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SOIL MOISTURE AVAILABILITY EFFECTS ON SEED GERMINATION AND GERMINATED SEED SURVIVAL OF SELECTED WARM SEASON GRASSES

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ABSTRACT

Germination rates and germinated seed survival under limited soil moisture conditions of five warm-season grass species were evaluated in laboratory growth chambers. Techniques were developed to relate seed germination characteristics at reduced soil water potentials to field soil moisture tension conditions for estimating potential rates and percentages of seed germination.

INTRODUCTION

Soil moisture availability is among the key factors affecting seed germination and seedling survival under rainfed conditions. With dry soil conditions, seeds will not initiate germination. During periods of wet soil, the seeds germinate and produce viable seedlings which develop into mature plants. If the initial wet period during germination or seedling growth is followed by an extended dry period, the germinated seed or seedling may die. Understanding the germination and survival characteristics of germinated seeds and seedlings, as affected by available soil moisture, offers the possibility of incorporating the probabilistic aspects of precipitation and soil water relations into a description of the seedling environment necessary for plant establishment.

To accomplish this task, information is needed on the critical length of the 'wet' period required for seed germination in soil. Information is needed on the quantity and/or tension of available soil water which constitutes a 'wet' condition from the perspective of the seed. And finally, information is needed on the effect of the relative length of the first dry period following planting on germinated seed survival.

Laboratory growth chamber studies were conducted to: (1) evaluate the survival characteristics of germinated seeds during extended periods of high moisture tensions, (2) evaluate the rate of seed germination at various soil moisture tensions, and (3) develop a technique for relating seed germination rates to field seedbed soil moisture conditions during drying. For the studies a germinated seed was defined as the stage of growth when the seed had a visible radicle but before a shoot had emerged.

BACKGROUND

Frasier et al. (1985), found that the seedling survival probabilities of seven warm-season grasses exposed to the first wet-dry watering sequence following seeding were a function of: (1) the number of seedlings produced in the first wet period which developed sufficient vigor to survive the subsequent dry period; (2) the number of ungerminated but viable seeds which remained after the first wet-dry watering sequence; and (3) the relative lengths of the wet and dry periods. The study did not provide information on the relative effects of the wet-dry watering sequences on seed germination or what constituted a 'wet' or 'dry' condition from a seed/seedling perspective.

Determining the effect of the quantity of available water on seed germination in a soil medium is difficult because the soil cover prevents direct observation of the germination process. One relatively common technique for evaluating the effect of water availability on germination is to place the seeds in salt or polyethylene glycol (PEG) solutions of various concentrations (Kaufmann and Ross 1970). These approaches are straight forward, suitable for laboratory controlled environments, and provide a rapid assessment of the relative differences in germination rates and total seed germination potential. There is a large volume of data in the literature on seed germination of many plant species in salt or PEG solutions. Unfortunately it is difficult to directly compare the results of various studies. It is usually necessary to develop some type of analytic relation for interpolating or extrapolating the results for comparison purposes.

There is also some concern that the results derived in solution studies are not representative of field results that might occur at the same matric water potentials. Kaufmann and Ross (1970), reported that PEG solutions do not represent many soil situations because the germination rate in solutions was much more rapid than that observed in the field. Earlier, Collis-George and Sands (1962), in studies utilizing different solutes at the same osmotic potential, found that osmotic and matric potentials were not interchangeable in their qualitative influence on seed germination. Sedgley (1963), concluded that the matric soil-water potential was not controlling seed germination. Rather the area of water contact with the seed was the more important factor. This theory was partially substantiated by Collis-George and Hector (1966), who found that there was an effect of the area of water contact at the higher matric potentials. Sharma (1973), found that total germination in PEG solutions and soils were similar if there was good seed-soil contact, water movement in the soil was non-limiting, and there was no undesirable microbial growth.

The water-seed contact area becomes an important factor with small seeds which approach the size of the soil particles. Hunter and Erickson (1952), reported that soil moisture tension but not soil texture, affected the germination of soybeans (*Glycine max*), corn (*Zea mays*), rice (*Oryza* spp.), and sugar beets (*Beta vulgaris* L.). With smaller sized seeds of Russian thistle, (*Salsola kali* var. *renuifolia* Tausch), germination in a clay soil and

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PEG solutions were similar. Germination of Russian thistle seeds in coarser textured loam and sandy soils was greatly reduced at matric potentials less than -2 bars (Young and Evans 1972). Similar results were obtained with cultivars of subclover (*Trifolium subterraneum* L.) (Young et al. 1970).

Once germination has occurred, the germinated seed and seedling are in a growth stage where adequate soil water can become a critical factor for continued growth and survival. Watt (1978), reported a complete loss of seed viability when germinated seeds of Queensland blue grass (*Dicanthium sericeum* L.) were placed in air-dry soil for 9 days then rewetted for 14 days. In another study, the survival of partially germinated seeds of bambatsi panic (*Panicum coloratum* L.) native millet (*Panicum decompositum* R. Br.), wallaby grass (*Danthonia lvevis* Vickery), windmill grass (*Chloris truncata* R.Br.), and purple pigeon grass (*Setaria porphyrantha* Stapf) was less than 50%. A germinated seed was defined as between "...when the colorhiza and/or coleoptile emerged from the caryopsis." and "...when the emerging radicle and/or shoot broke through the colorhiza or coleoptile." (Watt 1982). Hassanyar and Wilson (1978), found that the differences in the ability of crested wheatgrass (*Agropyron desertorium* [Fisch.ex Link] Schult.) and Russian wildrye (*Elymus junceus* Fischer) to survive a dry period following germination but prior to seedling development was correlated with the ability of the species to develop seminal lateral roots. Fulbright et al. (1984), found that dehydration of germinating seeds of green needlegrass (*Stipa viridula* Trin.) significantly reduced subsequent seedling emergence.

There are very little data concerning the actual soil-water tensions which exist in the shallow seedbed zone of many rangeland sites. Wilson et al. (1970), reported that water potentials in the surface soil decreased from -4 bars to -300 bars in a 2-day period. Soil water content changes equivalent to water potential changes of -2 bars to over -15 bars occurred in the surface 0.5 cm of soil with a single day of drying (Nakayama et al. 1973, Jackson 1973, private correspondence with R. D. Jackson).

MATERIALS AND METHODS

Germinated Seed Survival

The study was to evaluate the length of time that newly germinated seeds would remain viable on dry filter paper in a 95 to 100% R.H. incubator. This information is needed to determine the susceptibility of germinated seeds to severe desiccation following initial germination. The plant species used in the studies were; 'Premier' sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), 'A-68' Lehmann lovegrass (*Eragrostis lehmanniana* Nees), 'Catalina' lovegrass (*E. curvula* var. *conferta* (Schrad.) Nees), 'Cochise' lovegrass (*E. lehmanniana* Nees X *E. trichophora* Coss and Dur.), and 'SDT' blue panicgrass (*Panicum antidotal* Retz).

Seeds were germinated between two disks of Whatman No. 3 filter paper in 8.5-cm diameter x 1.5-cm deep petri dishes. The filter paper was saturated with deionized distilled water, covered with a lid and placed in an 29.4 C incubator for sufficient time to germinate most seeds. The time for initial seed germination varied from 15 to 68 hours (Table 1). The start time for the initial germination phase was staggered so that the seeds of all species would be at approximately the same stage of germination for the desiccation phase of the study.

Table 1. Seed germination time.

Species	Time for initial germination (hrs)
Sideoats grama	15-16
Catalina lovegrass	50-52
Cochise lovegrass	66-68
Lehmann lovegrass	50-52
Blue panicgrass	50-52

Ten germinated seeds per species with a visible radical less than 3 mm long were individually selected and placed between two layers of dry Whatman No. 3 filter paper in petri dishes. The petri dishes were randomly placed in a constant temperature incubator for the various dry period intervals. Following the dry period, the filter paper was wetted with distilled water and the petri dishes returned to the incubator (at the prescribed temperature) for 7 days at which time the number of surviving germinated seeds were counted.

The experimental design included six dry period intervals, five species, three temperatures, and three replications in time. Each replication consisted of the pooled count of six petri dishes. The dry period intervals were; 0, 1, 3, 5, 7, and 10 days. The incubator temperatures were 22, 29 and 35°C. Replication means of the surviving seed counts were subjected to analysis of variance to determine if differences among species, temperature and lengths of dry periods were significant.

Seed Germination at Reduced Water Potential

The objective of this study was to evaluate the rate of seed germination in selected soils at reduced water potentials. Three soils were used: a Vekol silty clay loam (thermic, Typic Haplargid) from the east side of Avra Valley, 25 km west of Tucson, AZ; a Sonoita silty clay loam (thermic, Typic Haplargid) from near Three Points, AZ, 50 km west of Tucson, AZ; and a Comaro sandy loam (mixed, thermic, Typic, Torrifluent) from the Santa Rita Experimental Range 60 km south of Tucson, AZ. (Soil description provided by Jack Stroehlein, University of Arizona, personal communication) The Avra Valley and Three Point soils were abandoned irrigated farmland areas.

The Santa Rita soil was from a semiarid grassland pasture. A composite soil sample representing the top 4 cm was collected at each site. Based upon the particle size distribution (hydrometer), the composite samples from the Three Points and Santa Rita areas were both classified as a sandy loam. The soils are dissimilar in their proportions of sand and silt. The textural analysis of the Avra Valley sample was a sandy clay loam (Table 2).

Table 2. Particles size distribution of the Avra Valley, Three Points and Santa Rita soils.

Soil	Sand	Silt	Clay	Soil texture classification
	(%)	(%)	(%)	
Avra Valley	43.3	34.1	22.6	sandy clay loam
Three Points	53.3	45.1	1.6	sandy loam
Santa Rita	69.4	22.2	8.4	sandy loam

Soils were sieved through a 4 mm screen. Approximately 250 g were placed on the surface of a prewetted ceramic plate in a pressure chamber. The soil was saturated with distilled water and pressures of 0.3, 1.0, or 7.0 bars were applied to the chamber for 24 hours. Three pressure chambers were used simultaneously, one for each pressure. Each pressure chamber held three pressure plates, one for each soil. After 24 hours approximately 35 g of soil from the pressure plates were placed in 6.0 cm diameter X 4.5 cm deep metal soil cans and lightly compacted with a rubber stopper. Ten seeds were placed on the soil surface and covered with a 1-2 mm layer of lightly compacted soil. The cans were covered with a lid and randomly placed in a 26.7°C constant temperature incubator. Each can was inspected daily for 14 days and the number of germinated seeds counted. A seed with any visible sign of a radicle was considered as germinated and was removed after counting. Each replication consisted of the pooled count from three cans (30 seeds). Two, 50-g, soil samples were collected from each soil and at each tension for gravimetric determination of the soil water content.

The rate of seed germination at zero (0) water stress was determined in petri dishes filled with 50 g of soil saturated with distilled water. Thirty seeds were placed uncovered on the soil surface, the dish covered, and placed in a 26.7°C incubator (one dish per species). The number of germinated seeds were counted daily for 12 days.

An estimate of the relative rate of germination without soil was determined by placing 30 seeds between two disks of Whatman No. 3 filter paper wetted with distilled water in covered petri dishes. The dishes were placed in a 26.7°C incubator for nine days. The number of germinated seeds were counted daily.

The experimental design consisted of five grass species, three soils, four water tensions (0, -0.3, -1.0, and -7.0 bars) and three replications. The accumulated daily plant count for each replication for each species, soil, and water tension was fitted by least squares techniques to the equation:

$$y = A + B \ln(x) \quad (1)$$

where,

y = the accumulative plant count, and
x = time in days.

Replication means of the linear regression coefficient (B) were subjected to analysis of variance to determine the differences in the best fit lines representing the responses in seed germination among species, soils and water potentials. When "F" values were significant, (P < 0.05), Duncan's new multiple range test was used to separate means (Hruschka 1973).

RESULTS AND DISCUSSION

Germinated Seed Survival

Analysis of variance of the results showed no differences among temperatures on the survival of the germinated seeds on the dry filter paper. There was a significant interaction between species and number of dry days (P < 0.05).

The results show that germinated seeds of sideoats grama were significantly more tolerant to severe drought periods of up to three days than the other four species evaluated. The mean seedling survival percentages with time across all temperatures for the five species are presented in figure 1. The differences in germinated seed survival required for significance on any day is 26.2% (P < 0.05). While not statistically significant, the results indicated that approximately 15% of the germinated sideoats grama seeds survived on dry filter paper for periods of up to 10 days.

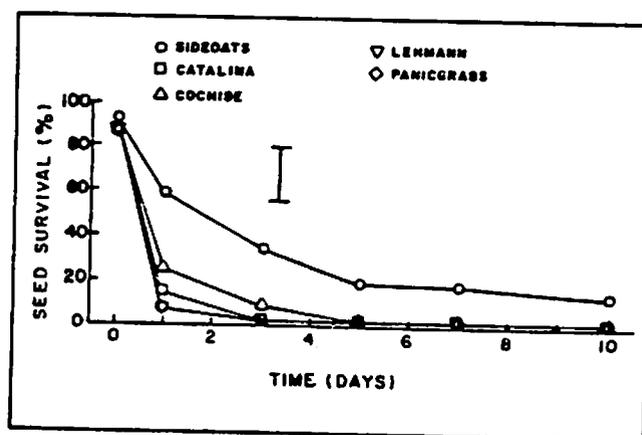


Figure 1. Survival of germinated seeds of five warm-season grasses on dry filter paper. The vertical bar represents the differences, (LSD), required for significance (P < 0.05).

These results implied that germinated sideoats grama seeds are more tolerant of a short-term drought than the three lovegrasses and the blue panicgrass. This evaluation procedure was originally considered a "harsh" test with the water tensions on the filter paper greater than the "wilting point" of -15 bars. This may not be that unrealistic. Evans and Young (1972) showed a rapid drying of the surface soil in shallow seedbeds. Wilson et al. (1970) showed soil moisture tensions in excess of -15 bars after a few days of drying. The test may be a good evaluation of drought resistance of germinated seeds.

Seed Germination at Reduced Soil Water Potential

The soil water contents at the three water potential levels at the time of seeding were highest with the sandy clay loam and lowest with the sandy loam from Santa Rita (Table 3).

Table 3. Soil water contents (mean and standard deviations, [SD]), by weight of three soils at three moisture tensions.

Soil	Soil Moisture Tension-bars					
	0.3		1.0		7.0	
	Mean	SD	Mean	SD	Mean	SD
	(%)	(%)	(%)	(%)	(%)	(%)
Avra Valley (sandy clay loam)	13.47	1.00	11.05	0.27	10.06	0.16
Three Point (sandy loam)	10.86	0.43	9.08	0.57	7.24	0.97
Santa Rita (sandy loam)	5.33	0.57	4.01	0.11	3.47	0.28

Analysis of variance of the coefficient (B) of the regression equation for the germination-time responses for the four water tension levels showed no differences among soil type ($P < 0.05$). The absence of any differences among soils with different water holding capacities shows that the germination process was affected by soil-water tension and not soil-water content.

There were differences among species and moisture tension levels and an interaction between species and soil moisture tension ($P < 0.05$). The values of the coefficients (A) and (B) of the regression equation of the pooled values across soils for the four soil-moisture levels and the filter paper based on 30 seeds are presented in Table 4.

The regression coefficient (B) for the germination rates were similar between the filter paper and the zero water stress on soils. While not always statistically significant, there was a general decrease in germination rate and total germination percentages with increasing soil moisture tensions with all species.

The final germination percentage of sideoats grama was considerably lower than expected because of some loss of seed viability, the cause of which is unknown. It is not known if this affected the rate of seed germination as represented by the regression coefficients (A) and (B). The coefficient (B) for the sideoats grama across the four soil-moisture levels did not differ significantly ($P < 0.05$) (Table 4).

No differences in the germination-time response curves (coefficient B) were found with the blue panicgrass until the soil-moisture tension was increased from -1 bar to -7 bars (fig. 2). Similar differences in the coefficient (B) occurred with the three lovegrasses, but at soil-moisture tensions changes of 0.0 to -0.3 bars as illustrated with Lehmann lovegrass (fig. 3). These results show the potential sensitivity that some species have to soil-water tensions. Even with the soil at "field capacity" (-0.3 bars), the rate of seed germination and total germination percentages may be reduced by 50% or more compared to germination at zero (0) water stress in soil or on filter paper.

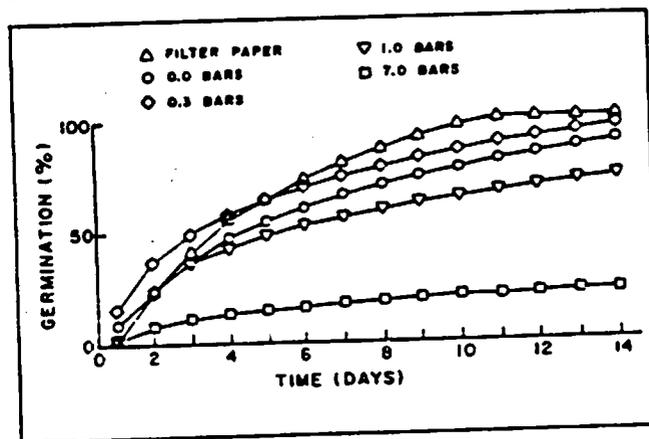


Figure 2. Germination of blue panicgrass on filter paper and in soil at 4 moisture tension levels.

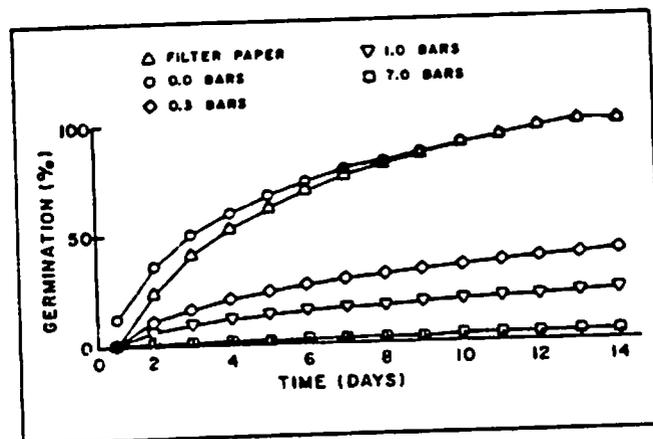


Figure 3. Germination of Lehmann lovegrass on filter paper and in soil at 4 moisture tension levels.

Table 4. Means of the coefficients (A) and (B) of the regression curves¹ representing the germination with time of five grass species on filter paper and four soil water potentials. Data are the pooled results from the three soils.

Species	Coef.	Filter Paper	Soil Moisture Tension-bars			
			0.0	0.3	1.0	7.0
Lehmann lovegrass	A	-0.948	3.706	0.497	0.280	-0.009
	B ₂	12.127	10.280 a ²	4.436 b	2.470 b	0.427
	r ²	.968	.878	.874	.782	.799
Catalina lovegrass	A	-2.312	0.267	0.028	0.130	-0.053
	B ₂	12.178	9.270 a	5.667 ab	2.046 bc	0.591
	r ²	.964	.876	.935	.820	.797
Cochise lovegrass	A	-3.286	-1.338	-0.747	-0.206	-0.077
	B ₂	9.354	8.636 a	3.385 b	0.860 b	0.241
	r ²	.938	.862	.874	.805	.664
Sideoats grama	A	1.412	2.318	1.735	1.573	0.434
	B ₂	3.442	2.729 a	2.775 a	2.609 a	1.024
	r ²	.930	.713	.757	.729	.756
Blue panicgrass	A	-2.597	0.002	4.658	2.571	1.019
	B ₂	13.806	10.236 a	9.189 a	7.413 a	2.155
	r ²	.957	.915	.760	.815	.796

¹Y = A + B Ln (X), where (Y) is the plant count resulting from 30 seeds on day (X). Analysis of variance was run only on the coefficient (B) for the four soil moisture tensions.

²Values in a row with different letters are significantly different at P<0.05.

APPLICATION OF RESULTS

Field data showing changes in soil water tensions in shallow seedbeds (0-1 cm) during drying is limited. Evans and Young (1972) presented data of soil moisture tensions during drying from fields in February in the top 1.5 cm of a loamy sand soil near Reno, Nevada. Similar data for the top 0.5 cm of a loam soil drying in March near Phoenix, Arizona was reported by Jackson (1973) and Nakayama et al. (1973)¹ (fig.4).

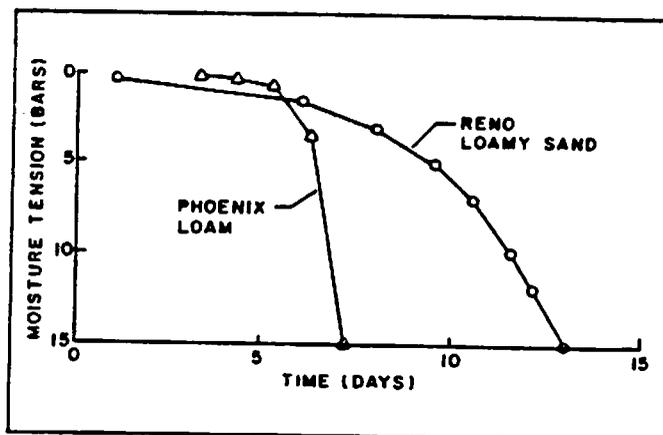


Figure 4. Soil moisture changes with time during drying of the seedbed zone of a loamy sand soil near Reno, NV in February and a loam soil near Phoenix, AZ in March. From Evans and Young (1972), Jackson (1973) and Nakayama et al. (1973).

¹Data were reported as volumetric water contents which were converted to soil moisture tensions by the following equation provided by R.D. Jackson, U.S. Water Conservation Laboratory, USDA-ARS, Phoenix, Arizona.

$$\psi = \exp [14.86 + 25.65\theta - 1773.7\theta^2 + 19163.2\theta^3 - 97687.7\theta^4 + 236565\theta^5 - 218317\theta^6]$$

where ψ = soil moisture tension in bars, and θ = volumetric water content

Least squares techniques were used to fit the soil water tension data to the equation

$$y = a e^{bx} \quad (2)$$

where y = soil water tension in bars, and
 x = time in days.

Table 5 presents the regression coefficients (a) and (b) for equation (2) for the two soils. Other soils at different times of the year and climatic conditions may have different soil moisture tension responses to drying.

Table 5. Coefficients (a) and (b) of the regression curve¹ representing the soil moisture tensions with time during drying of two soils.

Soil	Coefficient	
	a	b
Loamy sand- Reno	0.183	0.343
Loam- Phoenix	0.00029	1.495

¹Equation (2)

Solving equation (2) for (x),

$$x = (1/b) \ln (y/a), \quad (3)$$

permits estimation of the time (x) in days that the soil-moisture tensions are less than (y) bars. Typical lengths of time of the two soils at 3 selected soil-moisture tensions are presented in Table 6.

Table 6. Time with soil moisture tensions less than indicated values for two soils.

Soil	Soil moisture tension-bars		
	0.3	1.0	7.0
	(days)	(days)	(days)
Sandy loam-Reno	1.4	5.0	10.7
Loam-Phoenix	4.6	5.4	6.8

With information on the rate of seed germination at selected soil-moisture tensions, it is possible to estimate the number of seeds that would germinate at the selected soil moisture regime and those temperature and radiation conditions.

Equation (1) is divided by the number of seeds planted (30 in the studies) and multiplied by 100.

$$y = [(A + B \ln (x))/\text{number of seeds}] \times 100 \quad (4)$$

where y = expected seed germination in percent,
 x = time in days that soil moisture is less than specified value from Equation (3),
and

(A) and (B) = regression coefficients of seed germination at specified soil moisture tensions (Table 4).

Some expected germination percentages based on the results of the germination data of Lehmann lovegrass and blue panicgrass are presented in Table 7.

Table 7. Estimated germination percentages of Lehmann lovegrass and blue panicgrass on two soils as affected by soil water availability.

Soil	Species	Soil Moisture Tension-bars		
		0.3	1.0	7.0
		(%)	(%)	(%)
Sandy loam	Lehmann lovegrass	6.6	14.2	3.3
	Blue panicgrass	25.8	48.3	20.4
Loam	Lehmann lovegrass	24.2	14.8	2.7
	Blue panicgrass	62.3	50.2	17.2

This approach estimates only the effect of soil moisture tension on expected rate and total seed germination in the field. The soil data used in the previous discussion are presented only as an example for illustrating the technique. The soil-drying parameters must be derived under and be representative, of the climatic conditions and time of year that actual seed planting would be conducted. Other factors that must be considered are the effects of temperature and soil texture on seed germination. Finally, the survival of the germinated seeds and seedlings as affected by soil-water availability must be evaluated.

SUMMARY AND CONCLUSIONS

Available soil moisture is one of the key factors affecting seed germination. Information on the effects of soil moisture tensions on germination of range plant species has in the past been primarily derived from studies using solutions of salts or polyethylene glycol (PEG). These results may not be representative of field conditions.

Studies were conducted to develop information on the survival of germinated seeds at high soil water tensions. Germinated seeds of five warm-season grasses were placed on dry filter paper for periods of 1 to 10 days then rewetted to determine the number of seeds which survived. The results showed that sideoats grama was significantly more tolerant of the dry period following germination than were blue panicgrass or the three lovegrass species.

The rate of seed germination of the five grasses at four water-tension levels was evaluated on three soils. Germination was affected by soil-water tensions and not soil-water content. A technique was developed to relate the germination rate at reduced water-potentials to soil drying parameters for estimating the seed germination that might be expected in the field.

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