growth, especially of adventitious roots, is critical for seedling survival (Hyder et al., 1971; Newman and Moser, 1988a, 1988b; Ries and Svejcar, 1991).

Morphological Development of Shoots and Roots

Differences in MSCS were mostly between species at the first three sampling dates with very little variation accounted for by differences among the populations and by species and population interactions in Exp. I and Exp. II (Table 4). Rates of shoot morphological development as measured by log × MSCS across the four sampling dates were similar for all populations within each species in 1999 and 2000 (data not shown). At the fourth sampling date, multiple tiller Cycle 2 populations had a higher MSCS than the single tiller Cycle 2 populations for both grasses. Also at the fourth sampling date, MSCS averaged across the selected populations was not different than the average of the base populations. The difference in MSCS of the selected populations was to be expected because seedling tiller number was the selection criteria of these divergent populations (Smart, 2001) and increased tiller number ranks seedlings higher

Table 3. Root weight of big bluestem and switchgrass populations developed by divergent selection for seedling tiller number while selecting for high shoot weight in field trials at Lincoln, NE, in 1999 and 2000.

		Exp. I (1999)				Exp. II (2000)			
Species	Population†	19 May	4 June	18 June	2 July	8 May	22 May	5 June	19 June
		mg per plant							
Big bluestem	Base	0.4	0.7	10	44	0.6	1	11	53
	BMT	0.5	0.9	12	55	0.4	1	8	60
	BST	0.6	1.2	18	46	0.5	1	10	53
Switchgrass	Base	0.2	0.4	3	10	0.2	0.4	5	16
	SMT	0.4	0.3	1	2	0.2	0.2	4	14
	SST	0.2	0.5	4	10	0.2	0.2	2	11
Coefficient of variation, %		98	69	63	44	42	52	45	29
Source of variation		Mean squares							
Species (S)		0.40	2**	715**	10 822**	0.90**	4**	300**	12 389**
Population (P)		0.07	0.2*	52	4	0.02	0.1	11	55
S × P		0.08	0.1	28	234	0.02	0.09	10	50
MSE		0.14	0.19	24	144	0.02	0.10	9	105

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† BMT and BST are big bluestem multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively, and SMT and SST are switchgrass multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively.

Table 4. Mean stage count shoot of big bluestem and switchgrass populations developed by divergent selection for seedling tiller number while selecting for high shoot weight in field trials at Lincoln, NE, in 1999 and 2000.

		Exp. I (1999)				Exp. II (2000)			
Species	Population†	19 May	4 June	18 June	2 July	8 May	22 May	5 June	19 June
Big bluestem	Base	2.4	4.1	5.3	6.4	2.7	3.6	4.9	6.2
	BMT	2.0	4.3	5.7	6.8	2.9	3.8	5.2	6.3
	BST	2.3	4.2	5.5	5.9	2.6	3.9	5.1	5.8
Switchgrass	Base	1.8	3.4	5.0	6.1	2.6	3.6	4.7	6.2
	SMT	2.0	3.6	5.0	5.9	2.6	3.5	4.8	6.2
	SST	1.7	3.9	4.6	5.5	2.5	3.4	4.1	5.8
Coefficient of variation, %		12.0	6.0	6.0	9.0	11.0	5.0	8.0	7.0
Source of variation					Mean squares				
Species (S)		1.1**	2.1**	2.6**	2.0**	0.3	0.5**	2.4**	0.02
Population (P)		0.003	0.2*	0.2	1.3**	0.8	0.003	0.4	0.7*
S × P		0.38*	0.1	0.2	0.3	0.3	0.2**	0.4	0.001
MSE		0.06	0.06	0.10	0.15	0.08	0.03	0.14	0.19

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† BMT and BST are big bluestem multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively, and SMT and SST are switchgrass multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively.

in the staging system. Selection for morphological development in these populations occurred 6 to 8 wk after planting in the greenhouse, which may explain why biologically important differences in MSCS did not appear until the fourth sampling date, which was 6 to 8 wk after emergence.

The main difference in MSCR was between species. Population or the species × population interaction effects were small or nonsignificant (Table 5), and rates of root morphological development as measured by log × MSCR within each species were not different between populations (data not shown). Given the general lack of significance in root morphological development between the selected populations and the base populations, divergent selection for seedling tiller number while selecting for high seedling shoot weight did not alter root development.

Seedling Density

Grass stands of 10 to 20 seedlings m^{-2} in the year of establishment are adequate to produce productive swards in following years (Vogel and Masters, 2001). With the high seeding rates used, all plots produced good stands according to these standards (Table 6). Early emergence, represented by the first stand count, was greater ($P < 0.01$) for the average of BST and SST populations than for the average of BMT and SMT populations in Exp. I, but was the opposite in Exp. II. This inconsistency could be attributed to several factors, such as seedlot, planting date, soil temperature, and daylength differences between the experiments. The stand count for the average of the base populations was less ($P < 0.01$) than for the average of the selected populations in Exp. I, but not significantly different in Exp. II. The number of big bluestem seedlings that emerged by the first count averaged less ($P < 0.01$) than switchgrass seedlings in Exp. I; however, it was the opposite in Exp. II. Seedling survival, represented by the last stand count, was greater ($P < 0.01$) for the average of BST and SST populations than for the average of BMT and SMT populations in Exp. I, but the opposite was true in Exp. II. The difference between the first stand count and the last stand count are represented by seedling mortality. Big bluestem seedlings had greater ($P < 0.01$) survival than switchgrass seedlings as indicated by the differences in seedling numbers be-

Table 5. Mean stage count root of big bluestem and switchgrass populations developed by divergent selection for seedling tiller number while selecting for high shoot weight in field trials at Lincoln, NE, in 1999 and 2000.

		Exp. I (1999)				Exp. II (2000)			
Species	Population†	19 May	4 June	18 June	2 July	8 May	22 May	5 June	19 June
Big bluestem	Base	1.0	2.3	4.0	5.7	1.7	1.9	3.3	5.0
	BMT	1.0	2.5	4.3	5.8	1.7	2.1	3.3	5.1
	BST	1.0	2.5	4.4	5.5	1.6	2.1	3.3	4.8
Switchgrass	Base	1.0	2.9	4.1	4.7	1.7	2.3	3.6	4.7
	SMT	1.0	2.4	3.8	4.1	1.7	2.1	3.6	4.7
	SST	1.0	2.9	4.3	4.8	1.7	2.1	3.3	4.7
Coefficient of variation, %		2	13	7	8	10	9	8	8
Source of variation					Mean squares				
Species (S)		0.0005	0.7*	0.2	9.4**	0.02	0.06	0.4*	0.5
Population (P)		0.0005	0.1	0.3	0.2	0.02	0.008	0.08	0.03
S × P		0.001	0.4	0.2	0.7*	0.01	0.1*	0.06	0.07
MSE		0.0006	0.11	0.09	0.15	0.027	0.037	0.07	0.16

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† BMT and BST are big bluestem multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively, and SMT and SST are switchgrass multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively.

Table 6. Stand counts of big bluestem and switchgrass populations developed by divergent selection for seedling tiller number while selecting for high shoot weight in field trials planted at Lincoln, NE, on 3 May 1999 (Exp. I) and on 14 Apr. 2000 (Exp. II).

		Exp. I (1999)			Exp. II (2000)		
Species	Population†	19 May	11 July	Difference	5 May	29 May	Difference
		No. of seedlings per linear m					
Big bluestem	Base	41	29	12	50	37	13
	BMT	41	28	13	52	38	14
	BST	62	35	27	42	26	16
Switchgrass	Base	43	16	27	44	24	20
	SMT	60	10	50	52	17	35
	SST	91	23	69	31	10	21
Coefficient of variation, %		35	35	57	31	43	49
Source of variation		Mean squares					
Species (S)		1991*	1516**	7046**	272	2500**	1122**
Population (P)		3150**	264*	1907**	808*	503*	188
S × P		417	24	450	91	53	235
MSE		387	70	355	193	117	95

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† BMT and BST are big bluestem multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively, and SMT and SST are switchgrass multiple tiller Cycle 2 and single tiller Cycle 2 populations, respectively.

tween the first and last count and may be related to the fact that big bluestem seedlings had greater root weight and MSCR than switchgrass seedlings (Tables 3, 5). There was a greater mortality ($P < 0.05$) between the average of the base populations and the average of the selected populations in Exp. I than in Exp. II. Also, seedling mortality was greater ($P < 0.01$) for the average of BST and SST populations than for BMT and SMT populations in Exp. I, but was opposite in Exp. II. This was caused by greater emergence for single tiller Cycle 2 populations than multiple tiller Cycle 2 populations in Exp. I when environmental conditions were favorable. When the environment became drier, many of the newly emerged single tiller population seedlings did not have adequate root growth, so they died. These results suggest that divergent selection for seedling tiller number while selecting for high shoot weight in controlled environments had no measurable impact on establishment in the field.

In summary, big bluestem and switchgrass populations selected for seedling tiller number were not different in root weight and MSCR 8 wk after planting in the field. Single tiller Cycle 2 populations that showed greater fresh shoot weight from previous greenhouse experiments than other populations (Smart, 2001) did not have greater shoot weight in the field than the multiple tiller or base populations. Mean stage count shoot was higher for multiple tiller Cycle 2 populations than for single tiller Cycle 2 populations 8 wk after planting, which was consistent with the previous greenhouse study (Smart, 2001). Populations selected for shoot weight and divergently selected for seedling tiller number did not appear to differ in establishment under field conditions because root weight and adventitious root number were apparently not altered, which is important for seedling establishment and survival.

These results indicate that selection for aboveground traits in warm-season perennial grasses may not improve stand establishment in the field. Past breeding work in cool- and warm-season grasses on improving seedling vigor by selecting traits such as seed size, coleoptile length, and shoot weight, has had limited success on improving establishment. Breeding efforts for increasing seedling vigor in warm-season grasses should focus on direct selection of root traits that have been shown to be more important in seedling establishment than shoot traits.

REFERENCES

Berdahl, J.D., and R.E. Barker. 1984. Selection for improved seedling vigor in Russian wild ryegrass. Can. J. Plant Sci. 64:131–138.

Carren, C.J., A.M. Wilson, R.L. Cuany, and G.L. Thor. 1987. Caryopsis weight and planting depth of blue grama I. Morphology, emergence, and seedling growth. J. Range Manage. 40:207–211.

Glewen, K.L., and K.P. Vogel. 1984. Partitioning the genetic variability for seedling growth in sand bluestem into its seed size and seedling vigor components. Crop Sci. 24:137–141.

High Plains Regional Climate Center. 2000. Automated weather data network. Univ. of Nebraska, Lincoln, NE.

Hyder, D.N., A.C. Everson, and R.E. Bement. 1971. Seedling morphology and seeding failures with blue grama. J. Range Manage. 24:287–292.

Kneebone, W.R. 1972. Breeding for seedling vigor. p. 90–100. *In* V.B. Younger and C.M. McKell (ed.) The biology and utilization of grasses. Academic Press, New York.

Martin, A.R., R.S. Moomaw, and K.P. Vogel. 1982. Warm-season grass establishment with atrazine. Agron. J. 74:916–920.

McCarty, M.K., L.C. Newell, C.J. Scifres, and J.E. Congrove. 1967. Weed control in seed fields of sideoats grama. Weeds 15:171–174.

Moser, L.E., K.J. Moore, M.S. Miller, S.S. Waller, K.P. Vogel, J.R. Hendrickson, and L.A. Maddux. 1993. A quantitative system for describing the developmental morphology of grass seedling populations. p. 317–318. *In* J.R. Crush et al. (ed.) Proc. Int. Grassl. Congr., 17th, Palmerston North, New Zealand. 8–21 Feb. 1993. Keeling and Mundy, Palmerston North, New Zealand.

Nason, D.A., R.L. Cuany, and A.M. Wilson. 1987. Recurrent selection in blue grama. I. Seedling water uptake and shoot weight. Crop Sci. 27:847–851.

Newman, P.R., and L.E. Moser. 1988a. Grass seedling emergence, morphology, and establishment as affected by planting depth. Agron. J. 80:383–387.

Newman, P.R., and L.E. Moser. 1988b. Seedling root development and morphology of cool-season and warm-season grasses. Crop Sci. 28:148–151.

O'Brien, T.R. 2000. Morphological development and winter survival of switchgrass and big bluestem seedlings. M.S. Thesis. Univ. of Nebraska, Lincoln, NE.

Ries, R.E., and T.J. Svejcar. 1991. The grass seedling: When is it established? J. Range Manage. 44:574–576.

SAS Institute. 1999. SAS OnLine Doc. Version 8. SAS Inst., Cary, NC.

Sebolai, B. 1989. Evaluation of three cycles of stratified mass selection for high seedling shoot weight in three warm-season grasses. M.S. Thesis. Univ. of Nebraska, Lincoln, NE.

Skinner, R.H., and C.J. Nelson. 1994. Role of leaf appearance rate and the coleoptile tiller in regulating tiller production. Crop Sci. 34:71–75.

Smart, A.J. 2001. Divergent selection for seedling and multiple shoot tillering in big bluestem and switchgrass seedlings. Ph.D. diss. Univ. of Nebraska, Lincoln, NE. (Diss. Abstr. Int. 06B:2544)

Song, B.H., C.J. Nelson, and J.H. Coutts. 1990. Nitrogen effects on carbohydrate composition of tissues of two tall fescue genotypes. p. 131. *In* 1990 Agronomy Abstracts. ASA, Madison, WI.

Vogel, K.P., and R.A. Masters. 2001. Frequency grid—A simple tool for measuring grassland establishment. J. Range Manage. 54: 653–655.

Watson, A. 1997. Developmental morphology and stand establishment of warm-season perennial grass seedlings as affected by preemergence herbicides. M.S. Thesis. Univ. of Nebraska, Lincoln, NE.

Whalley, R.D.B., C.M. McKell, and L.R. Green. 1966. Seedling vigor and the early nonphotosynthetic stage of seedling growth in grasses. Crop Sci. 6:147–150.