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Effects of Seed Weight on Seedling Establishment, Forage Yield, and Seed Production Characteristics of Switchgrass (Panicum virgatum L.)

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EFFECTS OF SEED WEIGHT ON SEEDLING ESTABLISHMENT, FORAGE YIELD, AND SEED PRODUCTION CHARACTERISTICS OF SWITCHGRASS (*PANICUM VIRGATUM* L.)

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Switchgrass (*Panicum virgatum* L.), a warm-season grass native to North America, is distributed from Canada to Central America and from the Atlantic Coast to Nevada over a wide range of habitats (Hitchcock 1935). It exhibits tremendous promise for forage and soil conservation utilization in the Great Plains and True Prairie regions. The economic value of switchgrass as summer forage has long been recognized (Weaver and Fitzpatrick 1932) and its potential for improved variety production is great due to extensive ecotypic genetic variability (Nielsen 1944) and relatively good seed quality and production. A full season pasture system comprised of separate pastures of cool and warm-season species offers maximum beef production efficiency (Krueger and Curtis 1979), and switchgrass was found to yield the most beef gain per hectare of the major tall, warm-season grasses native to South Dakota.

Poor seedling vigor and inconsistent seed production have severely limited the widespread use of switchgrass. Kneebone and Cremer (1955) determined that selecting for seed size in switchgrass was an effective method for improving seedling vigor. Improved vigor results in quick germination and rapid seedling development, consequently increasing the chance of stand survival if a stress period is encountered during establishment.

Cornelius (1950) concluded native warm-season grasses were especially poor seed producers. Seed yield components need to be examined to identify those which have the greatest influence on seed yield. Identification of the important seed yield components would facilitate selection for specific characteristics resulting in improved seed yield. With improvements in seedling vigor and seed yield, switchgrass could make a substantial contribution to the total carrying capacity of full-season pasture systems.

The objectives of this study were (1) to determine variation for seed size within and among three switchgrass varieties grown in the same environment, (2) to identify an easy and accurate method for separating different seed weight fractions from bulk seedlots, (3) to determine the effect of weight of parent seed on seedling vigor and mature plant forage and seed characters, and (4) to evaluate, by employing multiple regression and path coefficient analysis, the relative contributions of four seed yield components to total seed yield of individual plants.

REVIEW OF LITERATURE

A. Forage and Conservation Utilization

Krueger et al. (1974), working in South Dakota, indicated beef gains on warm-season pastures during July and August were 83% greater than on cool-season pastures. Pasture systems utilizing warm-season pastures also increased total carrying capacity. Krueger and Curtis (1979) compared seeded pastures of switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* Vit.), Indian grass (*Sorghastrum nutans* (L.) Nash.), and sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), and found beef gain per hectare was highest in switchgrass and big bluestem pastures and beef gain per day was superior in switchgrass pastures.

Cornelius (1946) reported that a mixture of warm-season native grass produced higher yields and better erosion control than introduced cool-season species on thin upland soil of low fertility in Kansas. Schwendiman and Hawk (1973) reported switchgrass is one of the easiest native warm-season grasses to bring under cultivation due to its excellent seed yield, vigorous seedling growth, and high forage yields. Derscheid et al. (1977) reported that switchgrass is widely used for summer pasture and erosion control. They also reported yields of 5.4 MT/ha at Brookings with good yielding varieties.

B. Seed Germination

McGinnies (1960) looked at six cool-season grasses and found a positive correlation between seed weight and germination under moisture stress conditions. Maguire (1962) developed a rating for speed of germination and correlated high rating values with superior emergence in the greenhouse. In certain species, temperature and age of seed have been shown to affect germination. Ahring et al. (1959) found that constant temperature of 20°C resulted in less than 50% germination of six month old switchgrass seed, but that alternating temperatures of 20°-35°C increased germination to 80%. Shaidaee (1969) found that seven year old switchgrass seed was superior to one and six year old seed for speed of emergence. Sautter (1962) noted that switchgrass germination under constant temperatures of 27-29°C was zero, but if night temperatures were dropped to 4°C, germination increased to 50%. In the same experiment, scarified seed achieved 84% germination.

C. Seed Weight and Seedling Vigor

Kneebone (1972) stated that in any grass breeding program it is essential to select for good seedling vigor to improve stand establishment. Isely (1957) defined vigor as the sum total of all seed attributes which favors stand establishment under unfavorable field conditions. Increasing seedling vigor has been successfully conducted by selecting among different lines and among different weight classes within a line or variety. Henson and Tayman (1961), working with birdsfoot trefoil (*Lotus corniculatus* L.), and Kneebone and Cremer (1955), working with buffalo grass (*Buchloe dactyloides* Nutt.), Indian grass, sand bluestem (*Andropogon hallii* Hack.), sideoats grama, and switchgrass, used screens to separate seed into different size classes. Two to four seed weight classes were obtained per species. Kittock and Patterson (1962) used a South Dakota Seed Blower to separate different sized seeds in hard fescue (Festuca ovina var. Duriuscula L. Koch.), Russian bromegrass (Bromus tomentellus Boiss.), beardless wheatgrass (Agropyron inerme (Scribn. and Smith) Rydb.), pubescent wheatgrass (Agropyron trichophorum (Link) Richt.), intermediate wheatgrass (Agropyron intermedium (Host) Beauv.), Siberian wheatgrass (Agropyron sibiricum (Willd.) Beauv.), Nordan crested wheatgrass (Agropyron desertorum (Fisch.) Schult.), and crested wheatgrass (Agropyron cristatum (L.) Gaertn.). Seed was separated into different weight classes by increasing air flow increments.

McKenzie et al. (1946) evaluated eight cool-season grasses to determine maximum depth that they could be planted and still produce an adequate stand. He determined that maximum planting depths were 2.5 cm for crested wheatgrass; 3.8 cm for Russian wildrye (Elymus junceus Fisch.), smooth bromegrass (Bromus inermis Leyss.), and tall wheatgrass (Agropyron elongatum (Host) Beauv.); 5.1 cm for intermediate wheatgrass, reed canary grass (Phalaris arundinacea L.), and Virginia wildrye (Elymus virginicus L.); and 7.6 cm for slender wheatgrass (Agropyron caninum (L.) Beauv.). McGinnies (1973) looked at depth and time of planting for three cool-season grasses, crested wheatgrass, pubescent wheatgrass, and Russian wildrye, and found 1.9 cm to be the best depth for early plantings. Later in the season, the depth had to be increased due to dry soil surface evaporation.

Kalton et al. (1959) indicated that heavier seeds of smooth bromegrass lines planted at 5.1 cm were faster to emerge and had higher percent emergence than lighter seed lines when compared under greenhouse conditions. Lawrence (1957), working with intermediate wheatgrass, found no differences in percent emergence between large versus small seed at a depth of 7.6 cm. However, he did find differences among seed lines for percent emergence. Asay and Johnson (1980) determined that emergence and subsequent seedling vigor of Russian wildrye seed planted at 7.6 cm was highly significantly correlated with field vigor data. Lawrence (1963), also working with Russian wildrye, indicated large seed emerged better than small seed at a depth of 3.8 cm. Tossell (1960) found a highly significant correlation between seed weight and seedling vigor at 31 days in open-pollinated progenies of smooth bromegrass. Rogler (1954), working with crested wheatgrass, looked at the time that elapsed from a 5.1 cm planting until development of second and third leaves and found large seed reached these stages sooner than small seeds. Hudspeth and Taylor (1961) investigated how crusting of soil and moisture stress affect emergence of switchgrass at different depths and found that in rapid drying soils, switchgrass had a greater probability of emerging if planted at a depth of 5.1 to 7.6 cm.

Kaufmann and Guitard (1967) cut away 25 and 50% of the endosperm on large barley (Hordeum vulgare L.) seeds, resulting in four seed classes, large, small, 75%, and 50% seeds. Seeds with 50% endosperm were approximately the same size as small seed. They found that vigor of the large seed was followed by small, 75%, and 50% seeds, and concluded that additional endosperm in the 75% seed did not help seedling vigor.

Christie and Kalton (1960a, 1960b) showed that selecting for seed size in smooth bromegrass increased vigor initially but inbreeding caused depression in vigor. When recurrent selection was used in breeding for seed size, there was a wider variation among progenies and inbreeding was not a problem. Kneebone (1956) selected vigorous sand bluestem plants from an open-pollinated nursery. The seeds produced on the selected plants were 40% heavier than unselected seed. Plants grown from the selected Syn-1 seed were more vigorous and had a higher percent stand than the unselected Syn-1.

Kneebone and Cremer (1955) utilized screens to divide seed of five native species (buffalo grass, Indian grass, sand bluestem, sideoats grama, and switchgrass) into different seed weight classes. The larger seed in each species produced more vigorous seedlings. They also noted that in switchgrass the small seeds exhibited the poorest germination.

Ross (1973) found large amounts of phenotypic variation for seed size in native collections of big bluestem and switchgrass. Seed varied from 2.000 to 4.433 g per 1000 seeds for big bluestem and from 0.935 to 2.169 g per 1000 seeds for switchgrass. Heritabilities for seed size were 0.87 for big bluestem and 0.73 for switchgrass.

Schaaf et al. (1962) and Schaaf and Rogler (1963) looked at breeding for seed size and seed yield in crested wheatgrass. They found Syn-1 seed superior for seed size and seed yield, but these superior qualities were lost in Syn-2 and -3. They also noted that as plants aged they decreased for seed yield but not for seed size.

Perry and Moser (1975) indicated late maturing varieties of switchgrass had superior seedling vigor and should be better weed competitors.

D. Chemical Weed Control

Vogel et al. (1981) and Bahler et al. (1982) determined big bluestem and switchgrass could tolerate preemergence application rates of atrazine up to 3.4 kg/ha. Indian grass, sideoats grama, and sand lovegrass (Eragrostis trichodes (Nutt) Wood) were damaged by rates as low as 1.1 kg/ha during the establishment period. Smith (1971) found that in established stands of switchgrass 3.4 kg/ha did not hurt the stand and controlled 90% of the weeds in the field. Wrage and Derscheid (1977) listed silvex, MCPA, and 2,4-D, and 2,4,5-T as good chemicals for control of annual and perennial broadleaf weeds in warm-season grasses.

E. Seed and Forage Production

Gilbert et al. (1979) evaluated dry matter accumulation over time in four warm-season grasses (little bluestem, sand bluestem, sand lovegrass, and switchgrass), and found dry matter increased linearly all summer. The leaf to stem ratio changed from a high amount of leaf early to more stem material later in the season. Of the four grasses, switchgrass was found to have the highest percent of stem at the end of the summer.

Trupp and Carlson (1971), selecting for large seed in smooth bromegrass, found no significant yield reduction in seed or forage yield but found seedlings from large seed at 39 days after planting weighed more than plants from smaller seed. Lawrence (1963) evaluated twelve clonal lines of Russian wildrye and their polycross seed for seedling vigor and other traits, and found significant correlations between seed size and seed yield (0.808), seed size and forage yield (0.720), and seed yield and forage yield (0.633).

Raeber and Kalton (1956) developed the fertility index to determine, on an individual plant basis, the number of fertile florets per total number of florets. It is determined from the ratio of threshed (clean seed) weight/unthreshed weight of all inflorescences from an individual plant. They found a positive correlation (0.94) between fertility index and actual fertility in twenty smooth bromegrass clones.

Newell and Moline (1978) evaluated dry matter yields of grasses common to Nebraska. Crested wheatgrass, intermediate wheatgrass, and smooth bromegrass produced forage yields of 6.15, 5.17, and 8.6 MT/ha and protein contents of 9.0, 10.0 and 10.0%, respectively, while switchgrass, big bluestem, and Indian grass produced forage yields of 6.88, 5.82 and 5.04 MT/ha, and protein contents of 8.5, 8.0, and 10.0%, respectively.

MATERIALS AND METHODS

A. Seed Size Evaluation

Seed samples were obtained from SD 32 Syn-1 (an experimental population comprised of approximately 750 spaced-plants), and a replicated seed yield trial planted in 1979 and comprised of Summer, Nebraska 28, and SD 32 Syn-2. Ten 20 g samples from each of 1978, 1979, and 1980 SD 32 Syn-1 harvests, and eight 20 g samples from bulk seed of each variety in the 1980 seed yield trial harvest were separated into eight weight classes, utilizing a South Dakota Seed Blower. At each level of progressively increased air flow, seed lifted to the top of the column was collected and weighed. Two 100-seed and three 10-seed samples, randomly obtained from each weight class, were weighed on an analytical balance for analysis of intra and interclass variation. Two 100-seed samples were also taken from bulk harvests of individual plots in the seed yield trial in 1980 and 1981.

B. Greenhouse Seedling Vigor Study

A greenhouse seedling vigor study, utilizing five seed weight classes (135, 174, 192, 209, and 225 mg/100 seeds) from SD 32 Syn-1 1979 harvest, was conducted in May 1981. A randomized complete block with three replications of the five weight classes at two planting depths (1.25 and 2.5 cm) was employed. Five seeds were planted in a 3:1 soil to sand mix in each of five 7.6 cm^2 peat pots for every weight x depth combination in each replication. Pots were randomized within replications. At four day intervals after planting, emergence counts were made. Starting 12 days after planting, seedling heights were evaluated at four day intervals up to 36 days. Five weeks after planting, all seedlings except for the most vigorous one in each pot, were excised at the soil surface. The total length and width at the widest point of the two uppermost fully extended leaves from each of the harvested plants were measured at that time. The harvested plants were dried at 35°C for 96 hours and then weighed on an analytical balance. Analyses of variance were conducted on pot means for percent emergence and seedling height, and on parent seed weight x planting depth x repli- cation means for leaf length and width, and seedling dry weight.

C. Forage and Seed Yield Components Study

The 150 plants (30/parent seed weight class) saved from the greenhouse seedling vigor study were transplanted into a spaced-plant nursery at Brookings in June 1981. A randomized complete block design with three replications of ten plants for each parent seed weight class was utilized. In September 1982, data were recorded for individual plants as follows: (1) vigor (scale was from 1 = most vigorous to 5 = least vigorous), (2) leafiness (scale was from 1 = leafiest to 5 = least leafy), (3) basal area (scale was from 1 = greatest spread to 5 = least spread), (4) lodging (scale was from 1 = erect to 9 = prostrate), (5) plant height, (6) number of flowering culms, (7) total weight of unthreshed panicles, (8) total weight of fertile florets, (9) mean 100-seed weight from two samples, (10) fertility index (total weight of fertile florets/unthreshed panicle weight), and (11) weight of unthreshed seed per culm (unthreshed panicle weight/number of culms).

Analyses of variance for the above characters were conducted on means of the ten plants within each parent seed weight class and replication.

Individual plant seed characters were subjected to maximum r^2 stepwise multiple regression analysis. Path coefficients were computed from partial regression coefficients and standard deviations of the dependent and independent variables (Li, 1975). Seed yield was considered the dependent variable and components of seed yield (observations 6, 7, 9, 10) were considered independent variables. Path coefficients measure the direct influence of one variable upon another and permit separation of correlation coefficients into components of direct and indirect effects.

D. Field Establishment Studies

Two locations, one in northeastern South Dakota near Sisseton and the other near Brookings, were selected for field establishment studies. The soil at Sisseton was an Aastad loam (Udic Argiborall fine-loamy mixed) with 2 to 6% slope while the soil at Brookings was a Brookings silty clay loam (Pachic Udic Haploborall fine-silty mixed) with 0 to 2% slope. The Sisseton location had been planted to wheat in spring 1980 and plowed in fall 1980, while the Brookings location had been fallowed in 1980. The experimental design employed at each location was a randomized complete block with three replications and a factorial arrangement of five seed weight classes (135, 174, 192, 209, and 225 mg/100 seeds) of SD 32 Syn-1 1979 harvest and two check varieties (SD 32 and Nebraska 28), and three establishment methods (clear seeded switchgrass, and flax and proso millet companion crops).

Planting rate was 6,500 pure live seeds/plot. Planting was done with a four-row double-disk opener drill with depth bands and 30 cm row spacings. Planting depth was approximately 2.0 cm. Individual plot size was 1.2 by 6.3 m.

In the clear seeded switchgrass plots, emergence and height measurements were made at four and six weeks after planting at Brookings and Sisseton, respectively. The middle two rows of each plot were divided into seven 91.4 cm segments. Within a random segment from each row, number of seedlings and height of the nearest seedling at 15.2 cm intervals were noted.

In fall 1981, millet and flax plots at both locations were harvested for grain yield.

In spring 1982, 2.91 kg active ingredient/hectare of atrazine was applied at Brookings, and 0.17 kg active ingredient/hectare of MCPA was applied at Sisseton.

In fall 1982, forage harvested from a random 1.83 m section within each of the middle two rows of each plot was dried, separated into switchgrass and weed components, and then weighed. Analyses of variance were conducted for number of seedlings emerged, seedling height, and switchgrass forage yield.

RESULTS

A. Seed Size Evaluation

Overall mean 100-seed weights from the 1979 seed yield trial were 102.6, 157.5, and 200.6 mg in 1980 and 89.8, 140.4, and 191.1 mg in 1981 for Summer, Nebraska 28, and SD 32, respectively. In 1980, all three varieties contained fractions that averaged less than 100 mg/100 seeds, but the percentage by weight was much greater for Summer (51.5%) than Nebraska 28 (5.3%) or SD 32 (1.3%). At the other extreme, the greater than 200 mg/100 seeds percentage was much higher for SD 32 (42.9%) than Nebraska 28 (3.1%) or Summer (0.0%) (Fig. 1).

Coefficients of variability for three 10-seed samples from each weight fraction within each variety were generally small, ranging from 0.7 to 14.7%, 1.6 to 9.1%, and 1.2 to 7.1% for the heaviest to lightest fractions of SD 32, Summer, and Nebraska 28, respectively (Table 1).

Percentages by weight of SD 32 in the various weight class fractions were comparable in 1978, 1979, and 1980 (Fig. 2). Overall mean 100-seed weights for the three consecutive years were 180.9, 176.0, and 181.3 mg.

B. Greenhouse Seedling Vigor Study

Twelve days after planting, the two heaviest parent seed weight classes (209 and 225 mg/100 seeds) exhibited significantly higher emergence than the 174 mg class, which had significantly higher emergence than the lightest class (135 mg). This trend continued through the observation period up to 20 days, when significant differences for emergence were observed between the 135 and 174 mg classes and

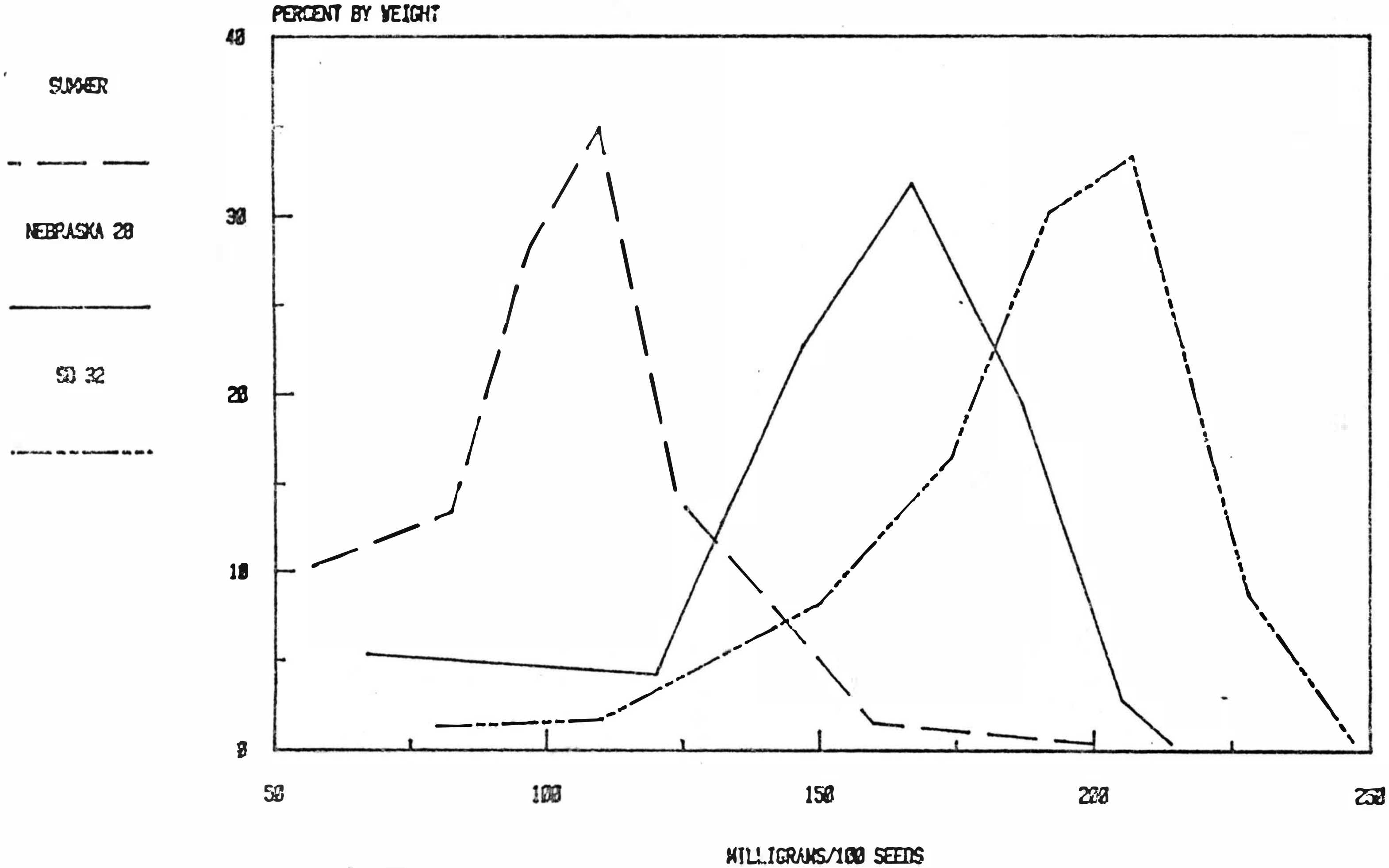

Fig. 1. Seed weight distribution within three switchgrass varieties harvested at Brookings in 1980.

Table 1. Mean weights and coefficients of variability for three 10-seed samples from each weight class.

Variety	Weight Class: Light 1	2	3	4	5	6	7	Heavy 8
				1979 Seed Yield Trial				
SD 32	8.6mg	12.1	13.7	17.3	19.4	20.4	22.8	25.9
CV	14.7%	9.5	2.3	2.0	0.5	2.6	2.7	0.7
Summer	5.5	8.3	9.9	11.6	12.7	16.1	*	
CV	9.1	2.5	5.0	1.8	1.7	1.6		
Neb 28	5.8	10.1	13.5	15.5	16.9	18.0	19.9	
CV	7.1	5.8	5.8	2.3	5.2	2.7	1.2	
				SD 32 Syn-1 Spaced Plants				
SD 32 1978	8.9	11.1	14.2	17.5	20.1	21.8	22.8	23.8
CV	12.8	2.4	2.8	4.2	1.5	2.7	1.5	2.5
SD 32 1979	5.9	11.7	14.5	17.3	18.8	20.8	22.2	24.6
CV	6.5	3.1	6.9	4.3	2.1	3.8	1.4	3.1
SD 32 1980	7.9	10.9	14.3	17.1	18.5	21.1	22.5	24.2
CV	5.8	5.0	2.9	2.9	3.6	1.0	0.4	1.5

*Fraction was lost before samples could be taken.

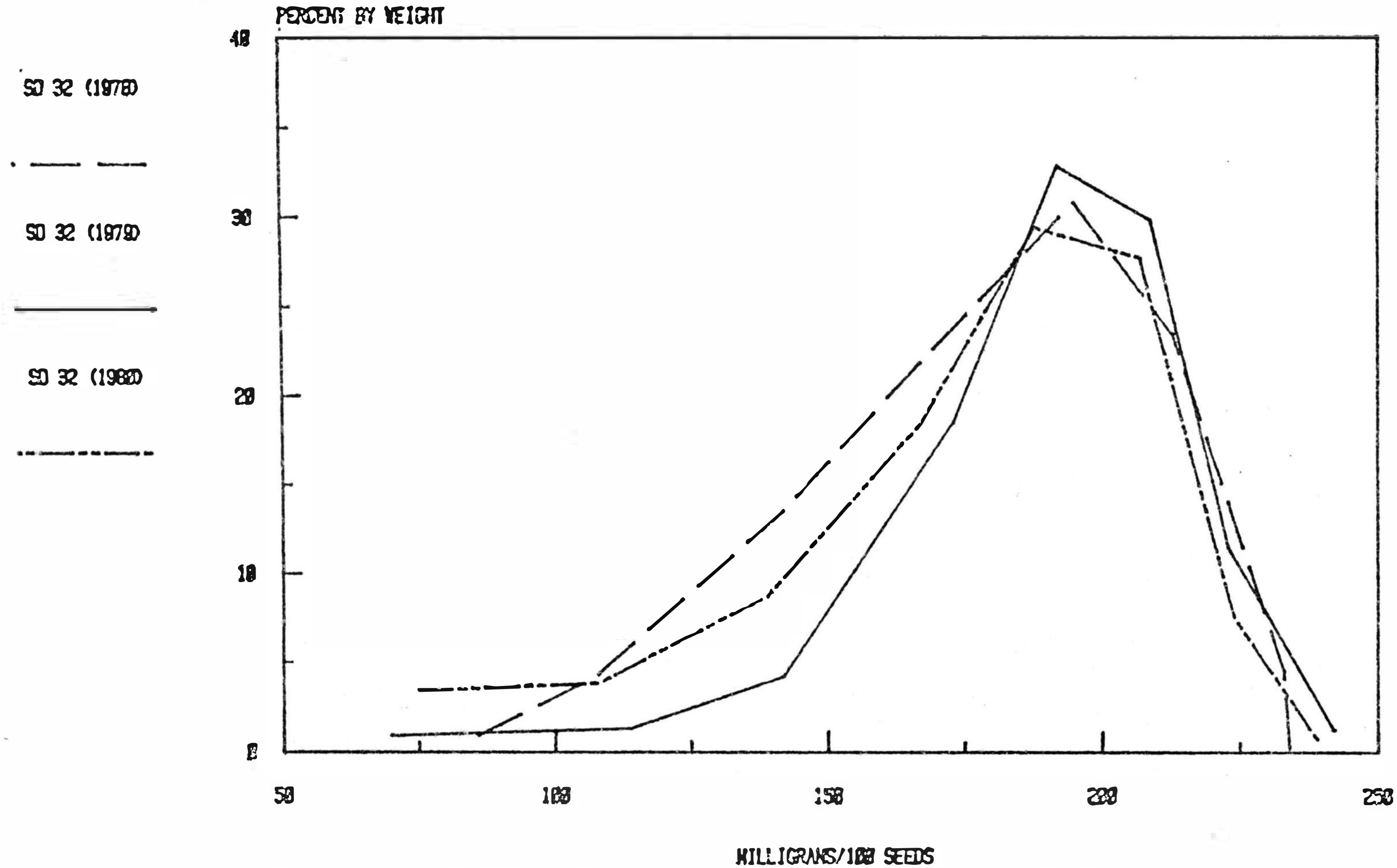

Fig. 2. Seed weight distribution for SD 32 Syn-1 harvested three consecutive years at Brookings.

the 174 mg and the two heaviest classes (Table A1).

Significant differences for height at 12 days were found between the 135 mg class and all other classes. The range in average heights at that period was from 37 mm for the 225 mg class to 24 mm for the 135 mg class. At 20 days, the 225, 209, and 192 mg classes were significantly taller than the 174 and 135 mg classes, and the 225 mg class was significantly taller than the 192 mg class. At the end of the observation period (36 days), seedling heights of the 225, 209, and 192 mg classes were not significantly different, but the 225 mg class was significantly taller than the 174 and 135 mg classes. The range in heights at the end of the observation period was from 190 mm for the 225 mg class to 122 mm for the 135 mg class (Table 2).

The relationship between parent seed weight and the length and width of leaves of seedlings 36 days after planting are shown in Figures 3 and 4. The contribution of linear regression to the parent seed weight sum of squares was highly significant for both leaf characteristics (Table 3). Linear coefficients of determination were 0.92 for leaf length and 0.77 for leaf width. Mean squares for quadratic regression and deviations from regression were not significant for either characteristic. Increased seed weights produced longer and wider leaves with leaf length and width increasing by 15.5 and 0.3 mm for each 25 mg increase in parent 100-seed weight. The ranges between the means of the 225 and 135 mg classes were 59.0 and 1.1 mm for leaf length and width, respectively (Table A2).

The relationship between parent seed weight and seedling dry

Table 2. Mean height for each parent seed weight class at four-day intervals in the greenhouse seedling vigor study.

Parent seed weight	Days after planting 12	16	20	24	28	32	36
	Plant heights (mm)						
225 mg	37A*	61A	80A	98A	118A	158A	190A
209 mg	37A	60A	76AB	93AB	111A	138AB	175AB
192 mg	37A	57AB	72B	88B	112A	138AB	178AB
174 mg	34A	51B	66C	80C	97B	123BC	164B
135 mg	24B	34C	49D	60D	73C	97C	123C

*Means followed by different letters in same column are significantly different at the 0.05 level.

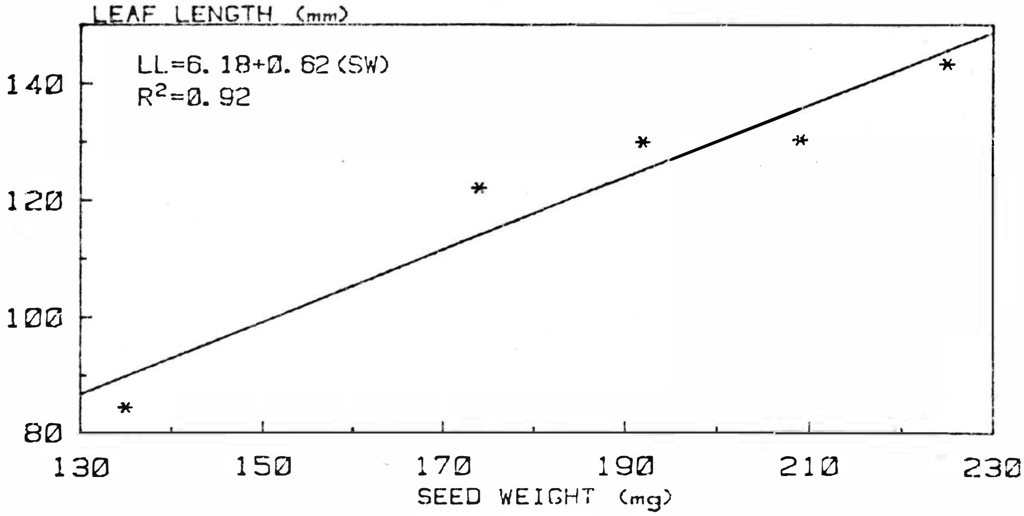

Fig. 3. Relationship between leaf length of 36 day old seedlings in the greenhouse and weight of seed.

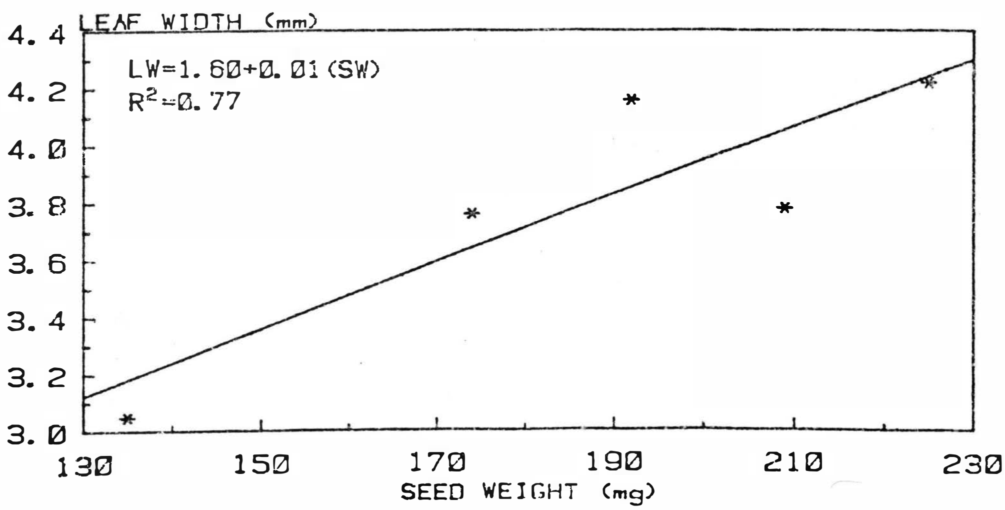

Fig. 4. Relationship between leaf width of 36 day old seedlings in the greenhouse and weight of seed.

Table 3. Analyses of variance for leaf length, leaf width, and seedling dry weight at 36 days after planting in the greenhouse seedling vigor study.

Source	df	Leaf Length		Leaf Width		Seedling Dry Weight	
		MS	F	MS	F	MS	F
Total	29						
Seed weight	4	3006.7	8.27**	1.29	3.79	1852.13	5.87*
Linear	1	11116.0	30.58**	3.99	11.74**	6910.44	21.89**
Quadratic	1	573.2	1.58	0.37	1.09	55.38	<1
Remainder	2	168.7	<1	0.41	1.19	221.34	<1
Experimental Error	8	363.5	1.42	0.34	1.09	315.75	2.18
Sampling Error	15	255.5		0.31		145.13	

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

weight at 36 days after planting is shown in Figure 5. The contribution of linear regression to the seed weight sums of squares was highly significant (Table 3). The linear coefficient of determination was 0.93. Mean squares for quadratic regression and deviation from regression were not significant. Increased seed weight produced heavier seedlings, with seedling dry weights increasing by 12.2 mg for each 25 mg increase in 100-seed weight. The range in seedling dry weight means between the 225 and 135 mg classes was 46.4 mg (Table A2).

C. Forage and Seed Yield Components Study

The relationships between parent seed weight and vigor, basal area, and leafiness of plants one year after establishment are presented in Figures 6-8. The contribution of linear regression to seed weight sums of squares was highly significant for basal area and significant for vigor and leafiness. Also, a significant quadratic regression was detected for leafiness (Table 4). Coefficients of determination were 0.71, 0.90, and 0.75 for vigor, basal area, and leafiness, respectively. Mean squares for linear regression and quadratic regression were not significant for lodging or height. Deviations from regression were not significant for any vegetative characteristic. Increased seed weights produced more vigorous seedlings with larger basal area by decreasing the vigor rating 0.2 and basal area rating 0.2 for each 25 mg increase in 100-seed weight. The ranges between means of the weight classes were 0.6, 0.5, 0.9, 1.0, and 12 cm for vigor, leafiness, basal area, lodging, and height, respectively (Table A3). The relationships between parent seed weight and progeny seed weight, fertility index, and seed yield are

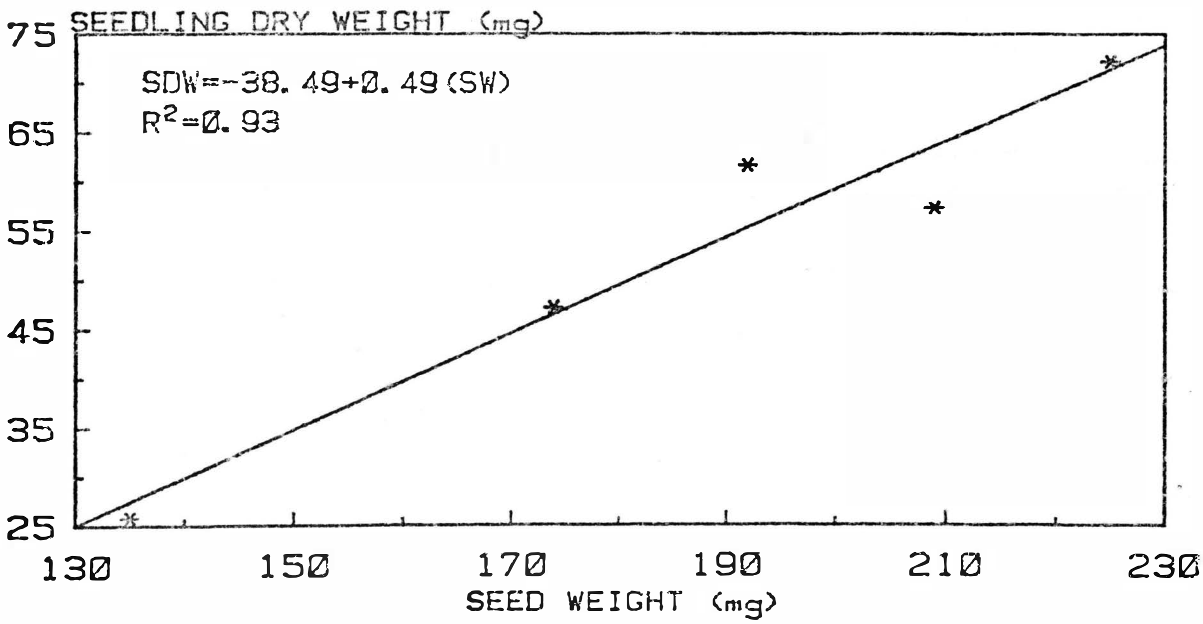

Fig. 5. Relationship between dry weight of 36 day old seedlings in the greenhouse and weight of seed.

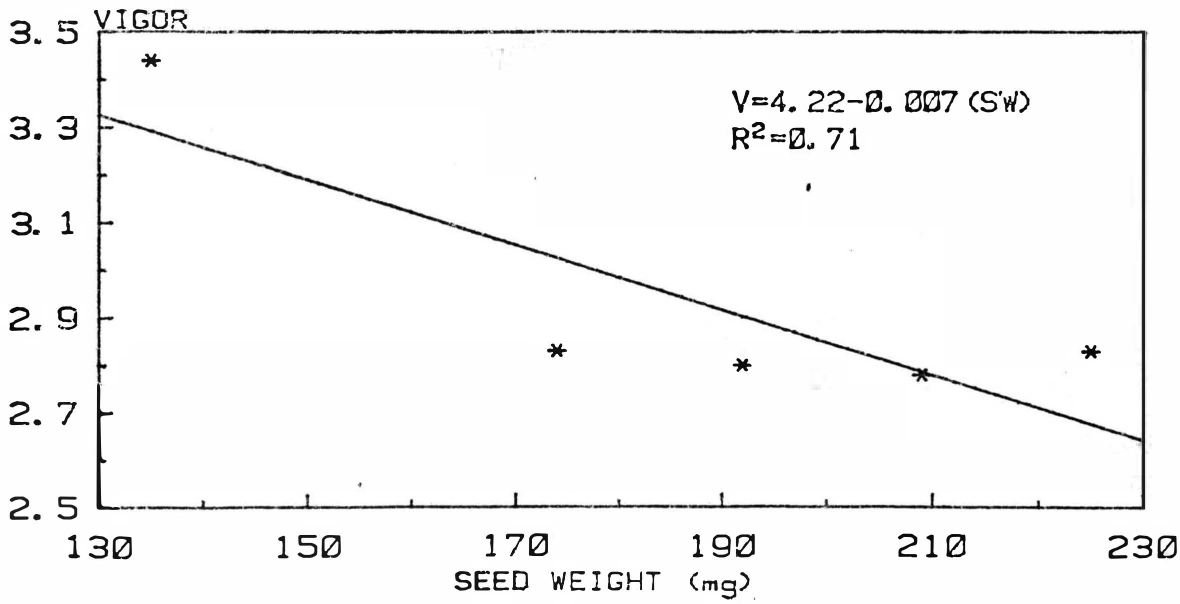

Fig. 6. Relationship between vigor of spaced-plants and weight of seed.

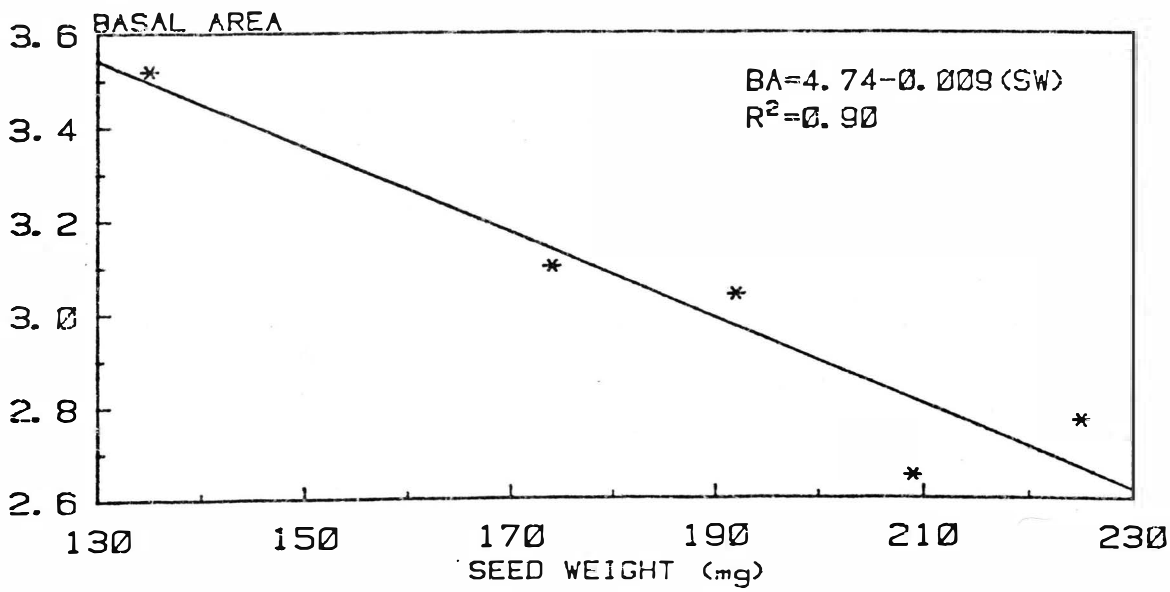

Fig. 7. Relationship between basal area of spaced-plants and weight of seed.

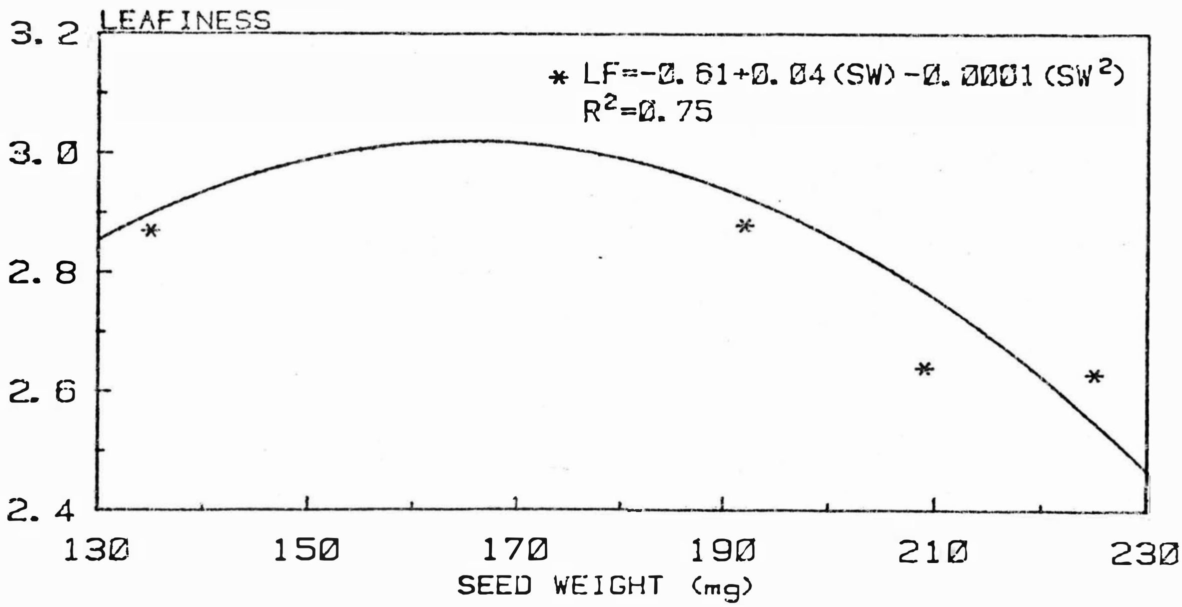

Fig. 8. Relationship between leafiness of spaced-plants and weight of seed.

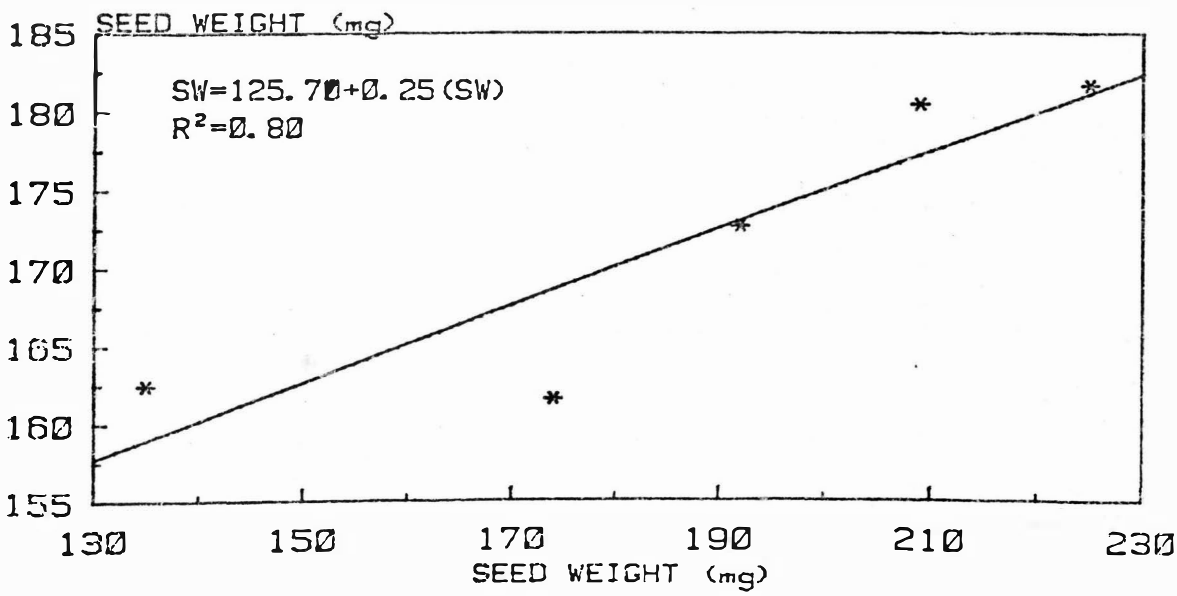

Fig. 9. Relationship between progeny seed weight of space-plants and weight of seed.

Table 4. Analyses of variance for vigor, leafiness, basal area, lodging, and height in the spaced-plant nursery.

Source	df	Vigor		Leafiness		Basal area		Lodging		Height	
		MS	F	MS	F	MS	F	MS	F	MS	F
Total	29										
Seed weight	4	0.482	3.45	0.254	4.46*	0.682	3.90*	0.919	<1	116.07	<1
Linear	1	1.361	9.75*	0.370	6.49*	2.465	14.09**	1.346	1.34	383.76	2.25
Quadratic	1	0.551	3.95	0.397	6.96*	0.025	<1	0.416	<1	1.98	<1
Remainder	2	0.008	<1	0.125	2.19	0.119	<1	0.958	<1	39.27	<1
Experimental Error	8	0.140	2.37	0.057	<1	0.175	4.27**	1.007	3.09*	169.78	4.81**
Sampling Error	15	0.059		0.074		0.041		0.326		35.27	

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

displayed in Figures 9-11. The contribution of linear regression to parent seed weight sum of squares was highly significant for progeny seed weight, fertility index, and seed yield (Table 5). Linear coefficients of determination were 0.80, 0.73, and 0.72 for progeny seed weight, fertility index, and seed yield, respectively. Mean squares for linear regression were not significant for number of culms and weight of unthreshed seed per culm. Mean squares for quadratic regression and deviations from regression were not significant for any seed characteristic. Increased parent seed weight produced heavier progeny seeds, higher fertility index, and higher seed yield. Progeny seed weight, fertility index, and seed yield increased by 6.16 mg, 2.7, and 5.67 g for each 25 mg increase in parent 100-seed weight. The ranges between means of the weight classes were 22, 20.1 mg, 244.3 mg, 11.6, and 25.84 g for number of culms, progeny seed weight/per 100 seeds, weight of unthreshed seed per culm, fertility index, and seed yield, respectively (Table A4).

Highly significant simple linear correlations were found between seed yield and all vegetative and seed characteristics excluding plant height (Table 6). Note that negative correlations between vigor, leafiness, and basal area and other characteristics are actually positive since ratings were on a one to five scale with one being best. Path coefficient analysis indicated that number of flowering culms, weight of unthreshed seed per culm, and fertility index had strong positive direct effects on seed yield (Table 7). Seed weight had a low direct effect, but due to positive indirect effects via number of culms,

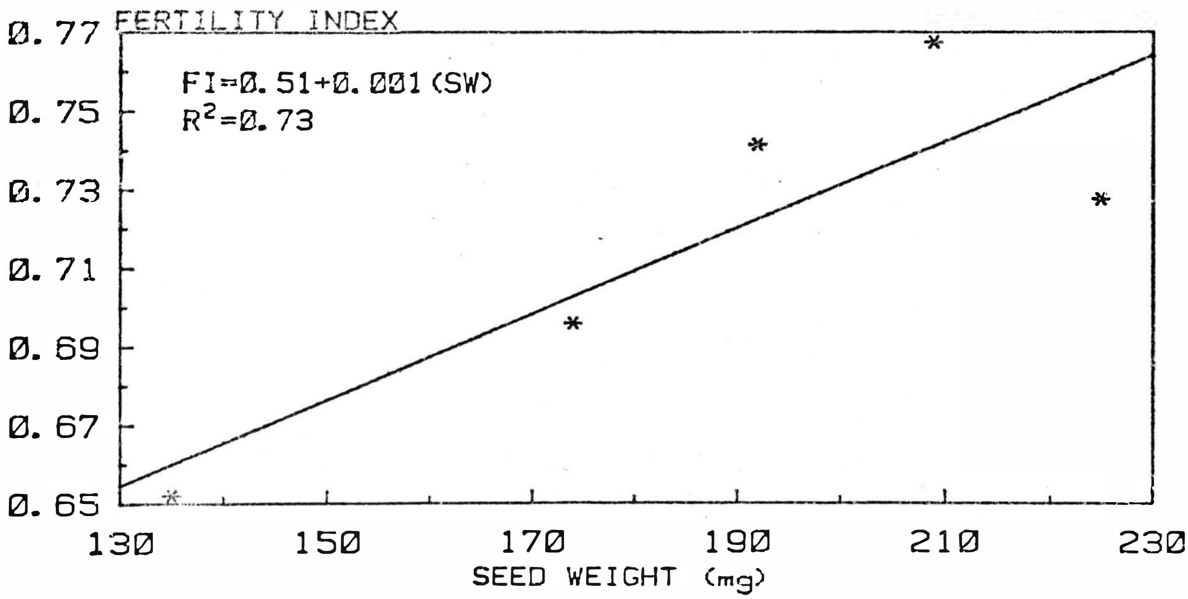

Fig. 10. Relationship between fertility index of spaced-plants and weight of seed.

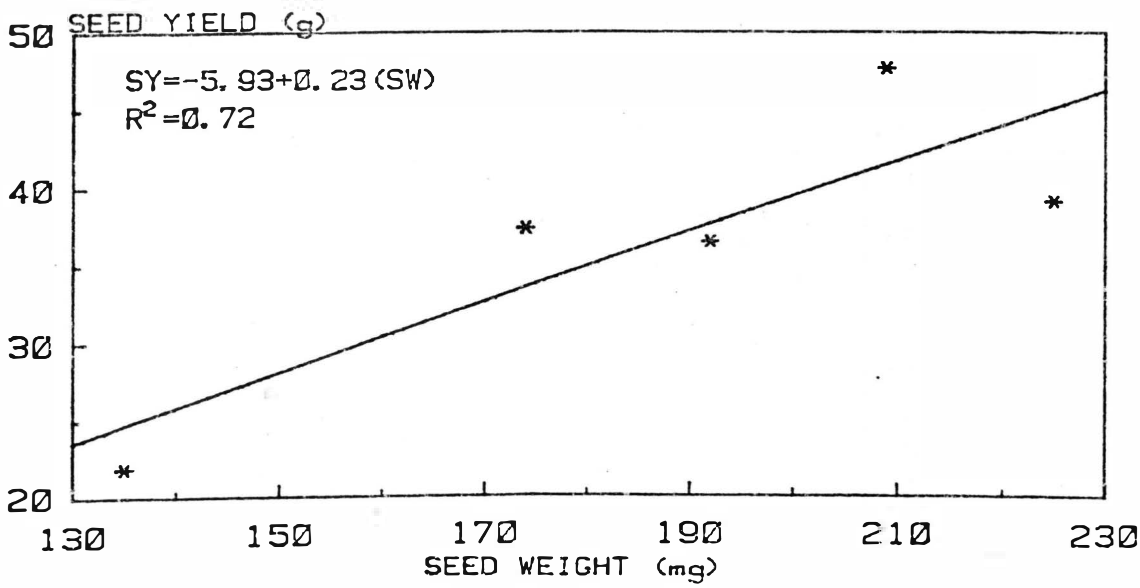

Fig. 11. Relationship between seed yield of spaced-plants and weight of seed.

Table 5. Analyses of variance for number of culms, progeny seed weight, weight of unthreshed seed per culm, fertility index, and seed yield in the seed yield components study.

Source	df	Culms		Progeny seed weight		Weight of unthreshed seed per culm		Fertility index		Seed yield	
		MS	F	MS	F	MS	F	MS	F	MS	F
Total	29										
Seed weight	4	421.32	1.67	548.97	5.36*	57559	2.74	119.05	8.5**	521.0	6.84*
Linear	1	1157.52	4.58	1758.24	17.16**	78686	3.74	348.29	24.9**	1491.6	19.59**
Quadratic	1	289.32	1.14	183.78	1.79	67355	3.20	46.21	3.3	259.0	3.40
Remainder	2	119.23	<1	126.93	1.24	42098	2.01	40.84	2.9	166.8	2.19
Experimental Error	8	252.96	2.16	102.46	<1	20970	<1	14.40	<1	76.1	<1
Sampling Error	15	117.07		162.30		37452		39.69		112.7	

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

Table 6. Correlation coefficients for forage and seed characters in the spaced-plant nursery.

	Vigor	Leafiness	Basal Area	Height	Number of Flowering Culms	Weight of unthreshed seed per Culm	Seed Weight	Fertility Index	Seed Yield
Vigor		0.23**	0.69**	-0.45**	-0.31**	-0.27**	-0.09	-0.14	-0.48**
Leafiness			0.39**	0.13	-0.40**	0.13	-0.09	-0.01	-0.24**
Basal area				-0.28**	-0.48**	-0.14	-0.12	-0.16*	-0.59**
Height					-0.07	0.21**	0.09	0.11	0.13
Number of Flowering Culms						-0.22**	0.15	0.17*	0.59**
Weight of unthreshed seed per culm							0.10	0.04	0.49**
Seed Weight								0.63**	0.35**
Fertility Index									0.42**

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

Table 7. Path coefficient analysis of number of culms, seed weight, fertility index, and weight of unthreshed seed per culm upon seed yield.

Pathways of Association	Coefficients
Seed yield vs. no. culms	
Direct effect	0.683
Indirect effect via seed weight	0.000
Indirect effect via seed/culm	-0.141
Indirect effect via fertility index	0.047
Total correlation	0.589
Seed yield vs. seed weight	
Direct effect	0.002
Indirect effect via no. culms	0.104
Indirect effect via seed/culm	0.066
Indirect effect via fertility index	0.176
Total correlation	0.348
Seed yield vs. seed/culm	
Direct effect	0.633
Indirect effect via no. culms	-0.152
Indirect effect via seed weight	0.000
Indirect effect via fertility index	0.013
Total correlation	0.494
Seed yield vs. fertility index	
Direct effect	0.280
Indirect effect via no. culms	0.114
Indirect effect via seed weight	0.001
Indirect effect via seed/culm	0.028
Total correlation	0.423

weight of unthreshed seed per culm, and fertility index, it had a highly significant total correlation with seed yield. The total correlation between seed yield and number of culms was decreased due to a large negative indirect effect via weight of unthreshed seed per culm. The total correlation between seed yield and weight of unthreshed seed per culm was decreased due to a large negative indirect effect via number of culms.

Using path analysis, 83.5% of the variation in seed yield could be explained by variation in the four independent variables (Table 8).

Field Establishment Studies

Significant differences among parent seed weight classes were found for seedling height at both locations and for emergence at Brookings (Table 9). Four weeks after planting at Brookings, the 225 mg class had the highest emergence (194 seedlings/0.9 m of linear row) and tallest seedlings (54 mm), while the 135 mg class had the lowest emergence (107 seedlings/0.9 m of linear row) and shortest seedlings (40 mm). The same relationship between heavy and light seed weight classes was observed for each of the characters when they were evaluated six weeks after planting at Sisseton (Table 10). The relationships between seed weight and seedling establishment characteristics (emergence and seedling height) at both locations are shown in Figures 12-15. The contribution of linear regression to emergence and seedling height sums of squares was significant at both locations. The quadratic regression mean square was significant for seedling height at Brookings, and the deviation from linear and quadratic regression mean square was

Table 8. Summary of stepwise multiple regression analysis of seed yield and seed yield components.

Regression equation[1]	Coefficient of Determination
SY = 11.35 + 0.40 FC	0.347
SY = -26.22 + 0.50 FC + 37.30 S/C	0.758
SY = -54.71 + 0.46 FC + 35.93 S/C + 44.50 FI	0.835
SY = -54.81 + 0.46 FC + 35.92 S/C + 44.29 FI + 0.002 SW	0.835

Sy = seed yield, FC = number of flowering culms, S/C = weight of unthreshed seed per culm, FI = fertility index, and SW = 100-seed weight.

Table 9. Analyses of variance for emergence and height at Brookings and Sisseton in the field establishment studies.

Source	df	Emergence				Height			
		Brookings		Sisseton		Brookings		Sisseton	
		MS	F	MS	F	MS	F	MS	F
Total	29								
Seed weight	4	6188.4	11.53**	2164.3	2.46	171.15	11.88**	3331.4	4.30*
Linear	1	14645.3	27.31**	8062.1	9.16*	502.50	34.87**	8077.1	10.42*
Quadratic	1	519.7	<1	68.9	<1	86.22	5.98*	423.7	<1
Remainder	2	4794.4	8.94**	263.1	<1	47.93	3.32	2412.5	3.11
Experimental Error	8	536.4	<1	880.2	1.17	14.41	<1	775.1	1.12
Sampling Error	15	845.6		749.3		25.73		692.1	

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

Table 10. Emergence, height, and forage yield for the five parent seed weight classes and checks in the field establishment studies.

Parent seed weight classes and checks	Brookings			Sisseton		
	emergence	height	forage yield	emergence	height	forage yield
225	194A†*	54A††	5521.9A	114A	240A	2645.6A
209	128BC	48B	2949.2A	92AB	212B	2336.0AB
192	146B	42CD	6013.3A	91AB	210B	2160.2AB
174	147B	45BC	4424.5A	83BC	231AB	2212.8AB
135	107C	40DE	5275.6A	62C	179C	1530.2BC
SD 32	137B	45BCD	4735.0A	73BC	220AB	2133.9AB
Neb 28	58D	36E	3339.0A	28D	140D	946.8C

†Number of plants emerged per 0.9 m of linear row.

††Height in millimeters.

*Means in same column followed by a different letter are significantly different at the $P < 0.05$ level.

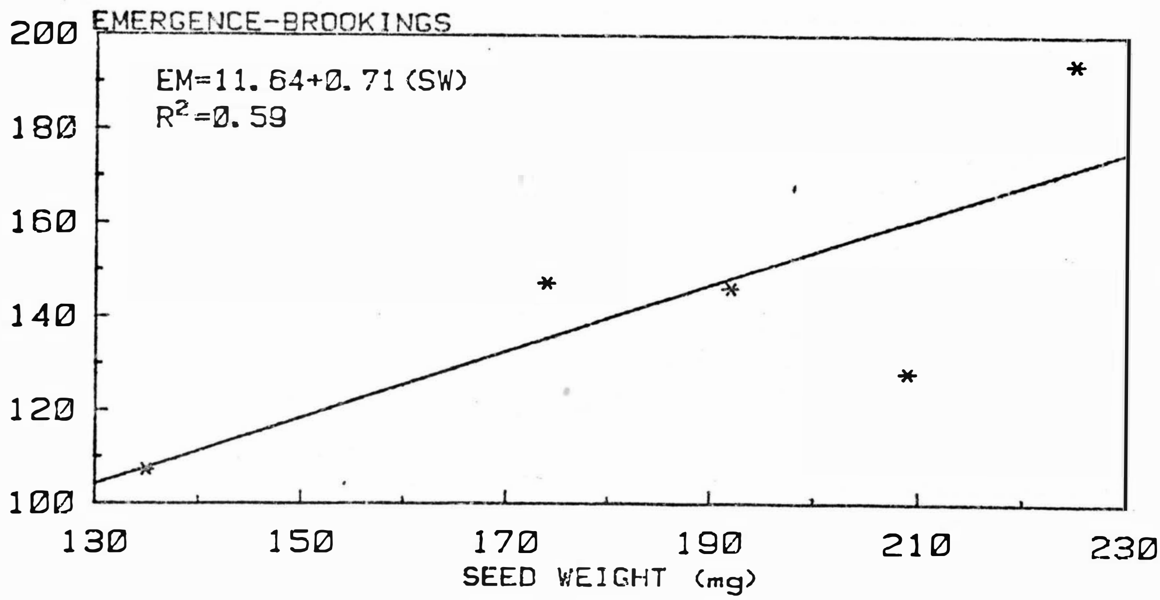

Fig. 12. Relationship between field emergence at Brookings and weight of seed.

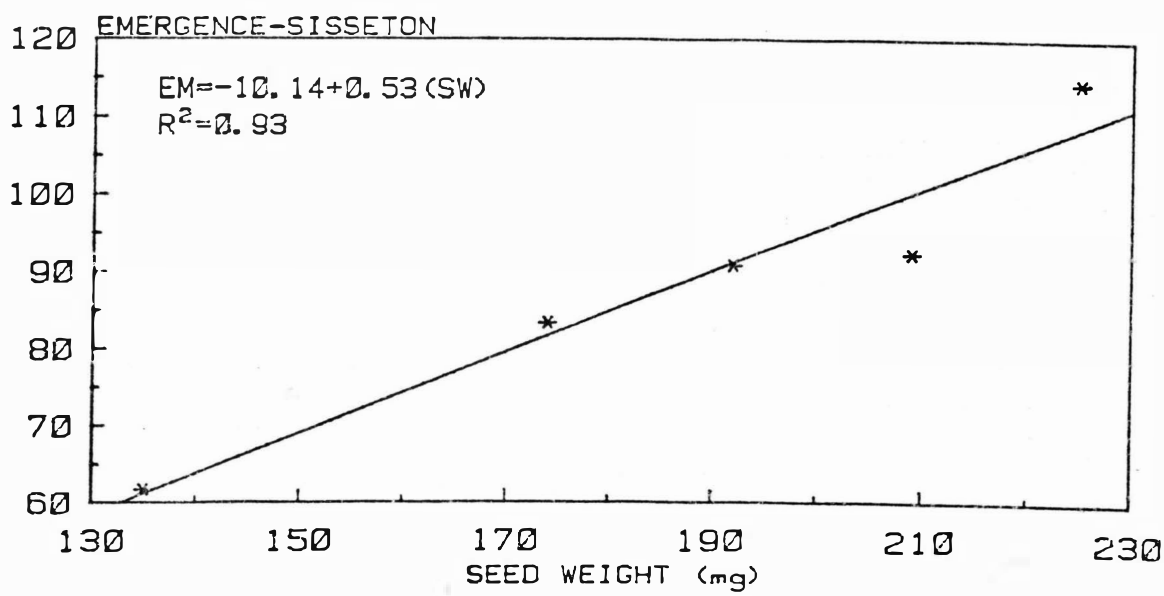

Fig. 13. Relationship between field emergence at Sisseton and weight of seed.

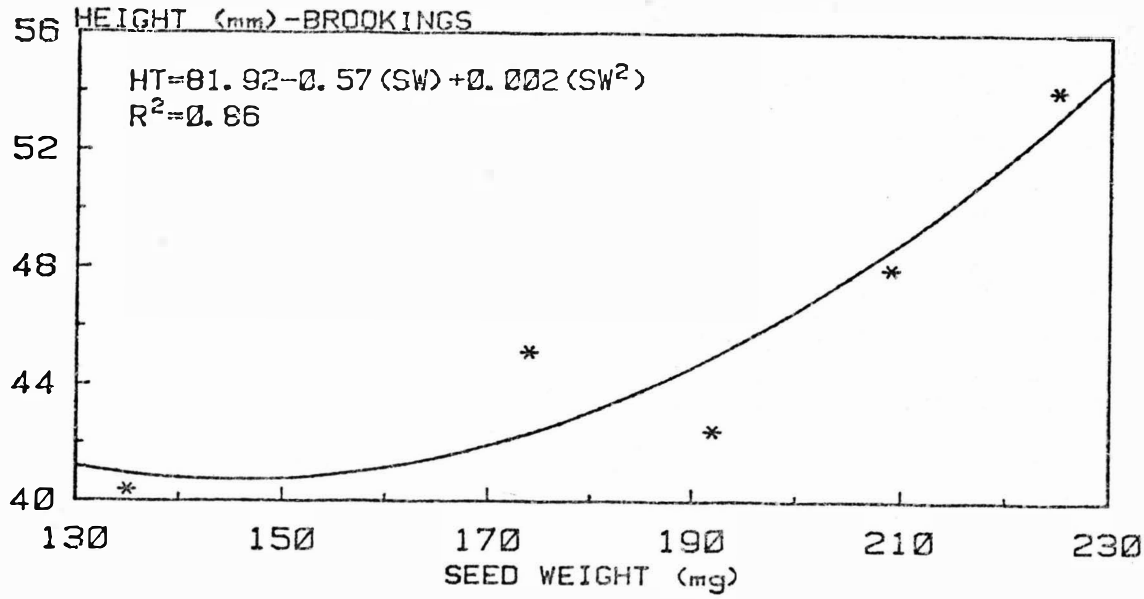

Fig. 14. Relationship between field seedling height at Brookings and weight of seed.

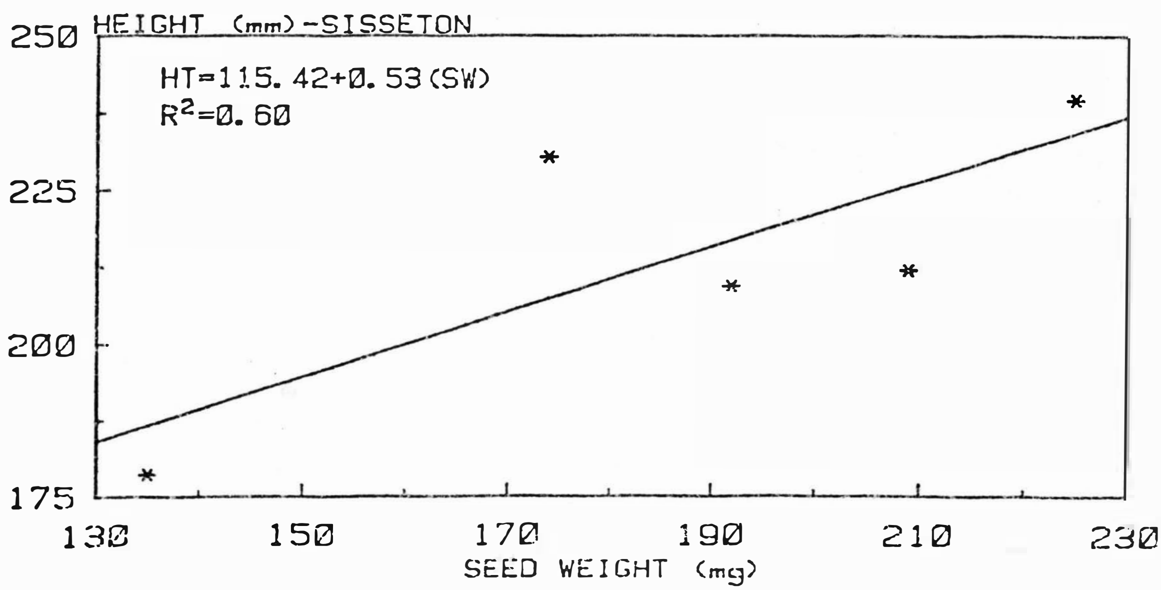

Fig. 15. Relationship between field seedling height at Sisseton and weight of seed.

highly significant for emergence at Brookings (Table 9).

The check variety, Nebraska 28, had significantly less emergence than all five parent seed weight classes and bulk SD 32 at both locations, and produced significantly shorter seedlings than all entries at both locations, except for the 135 mg class at Brookings (Table 10).

Companion crop grain yields in 1981 were near county averages at both locations and no differences were detected among plots underseeded with different seed weight classes of switchgrass.

Significant differences among parent seed weight classes were found for forage yield at Sisseton in 1982 (Table 11). The 225 mg class produced significantly more forage (2645.6 kg/ha) than the 135 mg class (1530.2 kg/ha) and Nebraska 28 (946.8 kg/ha) (Table 10).

Forage yields in 1982 at Brookings were similar for all five parent seed weight classes, bulk SD 32, and the check variety Nebraska 28.

Highly significant differences among establishment methods (crops) were found for forage yield at both locations in 1982 (Table 11). Highest mean forage yields were obtained from clear seeded plots (9052 kg/ha at Brookings and 5834 kg/ha at Sisseton), with drastically reduced yields occurring in companion crop plots of millet (2544 kg/ha at Brookings and 144 kg/ha at Sisseton) and flax (2163 kg/ha at Brookings and 7 kg/ha at Sisseton).

Table 11. Analyses of variance for forage yield at Brookings and Sisseton in the field establishment studies.

		Sisseton		Brookings	
Source	df	MS	F	MS	F
Total	44	19,348,108		40,787,546	
Crop (C)	2	39,537,363	20.51**	501,052,013	29.56**
Seed weight (SW)	4	2,991,368	4.02*	26,005,025	1.20
Linear	1	11,032,560	14.81**	2,732,976	<1
Quadratic	1	68,740	<1	2,971,890	<1
Remainder	2	432,087	<1	10,150,080	<1
Replication (R)	2	2,382,501	6.28**	39,355,316	15.40**
CxSW	8	2,483,568	6.55**	17,374,295	6.80**
CxR	4	1,927,848	5.08**	16,949,863	6.63**
SWxR	8	744,892	1.96	21,737,667	8.51**
CxSWxR	6	643,748	1.70	14,320,134	5.60**
Error	45	379,439		2,554,997	

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

DISCUSSION

Of all the selection criteria that a grass breeder can use to improve seedling vigor, seed size is probably the most important and promises the most immediate progress. Varieties that regularly produce large seed provide the first line of attack on poor stand establishment (Kneebone 1972).

In this study, extensive variation for seed weight was found among and within three switchgrass varieties (Summer, Nebraska 28, and SD 32) grown in the same environment. Ranges between lightest and heaviest seed weight classes exceeded 140 mg/100 seeds for all three varieties, and a 200 mg/100 seeds range was observed between the lightest class of the smallest-seeded variety, Summer, and the heaviest class of the largest-seeded variety, SD 32. The largest seeds of Summer were just slightly heavier than the mean 100-seed weight of Nebraska 28 while the largest seeds of Nebraska 28 were just slightly heavier than the mean 100-seed weight of SD 32 (Fig. 1). Wide variation for seed weight was found within SD 32 in each of three consecutive years (1978-1980), but seed weight distribution curves were similar for all three years (Fig. 2). The results indicate that large differences in seed size exist among diverse switchgrass populations, and that selection for seed size could be attempted in two stages: (1) identify varieties or populations that consistently produce large seed, and (2) utilize air flow separation to isolate, within certain large-seeded populations, the heaviest seed to be used for production of breeding nurseries and synthetic populations. The correlation between progeny seed weight in the open-pollinated nursery and parent seed weight was 0.89 (Fig. 9), indicating that these simple selection procedures were effective for increasing seed size in a breeding population.

Positive correlations between seed size and measures of seedling vigor and stand establishment have been obtained for numerous range and pasture grasses (Kneebone 1972).

Superior seedling vigor, as measured in this study by speed of emergence, seedling height at time intervals, leaf length, leaf width, and seedling dry weight in the greenhouse, and percent emergence and seedling height in the field, was observed for heavy compared to light seed weight classes of SD 32 (Figs. 3-5, 12-15). These results indicated that the greenhouse indicators of seedling vigor that were employed (Copeland 1976) were accurate estimators of stand establishment capabilities in the field. Success in seedling establishment of switchgrass should be increased by selecting varieties that have the ability to emerge quickly and increase in size rapidly when environmental conditions are favorable, as well as the ability to establish under unfavorable conditions, such as drought, poor seedbed preparation, and vigorous weed competition.

Factors that have caused reductions in emergence of forage grasses are late planting (McGinnies 1973) and soil crusting (Hudspeth and Taylor 1961). The lower emergence at Sisseton, compared to Brookings, may possibly be due to one or both of these factors. Planting at Sisseton was 23 days later than Brookings and a hard rain one day after planting caused soil crusting.

When selection is concentrated on one character (seed size in this study), other agronomic characters need to be evaluated to insure that they are not adversely affected. Trupp and Carlson (1971), working with smooth bromegrass, found no decrease in forage yield with increased parent seed weight. In this study, correlations between vegetative characters of spaced-plants and weight of parent seed were generally positive or nonsignificant, indicating that selection for seed size did not have detrimental effects on forage production components (Fig. 6-8).

Forage yield data from Sisseton revealed a highly significant positive relationship between weight of seed planted and forage yields the following year (Table 11), while at Brookings no relationship was detected. These results indicate that heavy seeds were not only superior for stand establishment the seeding year, but also exhibited higher forage yields under moisture stress conditions the following year. The moisture received at Sisseton from April through August, 1982 was 25.4 cm below normal, while precipitation at Brookings was above normal for the same period. A severe, late, non-uniform weed infestation in the plots at Brookings the seeding year was felt to be responsible for reduced stands in specific areas of the experiment. The highly significant seed weight x replication interaction (Table 11) reflects an inconsistency among and within individual plot environments that made forage yields the following year extremely variable.

Seed yield is another characteristic of paramount significance in any native warm-season grass breeding program. Cornelius (1950) concluded, that in general, native grasses were notoriously poor seed producers. In this study, significant increases in seed yield, progeny seed weight, and fertility index were found with increased parent seed weight, indicating that selection for large seed would have a positive effect on seed yield. Trupp and Carlson (1971) indicated no change in seed yield with increased seed size in smooth bromegrass.

Correlations comparing seed yield to seed weight, weight of unthreshed seed per culm, number of flowering culms, and fertility index, were all positive and highly significant, and 83.5% of variation in individual plant seed yield could be accounted for by variation in the four seed yield component variables. Path coefficient analysis revealed that the total correlation between seed weight and seed yield was largely attributed to indirect effects of other seed yield components. Boe (1979), working with big bluestem, also found seed weight to have a small direct effect, but the addition of positive indirect effects due to florets/culm and fertility index produced a highly significant positive total correlation. Path analysis revealed that total correlations could be misleading in studies of direct relationships between seed yield components and seed yield.

SUMMARY

1. The South Dakota Seed Blower was determined to be an accurate and convenient instrument for obtaining different seed weight fractions from bulk seedlots of three switchgrass varieties. Extensive variation among varieties was found for proportions of seed in each weight fraction. However, proportions in each fraction of SD 32 were relatively consistent across three harvest years.

2. In the greenhouse, seedlings produced from heavy seed weight fractions exhibited more rapid emergence, higher percent emergence, faster growth rate, larger leaves, and were heavier 36 days after planting than seedlings produced from light seed weight fractions.

3. Significant positive linear relationships were found between weight of parent seed and vigor, basal area, seed weight, seed yield, and fertility index of progeny spaced-plants grown from five seed weight classes. No linear relationships were detected between weight of parent seed and height, lodging, weight of unthreshed seed per culm, and number of culms of progeny plants.

4. Number of culms and weight of unthreshed seed per culm explained a large proportion of the variation in seed yield. Fertility index and seed weight had small direct effects on variation in seed yield.

5. Significant positive linear relationships were found between weight of parent seed and total emergence and seedling height at both locations, and weight of parent seed and forage yield at Sisseton.

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APPENDIX

Table A1. Mean percent emergence at four-day intervals in the greenhouse seedling vigor study.

Parent seed weight	Days after planting			
	8	12	16	20
225 mg	82.0A†*	83.4A	87.4A	90.6A
209 mg	78.0A	82.6A	87.4A	92.0A
192 mg	75.4A	75.4AB	80.6AB	87.4AB
174 mg	62.0A	65.4B	70.6B	78.0B
135 mg	30.0B	37.4C	44.0C	50.6C

†percent plants emerged out of five seeds planted per pot.

*Means followed by different letters in same column are significantly different at the 0.05 level.

Table A2. Mean leaf length, leaf width, and seedling dry weight for each parent seed weight class 36 days after planting in the greenhouse seedling vigor study.

Parent seed weight	Leaf length(mm)	Leaf width(mm)	Seedling dry weight(mg)
225 mg	143.4	4.2	72.3
209 mg	130.4	3.8	57.4
192 mg	130.0	4.2	61.7
174 mg	122.1	3.8	47.2
135 mg	84.4	3.1	25.9

Table A3. Means of vigor, leafiness, basal area, lodging, and height for each parent seed weight class in the spaced-plant nursery.

Parent seed weight	Vigor	Leafiness	Basal area	Lodging	Height(mm)
225 mg	2.8	2.6	2.8	2.7	174
209 mg	2.8	2.6	2.7	3.0	169
192 mg	2.8	2.9	3.0	2.7	167
174 mg	2.8	3.1	3.1	3.7	169
135 mg	3.4	2.9	3.5	3.3	162

Table A4. Means of number of culms, progeny seed weight, weight of unthreshed seed per culm, fertility index, and seed yield for each parent seed weight class of SD 32.

Parent seed weight	Number of culms	Progeny seed weight(mg)	Weight of unthreshed seed per culm (mg)	Fertility index	Seed yield (g)
225 mg	66	181.7	830.4	72.8	39.11
209 mg	71	180.5	945.0	76.8	47.71
192 mg	62	172.7	807.8	74.1	36.49
174 mg	66	161.6	922.6	69.6	37.37
135 mg	49	162.5	700.7	65.2	21.87