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# Water Requirements for Range Plant Establishment

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## Abstract

A conceptual model was developed which describes a series of pathways or transition sequences which a seed or seedling may follow during the initial wet-dry-wet periods after planting. Associated with each pathway is an occurrence probability related to the plant's response to a wet or dry environment and the relative lengths of the initial wet and dry periods. In most instances, the most probable response pathway can be determined from the relative seedling counts at selected times during a set of short-term experiments, which include a wet-dry watering sequence and an everyday wet watering sequence. The model was validated using data collected in greenhouse and field studies evaluating seedling establishment characteristics of selected warm season range grasses. Preliminary model assessment showed that it was possible to delineate specific wet-dry watering sequences which could be critical to establishment of some warm season grass species.

## Introduction

Plant establishment from seed in semiarid regions under natural rainfall regimes is difficult, because available soil moisture is favorable for seed germination and seedling establishment for only brief periods. Rainfall occurrences are highly variable, even in the 'rainy' season, and the dry periods between occurrences are usually longer than the wet periods.

Limited soil water availability during germination and seedling establishment was a factor in the survival of western wheatgrass (Agropyron smithii Rydb), alkali sacaton (Sporoblus airoides (Torr.) Torr.), galleta (Hilaria jamesii Torr.) Benth), blue grama (Bouteloua gracilis (Willd. ex. H.B.K.) Lag ex. Griffiths), mountain mahogany (Cercocarpus montanus Raf.), broom snakeweed (Gutierrezia sarothrae (Pursn) Butt. and Rusby), and mesquite (Prosopis juliflora (Sw.) DC) (Knipe 1968, 1973; Piatt 1976; Kruse 1970; Scifres and Brock 1969). A better understanding of the relationship between water availability, seed-germination and subsequent seedling-growth will improve the chances of successful plant establishment.

## Germination, Seedling Emergence and Seedling Survival Model

Frasier et al. (1985) found two factors which significantly affect the number of warm season grass seedlings surviving the first wet-dry

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watering sequence following planting. These were: (1) the number of seedlings produced in the first wet period with sufficient vigor to survive the subsequent dry period, and (2) the number of ungerminated, but viable, seeds which remain after the first wet-dry watering sequence. Frasier et al. (1984) showed how seedling emergence and seedling survival probabilities, derived under various wet-dry watering sequences, could be combined with estimates of the joint probability of the lengths of the first wet and dry periods after planting to select the optimum time for seeding. It is hypothesized that these seed germination, seedling emergence, and seedling survival probabilities can be used to characterize the ability of a plant species to survive the initial wet-dry periods following planting.

The response of a seed during the initial wet-dry watering sequence depends, in part, upon the relative lengths of the wet and dry periods. If the first wet period is short, the seed may not germinate, and may survive the wet-dry period as viable seed. If the wet period is of sufficient duration to germinate most seeds, and is followed by a long dry period, many, if not all, of the germinated seeds and seedlings will die. If the first wet period is long enough for the seedlings to develop a root system with which the plant can survive a drought induced quiescence, a high percentage of the plants might survive a long drought period.

The seed and seedling responses to the wet-dry watering sequences can be represented as possible pathways. Possible response pathways for a wet-dry-wet watering sequence are shown in Figure 1. Each box or circle represents the 'state' of the seed or seedling. The boxes indicate a seed and the circles represent a seedling. The transition from a seed to seedling (germination and emergence) may occur during any of the three moisture periods. The boxes or circles with an 'X' indicate the seed or seedling dies before the end of the final watering sequence. The solid lines connecting the points indicate pathways which are thought to have the highest probability of occurrence. The dashed lines are pathways which are possible, but may have a low probability of occurrence.

This approach assumes that the seeds are viable, and that any special germination enhancement, such as scarification and ageing, has been performed. The durations of the 'initial wet' and 'dry' periods are determined by the specific wet-dry watering combination under consideration. The 'final wet' period is of sufficient duration so that any ungerminated seed will have time to germinate and produce a viable seedling. The zone labeled 'wet-dry transition period' is the period when the soil environment changes from a 'wet' to a 'dry' condition. The length of this transition time depends upon the evaporative water loss rate and the sensitivity of the seed or seedling to moisture. In most instances, the length of time during this change is not clearly delineated. The change from the dry period to the final wet period is caused by the application of water, and is easily defined.

It is not expected that all seeds of a species in a given watering sequence would follow the same pathway. The model is concerned with determining the pathway that the majority of the seeds might follow for a given watering sequence. Assuming that the indicated most probable

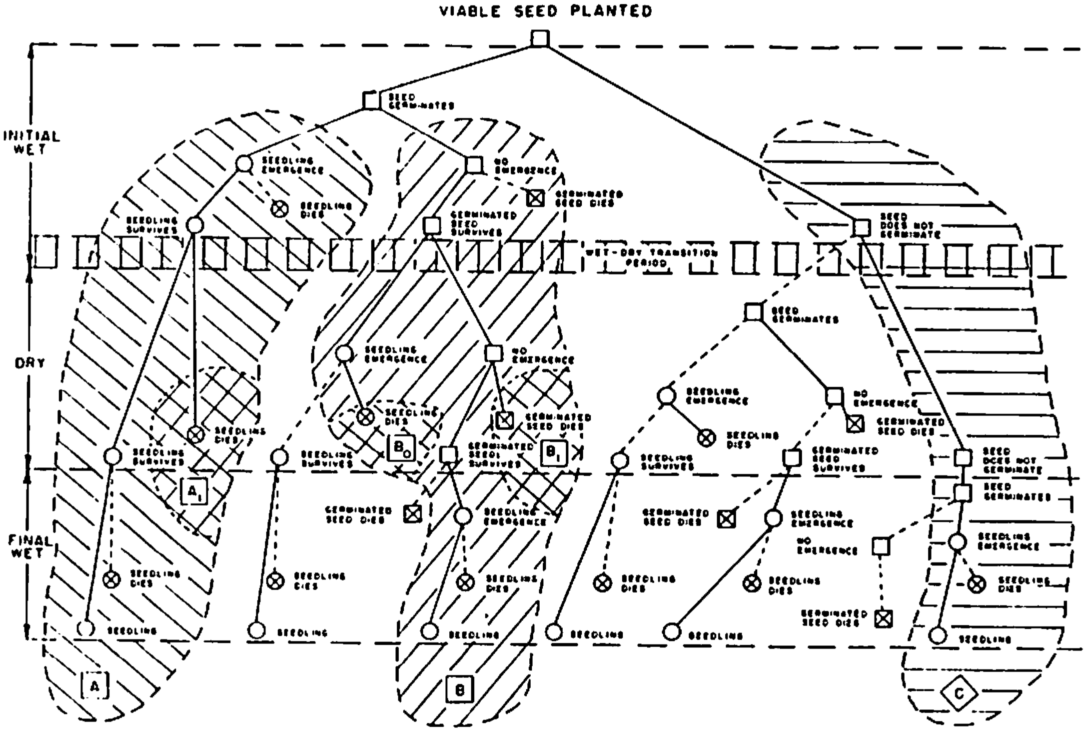

Figure 1. Possible pathwaysof a seed-to-seedling with an initial wet-dry watering sequence following seeding.

pathways are correct, there are 3 pathways which will result in a viable seedling (Figure 1). These pathways are: (A) In the first wet period, a seed germinates and a seedling emerges which survives the subsequent dry period; (B) the seed germinates in the first wet period, but does not produce a seedling until the final wet period; and (C) the seed does not germinate in the first wet and dry periods, but remains viable for a subsequent wet period. There are 3 pathway endings with a dead seed or seedling which have a high occurrence probability. These pathways are: ($A_1$) the seed germinates and produces a seedling in the initial wet period, but the seedling dies during the following dry period; ($B_0$) the seed germinates in the first wet period and forms a seedling which dies in the dry period; and ($B_1$) the seed germinates in the first wet period but dies in the dry period before producing a seedling.

To utilize this model, it is necessary to estimate transition probabilities from seedling counts at key points in time during the watering sequence. These relationships can be obtained from the seedling emergence counting process for a plant species subjected to a specific wet-dry watering sequence (Frasier et al. 1985). An example of a seedling emergence counting process for a specific wet-dry watering sequence of $t_w$ wet days followed by a dry period of $t_d - t_w$ days where $t_d$ is the end of the dry period as shown in Figure 2. The counting process represented by $N_{W:D}(t)$, $t = 0, 1, 2, \ldots, n$, is the seedling emergence count on day(t) for a specific wet-dry watering sequence. The counting function $N_W(t)$ represents the number of seedlings on day(t) with an everyday wet watering regime. M is the number of viable seeds planted.

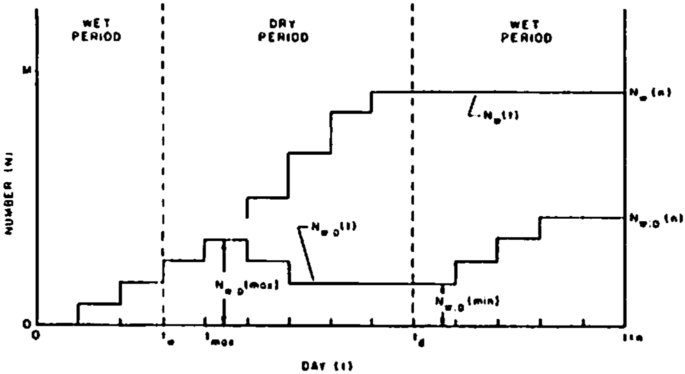

Figure 2. Sketch of seedling emergence response counting process following planting for a given wet-dry-wet $(N_{W:D}(t))$ watering sequence and an everyday wet $(N_W(t))$ watering treatment

In most instances, the most probable response pathway for a species and a given watering sequence can be determined from the relative seedling counts at selected periods from a set of experiments of time $t=n$ which include the specific wet-dry watering sequence and an everyday wet watering sequence. The specific seedling count data required are: (1) $N_{W:D}(\max)$, the maximum number of emerged seedlings resulting from the first wet period, (2) $N_{W:D}(n)$, the number of live seedlings on day $t=n$, the end of the experiment, and (3) $N_W(n)$, the final seedling count for the simultaneous everyday wet watering regime.

With short dry periods, it may be difficult to distinguish between pathways 'B' and 'C'. A species tendency between these pathways can be separated by conducting simultaneous experiments with the same length of initial wet period $t_w$, but with different lengths of dry periods ($D_1 < D_2$). In pathway 'C', the final seedling counts will remain the same for the two experiments;

$$N_{W:D_1}(n) = N_{W:D_2}(n). \tag{1}$$

In pathway 'B', the final seedling count in the experiment with the shorter dry period ($D_1$) will be greater than the final seedling count with the longer dry period ($D_2$);

$$N_{W:D_1}(n) > N_{W:D_2}(n). \tag{2}$$

## Model Verification

### Procedure

The model has undergone preliminary evaluation with data collected from a series of greenhouse and small field plot experiments designed to examine the seedling emergence characteristics of five warm season perennial grass species with various wet-dry-wet watering sequences. The grasses used in the experiments were 'Premier' sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), 'Cochise' lovegrass (*Eragrostis lehmanniana* Nees X *E. trichora* Coss and Dur.), 'A-68' Lehmann lovegrass (*E. lehmanniana* Nees), 'Catalina' lovegrass (*E. curvula* var. *conferta* (Schrad.) Nees), and 'SDT' blue panicgrass (*Panicum antidotale* Retz).

Greenhouse studies: Tapered, plastic greenhouse container cones, 3.8-cm in diameter by 20-cm long, were filled with 210-g of dry 60 mesh sand. Ten cones were prepared for each grass within each watering sequence. Ten seeds were placed on the dry surface of each cone and covered with a 2-3 mm layer of dry sand. The watering sequences used in the studies were: (1) 2 days wet, 5 days dry; (2) 3 days wet, 5 days dry; (3) 5 days wet, 5 days dry; and (4) 14 days wet (everyday wet). Following the dry periods, the cones were wet everyday for a total experiment length of $n=14$ days. Water was applied to the cones on the predetermined wet-dry-wet watering sequence with an overhead reciprocating spray system. All cones were initially wetted to approximately field capacity with 20-g of water (10% moisture by weight). In the wet periods, cones were sprinkled daily with sufficient water to bring the average moisture content to the original 10% level. Cones in a dry-day period were covered during sprinkling. The number of live plants in each cone were counted and recorded daily.

Field studies: The study was conducted on a Laveen loam (thermic, Typic Calciorthids) on the Walnut Gulch Experimental Watershed near Tombstone, Arizona. The study had the same watering sequences and grass species used in the greenhouse studies. Each plot, 30.5 by 30.5 cm, was smoothed, and 100 small depressions (6-mm deep) were made 2.5-cm apart on a 10 by 10 grid. Each plot was planted with 100 seeds of a single species, one seed in each depression, and covered with a 4-6 mm layer of soil. Water was applied to the plots in the predetermined watering sequence with a reciprocating spray bar. Ten to 12 mm of water was applied immediately following seeding. The quantity of water applied on subsequent days was based on the pan evaporation loss which had occurred since the previous day or water application. A moveable roof was used to protect the plots from precipitation. The cover was pulled over the plots when rain was imminent, or at sundown, and removed at sunup the next morning. Each morning, the number of live seedlings on each plot was counted and recorded.

## Results and Discussion

Typical $N_{W:D}(t)$ and $N_W(t)$ , counting functions of the mean daily seedling counts of Catalina lovegrass, sideoats grama and Lehmann lovegrass from 14-day greenhouse and field studies, are shown in Figures 3a, 3b, and 3c for initial wetting sequences of 2, 3 and 5 days wet, respectively. Also shown are the 14 day wet sequences. Figures 4a, 4b and 4c show the maximum plant count from the initial wet period ($N_{W:D}$ (max)) and the final plant count ($N_{W:D}(14)$) and ($N_W(14)$) for these same studies. The predominant seedling emergence response pathways for the indicated wet-dry (W:D) water sequences are noted in each figure.

The probable pathway for the Catalina lovegrass (Figure 4a) is a 'C'. This is indicated by the relatively low plant count for the initial wet period ($N_{W:D}(max)$) of the wet-dry watering sequence and similar final plant counts, $N_{W:D}(14)$ and $N_W(14)$.

The sideoats grama generally followed the 'A' pathway. This was indicated by a high initial plant count ($N_{W:D}(max)$). In the field the final plant counts, $N_{W:D}(14)$ and $N_W(14)$ were similar. In the greenhouse there was a decrease in plant count during the dry period, indicating an '$A_1$' pathway. The differences between the field and greenhouse studies are believed to be caused by a higher proportion of moisture loss from the sandy soil surface in the greenhouse during the dry period than from the finer textured soil surface in the field. The species may also be susceptible to low soil moisture contents.

The most probable pathway for the Lehmann lovegrass is a combination of 'A' and 'B'. The initial plant count, $N_{W:D}(max)$, shows a significant number of seedling from the first wet period. There are fewer seedlings at the end of the experiment with wet-dry watering sequence, $N_{W:D}(14)$, than with the everyday wet treatment, $N_W(14)$. This indicates there were seeds which germinated but died before a seedling emerged.

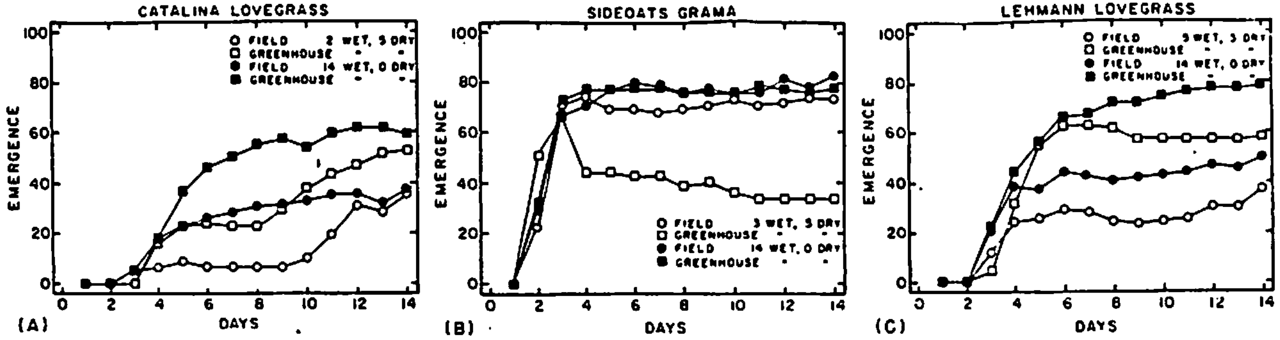

Figure 3. Typical seedling emergence curves for a wet-dry-wet $N_{W:D}(t)$ and an everyday wet $N_W(t)$ watering sequence from field and greenhouse studies for three grass species: (A) Catalina lovegrass, (B) sideoats grama, and (C) Lehmann lovegrass for 2-wet, 5 dry; 3-wet, 5-dry, and 5-wet, 5-dry watering sequences respectively.

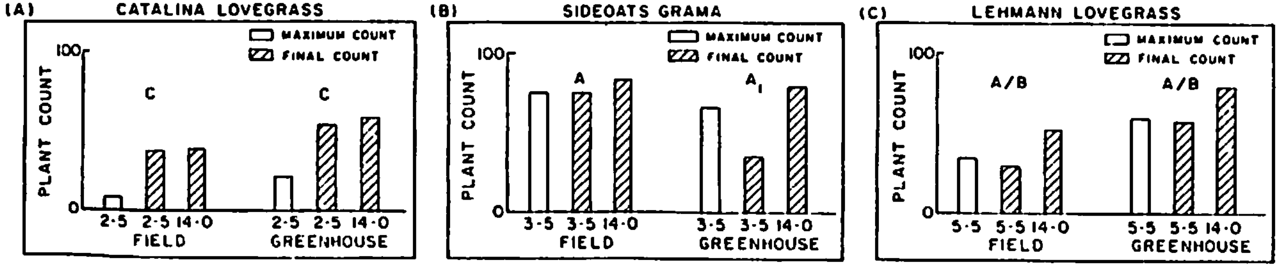

Figure 4. Comparison of maximum initial seedling counts $N_{W:D}(\max)$ and final seedling counts $N_{W:D}(14)$ and $N_W(14)$ from field and greenhouse studies for three grass species: (A) Catalina lovegrass, (B) sideoats grama, and (C) Lehmann lovegrass for 2-wet, 5-dry; 3-wet, 5-dry; and 5-wet, 5-dry watering sequences respectively.

## Summary and Conclusions

This conceptual model of a seed to seedling response provides a means of comparing seedling establishment characteristics as related to water availability. Preliminary evaluation indicates that the model does describe probable pathways or responses to water availability as affected by the length of the initial wet and dry periods and differences between plant species. Similar results were obtained in greenhouse and field studies. It is believed that greenhouse data can be utilized to delineate specific combinations of initial wet-dry watering sequences, which could be critical to establishment of warm season grass species.

These studies were concerned with developing general trends. Further studies of other plant species are required to determine the full range of model applicability. It is believed that this approach can be combined with stochastic descriptions of daily weather variables to obtain estimates of the chances of successful field plantings for a given planting date.

## Appendix-References

Frasier, G.W., Cox, J.R., and Woolhiser, D.A., "Emergence and Survival Response of Seven Grasses for Six Wet-Dry Sequences," Journal of Range Management, Vol. 38, No. 4, 1985, pp. 372-377.

Frasier, G.W., Woolhiser, D.A., and Cox, J.R., "Emergence and Seedling Survival of Two Warm-Season Grasses as Influenced by the Timing of Precipitation: A Greenhouse Study," Journal of Range Management, Vol. 37, No. 1, 1984, pp. 7-11.

Knipe, O.D., "Effects of Moisture Stress on Germination of Alkali Sacaton, Galleta, and Blue Grama," Journal of Range Management, Vol. 21, 1968, pp. 3-4.

Knipe, O.D., "Western Wheatgrass Germination as Related to Temperature, Light, and Moisture Stress," Journal of Range Management, Vol. 26, 1973, pp. 138-140.

Kruse, O.D., "Temperature and Moisture Stress Affect Germination of Gutierrezia Sarothrae (Broom Snakeweed)," Journal of Range Management, Vol. 23, 1970, pp.143-144.

Piatt, J.R., "Effects of Water Stress and Temperature on Germination of True Mountain Mahogany," Journal of Range Management, Vol. 29, 1976, pp. 138-140.

Scifres, C.J., and Brock, J.H., "Moisture-Temperature Interrelations in Germination and Early Seedling Development of Mesquite," Journal of Range Management, Vol. 22, 1969, pp.334-337.