Caryopsis Weight and Planting Depth of Blue Grama II. Emergence in Marginal Soil Moisture

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Abstract

Blue grama [Bouteloua gracilis (H.B.K.) Lag. ex Steud.] has not been able to establish itself, or to be successfully planted, from seed on abandoned croplands of the Central Plains. The objectives of this study were to test blue grama plant material under limited moisture and develop methods for improving emergence and establishment of blue grama seedlings. Experiments were conducted in the greenhouse and at the Central Plains Experimental Range near Nunn, Colorado, with 3 accessions. Under limited moisture conditions in the greenhouse, seedlings emerged better from planting depths of 2.0 and 2.5 cm than from depths of 0.5, 1.0 or 1.5 cm. Higher caryopsis weight was associated with a significant increase in percentage emergence at all planting depths. Accession PM-K-1483 had greatest emergence, followed by 'Hachita' and 'Lovington'. Under favorable soil moisture conditions in the field (2 cm of water applied at planting dates in June and July 1981), deep planting resulted in decreased emergence. Averaged over all planting depths, percentage emergence increased nearly 2-fold with an increase in caryopsis weight from 39 to 59 mg/100. When soil moisture conditions were marginal (only 1 cm water added), satisfactory emergence was obtained only when highweight seeds were planted at a depth of 2 cm. Soil at a planting depth of 1 cm dried quickly and prevented emergence. Genetic improvement of caryopsis weight combined with planting at depths of about 2.0 cm should improve the emergence and establishment of blue grama seedlings.

Key Words: Bouteloug gracilis, seedling establishment, path analysis, seed weight

The rationale for this study is given in the companion paper (Carren et al. 1987). In that study, we found that deep plantings resulted in reductions in emergence for all weight classes of blue grama seedlings under favorable soil moisture conditions. However, conditions on the Central Plains are seldom favorable because the soil surface dries rapidly after rainfall. This study was conducted to determine the effects of planting depth and caryopsis weight on emergence and growth of blue grama seedlings when soil moisture was not optimal. Experiments were conducted in the greenhouse and under field conditions. The greenhouse study simulated conditions in which the soil profile was moistened from rainfall but no additional water was supplied after the initial amount. The field study was conducted to determine the effects of planting depth, caryopsis weight, and soil moisture on the emergence of blue grama seedlings on the Central Plains.

Materials and Methods

Greenhouse Study

Spikelets (seeds) from the 3 blue grama accessions described in

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The authors wish to thank Phillip Morrisey and Patricia Fashing for technical

assistance in the study.

The authors also wish to thank Dr. M.A. Brick and Dr. C.H. Pearson of the Department of Agronomy; Dr. M.J. Trlica of the Department of Range Science; Dr. P. Coyne of the USDA Southern Great Plains Range Research Station, Woodward, Okla.; and Dr. D.D. Briske of Texas A&M University, College Station for their comments in reviewing this paper.
Funding was provided by Colorado State Univ., Agr. Exp. Sta. and the USDA,

Manuscript accepted 3 November 1986.

Carren et al. (1987) were used in this study: 'Hachita', 'Lovington', and PM-K-1483. Seeds of these 3 accessions were harvested in 1978 in related research (Wilson et al. 1981) from individual plants. Average caryopsis weight of the seeds from each plant was determined, and each plant was assigned to 1 of 5 carvonsis weight classes (35-40, 40-45, 45-50, 50-55, and 55-60 mg/100 caryopses, designated as class 1 to 5, respectively). The spikelets were processed with a South Dakota seed blower to eliminate unfilled spikelets. An equal quantity of seed from 10 plants within each of the 3 accessions and 5 weight classes was taken to form 15 seed lots. Plastic pots (20 cm diameter by 20 cm deep) were filled with sterilized, screened sandy loam. Fifty seeds were spaced evenly on the soil surface and covered with 0.2 cm of soil. Enough water was added to the top of the pot to bring the soil to field capacity (about 20%). Seeds were covered with an additional amount of dry soil to give planting depths of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 cm. Seedlings emerged through the dry soil layer as described in Carren et al. (1987), but in contrast to that study no additional water was added after planting. Six additional pots per planting depth (without seeds) were prepared to determine percent gravimetric soil water content at planting depth. Each of the 4 replications of 126 pots [(15 seed lots \times 6 depths) + (6 extra pots \times 6 depths)] was completely randomized, with replications being conducted consecutively in time. The study was carried out in the greenhouse where daylength was 15 hours (supplemented with sodium vapor lamps) and air temperatures varied from 25 to 35° C. Rate of germination index, rate of emergence index, and percentage emergence were determined as in Carren et al. (1986).

All pots were weighed on the day of planting and on the 3rd, 6th, and 9th day after planting to determine the total amount of water evaporated from the pots for each of the 6 planting depths. On days 0, 1, 2, 3, 4, and 5 for the 0.5 and 1.0-cm depths, and days 0, 2, 4, 6, and 8 for the 1.5 through 3.0-cm depths, percentage soil moisture at planting depth was determined gravimetrically. Soil samples for this measurement were taken by collecting a 1-cm increment of soil around each planting depth. The rate of drying of the soil at each planting depth was estimated as g water evaporated per 100 g soil per day (g water \times 100 g⁻¹ \times day⁻¹).

Analysis of variance was performed on each variable measured. Polynomial regression was performed for each planting depth to determine relationships between water evaporated and sampling date. Duncan's multiple range test was used to evaluate differences among accessions in percentage emergence, emergence index, and germination index. Path coefficient analysis (Nie et al. 1975, Wright 1934) was used to evaluate possible cause-and-effect relationships among plant and seedbed characteristics.

Central Plains Study

This experiment was conducted at Section 18 of the Central Plains Experimental Range about 16 km northeast of Nunn, Colo. Soil was a sandy loam (fine-loamy, mixed, mesic Aridic Argiustoll) as in the greenhouse experiment. Before planting, the field was plowed, disced, and packed. Seeds for this study were harvested in 1980 from individual plants in the author's 1680-plant Cycle-1 breeding nursery at Los Lunas, New Mexico. Average caryopsis weight of individual plants was determined and plants were assigned to 1 of 5 weight classes. Seeds from 10 plants in each weight class (30-40, 40-50, 50-60, 60-70, and 70-80 mg/100)

caryopses) were thoroughly mixed to give 5 combined weight classes. Accession was not included as a variable because the seed was derived from recombination in the population.

Metal frames (10 cm wide by 100 cm long by 8 cm deep) were hammered into the soil until the top of the frame was even with the soil surface. The 4 planting depths were obtained by using a metal scraper inside the frame to remove a layer of soil 1, 2, 3, or 4 cm deep. One hundred seeds from each weight class were sprinkled within the frame and covered with 2 mm of soil; then each plot was irrigated. The additional soil that had just been removed was added to level the soil in the frame with the surrounding soil surface, then the frame was removed. There were twenty 1-meter plots per row, with a 30-cm space between plots along the row and 60-cm distance between rows.

Seeds were planted on 4 dates (11 June, 23 June, 7 July, and 22 July 1981) each with 3 to 5 replications of 20 plots each (5 weight classes × 4 planting depths). Plots of the first planting received 1 cm of supplemental water, and plots of the second, third, and fourth plantings received 2 cm at the time they were planted. Percentage seedling emergence 3 weeks after planting (based on the number of germinable seeds planted) was analyzed separately for each planting date. Percent stand (aerial cover) was determined in September 1982 at the end of the growing season and was analyzed on data averaged from the 4 planting dates.

On each planting date an additional row of plots was prepared without any seeds. Plots were irrigated with 1 or 2 cm of water (as indicated) and sampled 1 week later to determine soil moisture gravimetrically at planting depth. Rainfall (31 cm average annually) is erratic at this location and a 1980 experiment with no supplemental water failed because of insufficient June-July rainfall following a cold May.

Results and Discussion

Greenhouse Study

There were no significant differences in germination index among seed weight classes; however, germination indices were significantly different for different accessions (Table 1).

Table 1. Rate of germination index of composite 10-plant seed sources (1978 harvest).

		Accession					
Accession	35-40	40-45	45-50	50-55	55-60	mean	
PM-K-1483	45.0	42.3	48.0	43.9	45.8	45.0a ²	
Hachita	34.8	39.1	39.0	37.1	33.8	36.7c	
Lovington	43.1	43.0	42.2	40.3	44.4	42.6b	
Wt. class mean	41.03	41.4	43.1	40.4	41.3		

Weight classes were actually 35.0-39.9 mg/100 etc.

The dry layer of soil acted as an effective mulch and slowed down the total water loss from the pots throughout the 10-day test (Fig. 1). The 3.0 cm planting depth retarded moisture loss the most. Water evaporated rapidly from pots with 0.5 cm of dry soil during the first few days of the test, whereas evaporation from pots with 3.0-cm of dry soil was slower. Rates of drying of the 1-cm increments of soil at planting depth also showed a decrease in rate of water loss with an increase in thickness of the dry soil layer (Table 2).

Seedling emergence increased from a low of 4% at the 0.5-cm depth to a high of 72% at 2.0 and 2.5 cm, and then decreased to 67% at 3.0 cm (Fig. 2). The high emergence at 2.0 and 2.5 cm resulted from 2 different effects associated with deep plantings. The first effect was a reduction in rate of water loss from the seedbed when the depth of overlying dry soil increased. The second effect was related to the capacity for elongation of the subcoleoptile inter-

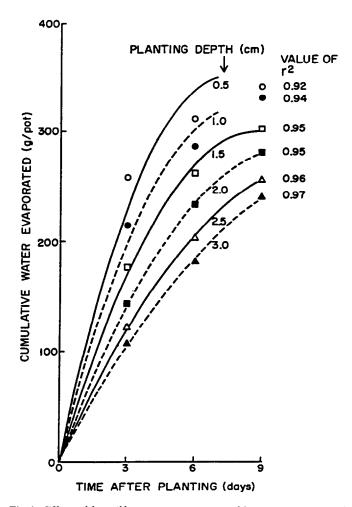


Fig. 1. Effects of dry soil layer on water evaporated from pots over a period of 9 days. Differences between time after planting and between planting depths were significant (p \leq 0.01). The interaction of time \times depth was significant (p \leq 0.01).

Table 2. Effect of planting depth on rate of drying of soil at planting depth and rate of emergence index for blue grama seedlings grown under drying soil conditions.

	Planting	depth (cm)			
	0.5	1.0	1.5	2.0	2.5	3.0
Rate of soil drying (g	water ×	(100g ⁻¹)	≺ day ⁻¹)¹			
	11.2	6.0	2.8	2.3	1.9	1.8
Emergence index ²	14.3	35.7	31.5	28.6	25.7	23.7

Differences among planting depths were significant ($p \le 0.01$). Differences among planting depths were significant ($p \le 0.01$).

node. Soil depths of 2.0 or 2.5 cm, over the planted seed, did not exceed the maximum reach of the subcoleoptile internode for most seedlings; but a soil depth greater than 3 cm often exceeded the potential of the subcoleoptile internode and coleoptile to elongate and to reach the soil surface (Carren et al. 1987). Accession PM-K-1483 had the highest overall emergence, 62.8%, as compared with 43.8% for Hachita and 49.3% for Lovington. High emergence was generally associated with high caryopsis weight (Table 3). There was a significant interaction of accession and planting depth, which resulted from high emergence of PM-K-1483 from shallow planting depths (Fig. 2). There was also a significant interaction of accession and caryopsis weight, which resulted from the highest

²Accession means differed significantly with Duncan's multiple range test ($P \le 0.01$). There was a significant accession \times weight class interaction ($P \le 0.01$).

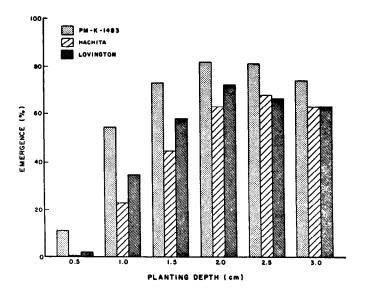


Fig. 2. Effects of accession and planting depth on emergence of blue grama seedlings grown in the greenhouse under drying soil conditions. Differences among planting depth means were significant (p≤0.001). Accession means differed significantly (p≤0.01) in Duncan's multiple range test. The interaction of accession × planting depth was significant (p≤0.01).

Table 3. Effects of caryopsis weight (mg/100) and accession on percent emergence of blue grama seedlings grown under drying soil conditions in the greenhouse.

	Caryopsis weight class					
Accession	35-40	40–45	45-50	50-55	55-60	Mean
PM-K-1483	54.1	58.0	65.8	67.3	68.8	62.8a1
Hachita	31.7	49.6	49.5	44.9	43.2	43.8c
Lovington Mean of three	45.1	47.3	46.6	59.2	48.3	49.3c
accessions	43.62	51.6	54.0	57.1	53.4	52.0

Accession means differed significantly ($p \le 0.01$) in Duncan's multiple range test. ²Weight class means differed significantly (p≤0.01). The interaction of accession × weight class was significant $(p \le 0.01)$.

emergence within each accession occurring in different caryopsis weight classes (Table 3). A possible explanation for this interaction is that caryopsis weight classes were made up from different plants and therefore differed in genetic characteristics that were independent of seed weight.

Seedlings emerged most rapidly from a planting depth of 1.0 cm, and their emergence index then decreased with a further increase in planting depth (Table 2). It was expected that seedlings from 0.5 cm would emerge most rapidly because they had less distance to grow. However, the rapid drying of soil at 0.5 cm probably adversely affected the developing seedlings and slowed their rate of growth. There was no significant difference among caryopsis weight classes in emergence index. For the equivalent weight classes accession PM-K-1483 emerged significantly more rapidly $(P \le 0.01)$ with an index of 30.0, as compared with 23.7 and 25.9 for Hachita and Lovington, respectively. The trend in rate of emergence among accessions was the same for rate of germination (Table 1), indicating that seeds that germinated rapidly also emerged rapidly. Caryopsis weight was not apparently an influential factor in speed of emergence; therefore, some other unknown factor was involved. Rapid germination and emergence appeared to be under genetic control, evidenced by differences among accessions. A combination of the high caryopsis weight with the rapid emergence of genotypes would appear to be a useful breeding objective.

Path coefficient analysis was used to determine the relationships among caryopsis weight, rate of germination index, planting depth, and rate of drying of soil at planting depth, and to evaluate their relative effects on percentage emergence (Fig. 3; Table 4).

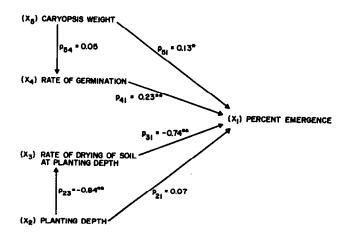


Fig. 3. Path coefficient diagram of relationships among caryopsis weight. rate of germination, planting depth, rate of drying of soil at planting depth, and percent emergence of blue grama seedlings grown under drying soil conditions. * Significant at $P \le 0.05$, ** significant at $P \le 0.01$.

Table 4. Partitioning of total correlation (r) among causal direct effects (p), causal indirect effects, and noncausal correlation in the study of blue grama seedling emergence under drying soil conditions in the greenhouse.

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	Variables ¹	Total correlation (r)	Direct (p)	Indirect	Total (c)	Noncausal correlation
p ₅₁	Percent emergence-caryopsis weight	0.137**2	0.126*	0.011	0.136	0.001
P ₄₁	Percent emergence-rate of germination	0.234**	0.228**	0	0.228	0.006
031	Percent emergence-rate of drying of soil	-0.796**	-0.738**	0	-0.738	-0.058
D ₂₁	Percent emergence-plant depth	0.690**	0.069	0.621	0.690	0
)23	Rate of drying of soil-planting depth	-0.842**	-0.842**	0	-0.842	0
054	Rate of germination-caryopsis weight	0.049	0.049	0	0.049	0

¹The dependent variable is given first.

²Double asterisk (**) indicates significance at p≤0.01. Indirect, total causal, and noncausal effects do not have significance tests.

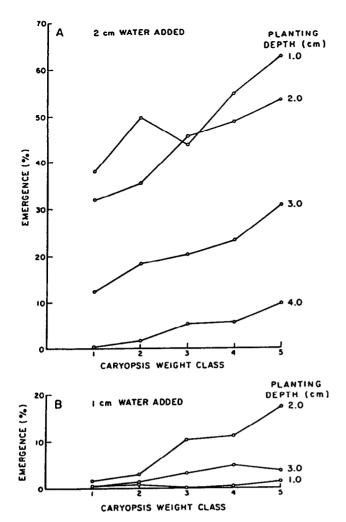


Fig. 4. Effects of caryopsis weight class and planting depth on percent emergence of blue grama seedlings grown under (A) favorable (2 cm water added) and (B) marginal (1 cm water added) soil moisture conditions at the Central Plains Experimental Range. (A) Differences among weight class means and planting depths were significant (p≤0.05 and p≤0.01, respectively). (B) Differences among planting depths were significant (p≤0.01). The interaction between weight class and planting depth was significant (p≤0.05).

Cause and effect assumptions were made on the above variables based on the chronological sequence of events that occur in germination and emergence. A path coefficient is a standardized partial regression coefficient that yields statistically comparable values. A direct causal effect (path coefficient, P) and the direction of that effect is shown by an arrow extending from the independent to the dependent variable. Independent variables may also exert indirect effects through their actions on other independent variables which are illustrated (Fig. 3) by alternative paths that connect the independent and dependent variables. The magnitude of the indirect effect is equal to the product of coefficients along the connecting path.

High caryopsis weight had a small direct influence on emergence $(P_{51} = 0.13)$. This coefficient was smaller than expected, perhaps because none of the seed sources was planted deeply enough to prevent emergence; even seeds of the low weight class emerged fairly well. Rapid germination was associated with increased emergence $(P_{41} = 0.23)$, most likely because seeds that germinated rapidly resulted in emergence (and rooting) of seedlings before the soil had a chance to dry out.

The analysis indicated no significant direct effect of planting depth on percentage emergence (Fig. 3; Table 4). The influence of planting depth on emergence was primarily expressed through the

negative effect of depth on rate of drying of soil ($P_{23} = -0.84$). Soil at shallow depths dried rapidly and prevented emergence, whereas with deep plantings the soil remained moist long enough for seedlings to emerge. The total positive effect of planting depth on percentage emergence (c = 0.69) resulted primarily from the indirect effect given by the product of $P_{23} \times P_{31}$ ($-0.84 \times -0.74 = 0.62$).

Central Plains Study

Emergence was highest for the 2-cm planting depth and lowest for 1-cm under the dry soil conditions of plots that received 1 cm of additional water (Fig. 4B). Apparently, the soil at 1 cm dried too quickly for seeds to germinate and seedlings to emerge. Soil moisture at the 2-cm depth was favorable long enough to permit emergence, whereas at 3-cm emergence decreased because of the detrimental effects of deep planting. Emergence increased at the 2 and 3-cm depth with an increase in caryopsis weight. At 1 cm, high weight seeds did not improve emergence. No seedlings emerged from a 4-cm planting depth.

In the plantings which received 2-cm of additional water, moisture conditions were more favorable at the 2-cm planting depth than at the 1-cm depth. Germination, rooting, and emergence occurred at both depths even though soil moisture was low 1 week after planting (4.9 and 2.2% moisture by weight for 2 cm and 1 cm depths, respectively). Emergence decreased with increased planting depth (50, 43, 21, and 5% averaged over all caryopsis weights for 1, 2, 3, and 4 cm, respectively) (Fig. 4A). Emergence increased with increased caryopsis weight (21, 26, 29, 33, and 39% averaged over all depths for weight classes 1-5, respectively) (Fig. 4A). High caryopsis weight overcame the disadvantage of deep planting. For example, seeds in weight class 5 planted at 2 cm had a higher emergence than seeds in weight class 1 planted at 1 cm (53% and 38%, respectively). Class 5 could even be planted at 3 cm and still have emergence over 30% (Fig. 4A).

Percent stand after 1 year (averages of all 4 planting dates) gave an indication of seedling establishment. The trends observed for emergence continued; high caryopsis weight was associated with increased stand and deep plantings were associated with decreased stand (Table 5). Satisfactory stands were obtained from 1, 2, and 3

Table 5. Percent stand (aerial cover) of blue grama plants one year after planting (averaged over all four planting dates).

Caryopsis Weight class					
	1	2	3	4	Mean
30 - 40	47.0	28.9	12.8	1.2	22.51
40 - 50	74.0	41.2	31.5	2.2	37.2
50 - 60	63.2	54.5	29.0	9.5	39.0
60 – 70	73.0	59.0	39.2	6.8	44.5
70 – 80	73.7	62.5	36.5	9.2	45.5
Mean	66.21	49.2	29.8	5.8	

'Differences among weight class means and among planting depth means were significant ($p \le 0.01$). The interaction of weight class \times planting depth was significant ($p \le 0.05$).

cm. However, it must be remembered that some supplemental moisture was used in this field experiment. Although planting at 2 cm did not always result in higher emergence than at 1 cm (Fig. 4A) and showed less stand survival after 1 year (Table 5) under favorable moisture conditions, planting at a 2 cm depth may be the most reliable, particularly under water-limited conditions. Planting at a 2-cm depth will maximize the probability of establishment and will reduce the chances of exposure to the highly fluctuating soil moisture conditions near the soil surface.

Conclusions

Heavier seeds emerged more successfuly from deeper depths than lighter seeds in both the greenhouse and the field. When moisture conditions were marginal, deep planting increased emergence because seeds remained in moist soil during the crucial emergence in the field under water-limited conditions, blue grama requires adequate soil moisture, which is rarely found at such a shallow depth. Genetic improvement of caryopsis weight (in progress) and planting at depths of 2 cm should improve emergence and establishment of blue grama seedlings.

period of germination and emergence. The recommended planting

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