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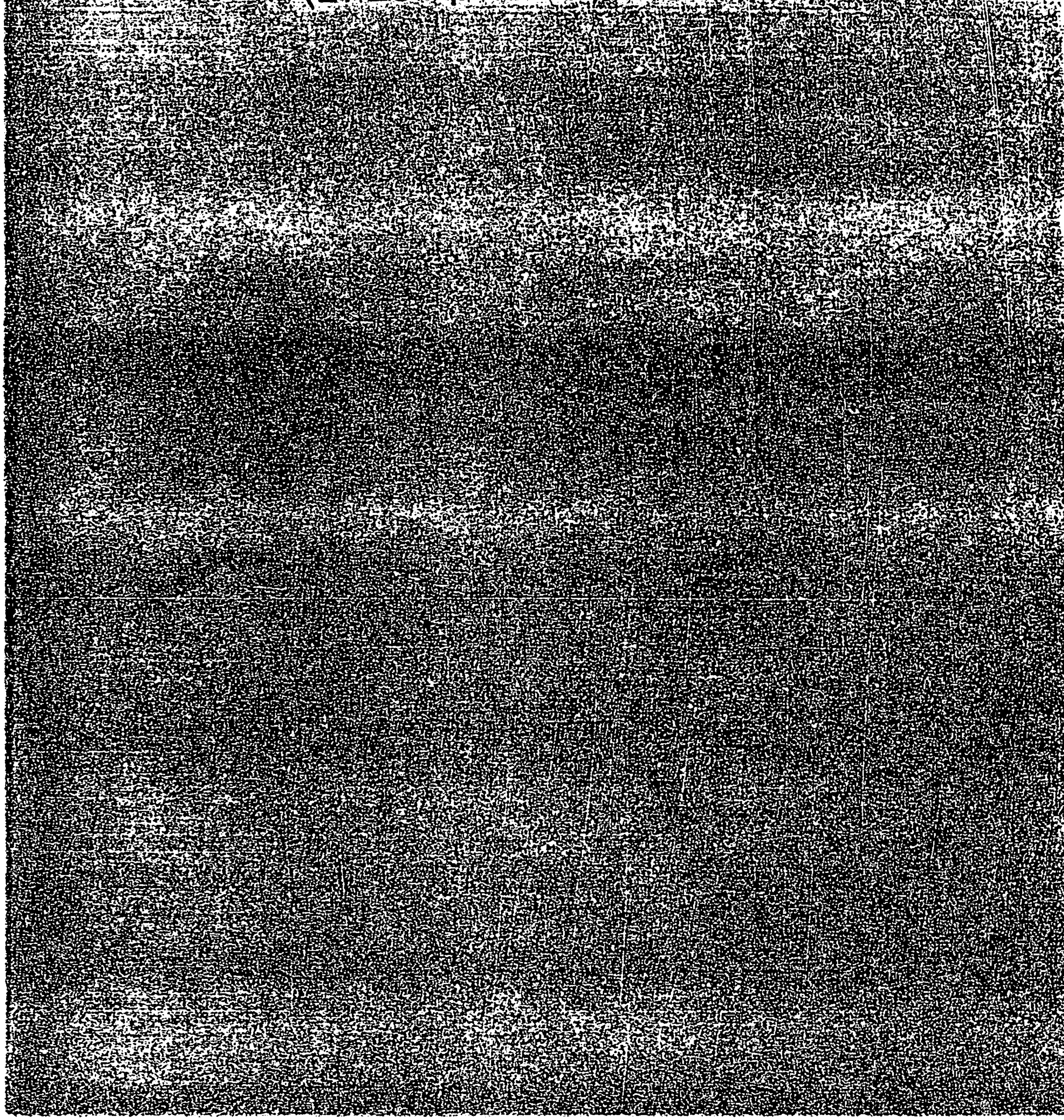

EARLY ROOT LENGTH DISTRIBUTIONS OF WARM SEASON PERENNIAL GRASSES AS INFLUENCED BY SOIL MOISTURE: A MODELING CONCEPT

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ABSTRACT

Soil moisture availability is one of the most important factors controlling root elongation during seedling establishment. A procedure is presented for combining information of the rate of early root elongation with soil moisture distribution drying data to evaluate the chances of successful seedling establishment.

INTRODUCTION

"A knowledge of root relations leads to the intelligent solution of problems of range management and improvement and, indeed, to all problems where natural vegetation is concerned" (Weaver and Clements 1929, p. 216).

"It is probably impossible to think of an aspect of plant physiology which reveals greater ignorance and confusion than that which is concerned with natural regulation of growth and differentiation in roots." (Wareing and Phillips 1978, p. 114).

Without adequate root growth, the chances for a plant's success are greatly reduced. Roots absorb water and nutrients from the soil for transport to the plant stem; they are the site of synthesis of some plant hormones; they may act as food storage organs; and they anchor the plant to the soil (Russell 1973). One of the most critical phases of a plant's life is in the germination to early seedling stage when the plant's survival is dependent upon the moisture uptake of the seminal root (Mueller and Weaver 1942, Tapia and Schmutz 1971). During this period, the root system must be most efficient in supplying the developing seedling with moisture. Root elongation rates must be sufficiently high to maintain contact with the receding soil moisture front if the seedling is to survive.

This paper presents a conceptual model of the approach for combining root elongation data with soil moisture distribution data during drying for evaluating seedling survival characteristics. Data used in the paper are derived from various studies which were not designed to evaluate our hypothesis. As such, the results are meant to be used only to illustrate points and not to construe real differences that might be expected in laboratory or field situations.

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BACKGROUND

Little information is available on the early rooting characteristics of range grasses. The majority of the literature refers to root growth studies of older-aged agronomic species with specific reference to field established plants.

Limited studies have indicated differences in root elongation rates among species. Wilson and Briske (1979) found that seminal root elongation rates of blue grama (*Bouteloua gracilis* (H.B.K. Lag. ex. Griffiths) ranged from 6 to 10 mm per day. A quadratic equation was used to fit root length (cm) versus time (days). Sosebee and Herbel (1969) reported that 21 days after planting, sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.) had an average length of 96 mm and that alkali sacaton (*Sporobolus airoides* Torr.) had an average length of 38 mm. Simanton and Jordan (1986) mean root lengths at 165 hours of 16 mm for Cochise lovegrass (*Eragrostis lehmanniania* Nees X *E. trichophora* Coss and Dur.) to 67 mm for sideoats grama. These differences in root elongation rates are not considered either fast or slow. Since these plants have been successfully established in various semiarid regions it would be concluded that the roots can keep up with a soil drying front, at least with some soil-climatic conditions. We also know that there have been unsuccessful seedings.

Soil moisture stress is probably the most common and thus important root growth limiting condition. Root elongation responses to soil moisture stress varies not only in magnitude among species but also in the critical moisture stress which significantly affects root growth. Native grass species, *Bouteloua gracilis* and *Agropyron smithii*, showed a root elongation cessation at soil water potential of -16.6 bars and -8 bars, respectively (Majerus 1975).

Soil moisture is seldom uniformly distributed throughout the soil profile and root growth may be restricted in an area of low soil moisture. This may be compensated for by greater growth in an area favorable in soil moisture (Russell 1973). Root growth studies have indicated that roots will normally only grow into moist soil zones (Hendrickson and Veihmeyer 1931, Trouse 1972). There is evidence though that some warm season grass species will grow into soil zones where the moisture level is below the wilting point (Salin, et al. 1965). Roots have been observed to elongate into dry soil (-40 bars) as long as the plant water potential remained sufficiently high and that water was available to other parts of the root system (Portas and Taylor 1976).

MODEL CONCEPT

It is hypothesized that the rate of primary root elongation can be combined with soil moisture data or models of soil moisture distribution during drying to estimate probabilities of seedling survival and plant establishment. This would allow the use of rainfall probability data to estimate the optimum time for seeding or to select the optimum species for seeding under a specific rainfall, soil-moisture regime.

Mathematical models have been developed to describe soil water movement, with reference to plant roots; in both saturated and unsaturated soils (e.g., Belmans, et al. 1979, Gardner 1964, Hillel, et al. 1976, and Qashu et al. 1973). Experimental analyses suggest that both the root and soil resistances play an important role in movement of water to roots. Belmans, et al. (1979) found that soil resistance to root penetration may dominate through the lower range of plant available soil moisture levels and that soil hydraulic resistance becomes more important as the soil moisture becomes depleted. Soil water potential in the surface 10 cm of semiarid soils is not maintained above -15 bars for extended periods in the summer (Noy-Meir 1973). Over a period of time, possibly only a few days, roots need to elongate into moist soil to keep soil water resistances from getting so large that the plant cannot extract enough water to grow or survive. Models of soil surface moisture evaporation have been proposed that can give estimates of temporal and spatial moisture amounts during the seed to seedling stages of a plants life (Ritchie et al. 1976). These models stress the importance of root elongation into the soil and, if coupled with time-dependent root elongation relationships, could be useful in estimating success in establishment of range grass seedlings.

This root elongation, soil moisture model assumes that a seed has germinated under field capacity conditions and if the germinated seed is to emerge and become a established plant, the primary root elongation rate must exceed the rate of the receding soil moisture front (fig. 1). Without additional water, the germinated seeds and seedling of species with root elongation rates less than the rate that the soil moisture front recedes into the soil will die. Distributions of root elongation rates needed for such a model could be experimentally determined for selected plant species grown under various moisture, temperature, and soil conditions. Also, test environments could be designed to meet comparable natural conditions.

Soil moisture distributions over time for different texture classes could either be experimentally determined or estimated using current or developed soil moisture evaporation models (fig. 2). These models can be as simple or as complex as needed to relate soil water loss in the seeding zone to various soil and climatic factors.

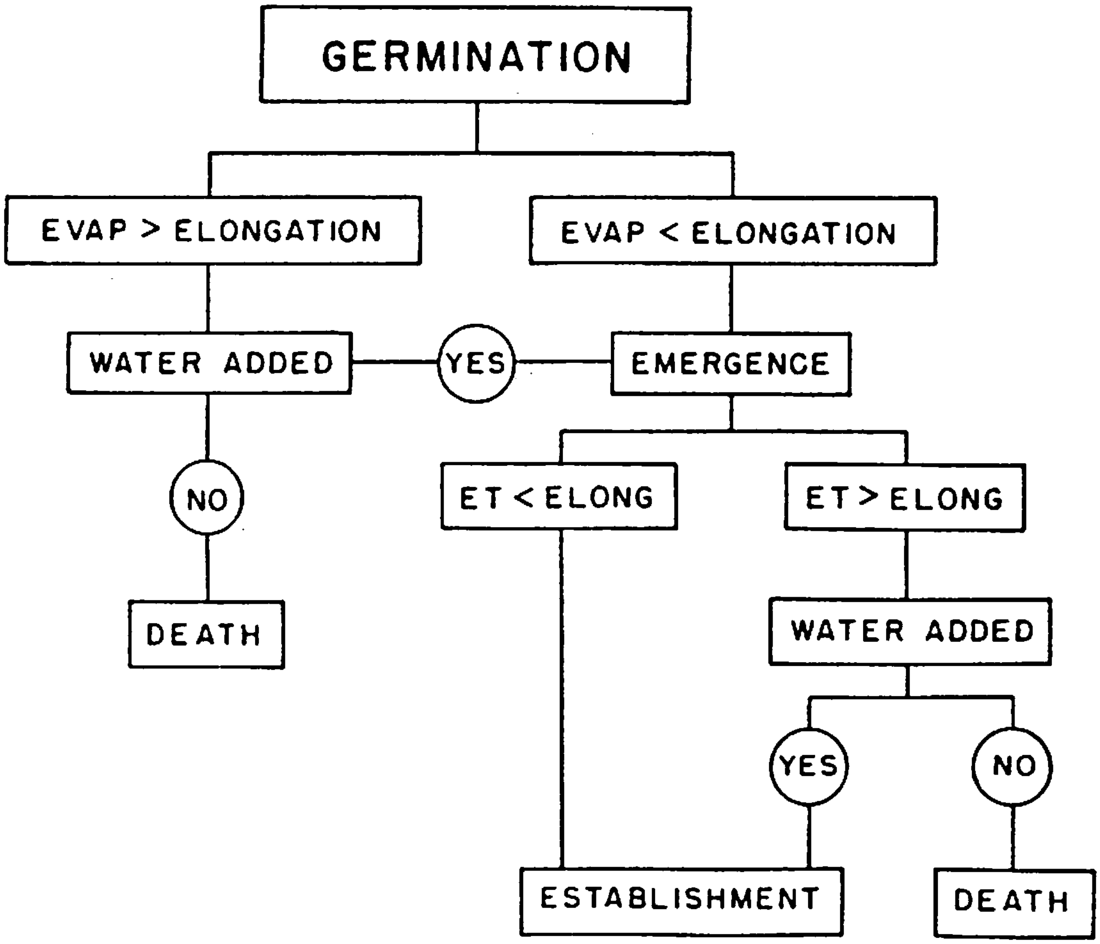

Figure 1. Model concept of root elongation versus soil water loss by evaporation.

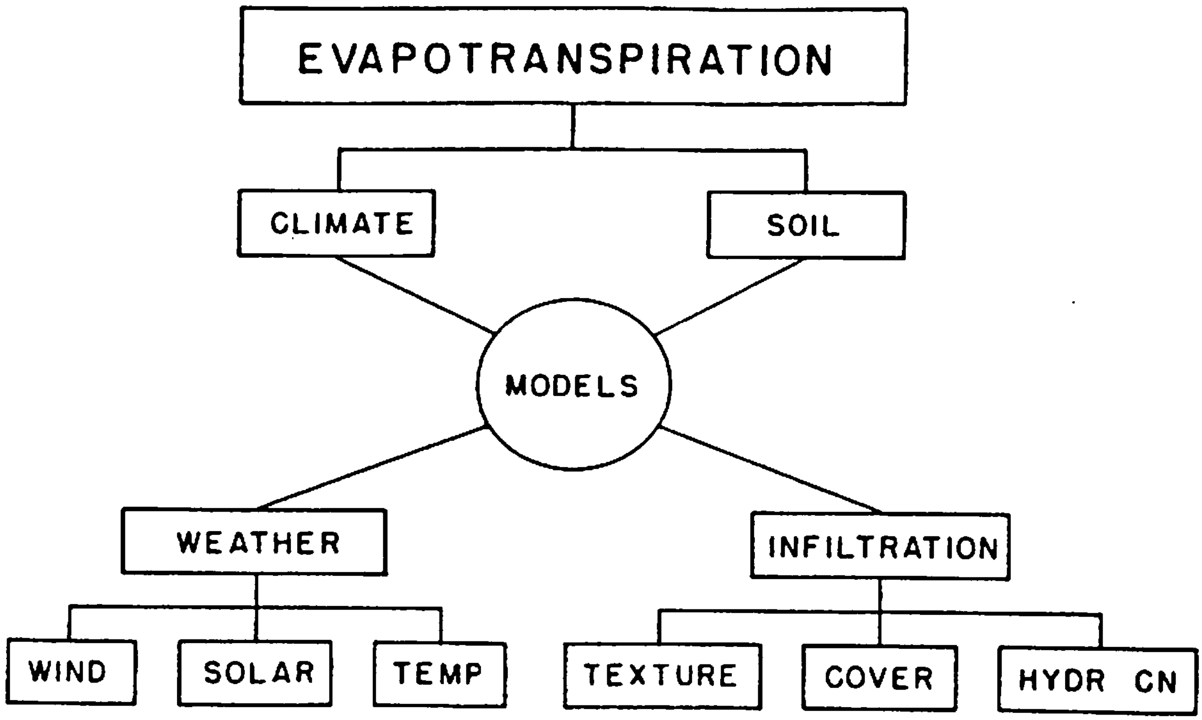

Figure 2. Conceptual evapotranspiration model.

Irrespective of the source of the soil water, precipitation or runon, the various parameters associated with water availability can be assigned probabilities of likely occurrence (fig. 3). It is then possible to develop a complete description of soil water availability for various rangeland regions. Root length distribution probabilities coupled with the soil moisture and rainfall probabilities could give probabilistic estimates of seeding successes.

MATERIAL AND METHODS

The root elongation data for the paper was obtained from studies conducted at the USDA-ARS, Aridland Watershed Management Research Unit, Tucson, Arizona. Portions of the data were reported by Simanton and Jordan (1986). The soil moisture drying data was obtained from Ray Jackson, USDA-ARS, U.S. Water Conservation Laboratory, Phoenix, Arizona. Portions of the data have been reported by others.

Root Elongation Studies

Root lengths of 5 warm season range grasses were determined at 12 hr intervals from seed germination to early seedling stage of 5 days. Grass species used were "Premier' sideoats grama, Cochise lovegrass, 'A-130' blue panicgrass (Panicum antidotale Retz.), and accessions "PMT-1733-77" and "NM-184" alkali sacaton.

Seedlings were grown in cylinders made from 150-mm lengths of 25-mm diameter polyvinylchloride pipe cut in half lengthwise. The 2 halves were held together with rubber bands to form a cylinder open at both ends. The cylinders were placed upright in a holding tray and filled with 135 g of 20 mesh white silica sand. One seed was placed on the surface of each half of each cylinder and covered with 5-mm of sand. The sand was watered to field capacity with 15 ml of distilled water. The study was conducted in a light and temperature controlled growth chamber with alternating temperatures of 30 and 22°C and relative humidity near 100%. There were 14 hr of light and high temperature alternated with 10 hr of darkness and low temperatures. These sequences were similar to those reported as optimum for germination and seedling growth of the species studied (Knipe 1967, Sosebee and Herbel 1969).

Root length measurements were begun 12 hrs after germination was first observed in an adjacent seed germination study and then each succeeding 12 hrs. At each evaluation time, 10 cylinders for each species were randomly selected, separated and the root length measured to the nearest millimeter. The total number of roots at each millimeter length increment were tabulated for root-length distribution analysis for each evaluation period.

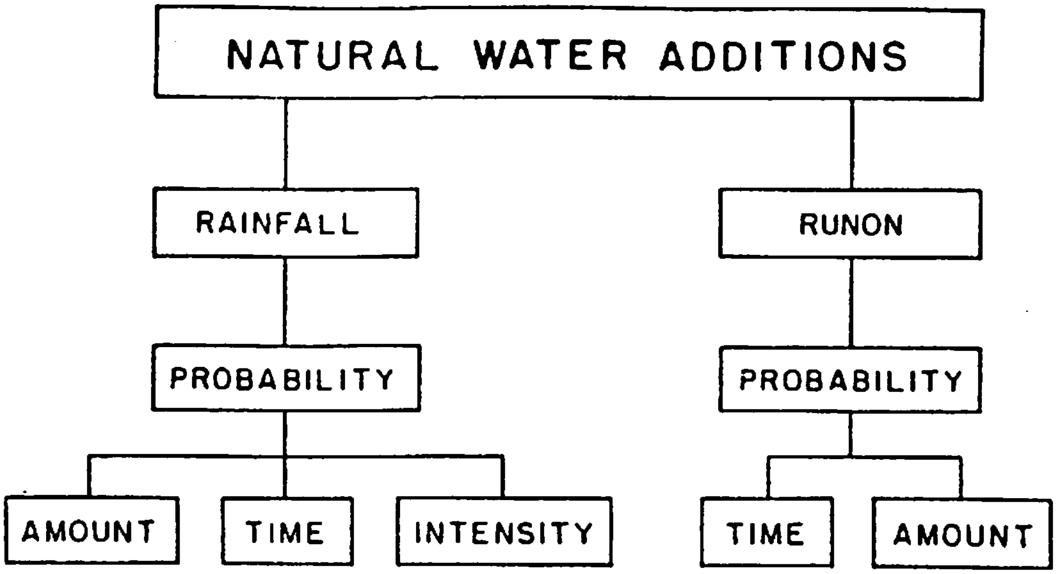

Figure 3. Conceptual water application effects to root elongation model.

Soil Water Characteristics

The experimental site was a 72 by 90-m field at the U.S. Water Conservation Laboratory, Phoenix, Arizona. The soil was a reasonably uniform loam texture to a depth of about 100 cm. The area was leveled and watered by flood irrigation between borders. Following irrigation, soil water contents were measured gravimetrically. Soil samples were taken of the 0- to 0.5-cm depth and in 1-cm increments to 5 cm depth and in 2-cm increments from 5 to 10 cm depth. Samples were taken at 0.5-hr intervals from 4 March to 19 March. Six sites were sampled at each time and composited for each depth increment. Water contents were converted to volumetric basis by multiplying by the bulk density (Jackson, 1973). The soil water contents were converted to soil moisture tensions by the equation:[1]

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

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

[1] Personal communication, R.D. Jackson, U.S. Water Conservation Laboratory, Phoenix, Arizona.

RESULTS AND DISCUSSION

The root elongation study was conducted on a silica sand maintained at approximately field capacity (<-0.3 bars) for the duration of the study period. Because of this, we don't know how the root elongation rate at various soil moisture tensions compares to that measured at zero water stress. It is known that soil moisture tension in the seedbed layer is at field capacity for only a very short time, in the order of a few hours. For purposes of the paper we have arbitrarily selected the range of 0 to -2 bars to represent zero water stress. Therefore, soil water tensions greater than -2 bars represent a condition at which the root would no longer elongate. Because of the conceptual nature of the model and limited data to analyze, we are not considering the interactions that might occur between temperature and water nor the effects soil texture might have on root elongation rate. Also, only the data from the sideoats grama and Cochise lovegrass is used in the discussions.

Jackson (1973) reported on the phenomena of soil moisture redistribution or rewetting of the soil surface layers during the evening and nighttime periods. These changes in soil water contents between the times of 0600 and 1800 hours represented fluctuations in soil moisture tensions of 1 to 2 orders of magnitude with the driest period occurring in late afternoon. For our discussion, we selected the soil moisture values measured at 1800 in the evening and have not addressed the effect of root elongation during cyclic water contents such as what happens during moisture redistribution. All times were referenced to 1800 on 5 March when the surface 2-cm had drained to water contents representing -0.3 bars (irrigation applied on the afternoon of 2 March).

The distribution of soil moisture tensions with depth for 24 and 144 hr for the Phoenix data are presented on the left side of figure 4. The root distribution of sideoats grama for two evaluation periods, 34 and 140 hrs after seed germination are presented on the right side of figure 4. At both time periods, root lengths for the majority of the samples were greater than the depth to the -2 bar soil moisture tension. This implies that the root elongation rate was faster than the soil drying rate and that the seedling would not have encountered water stresses that would have affected growth.

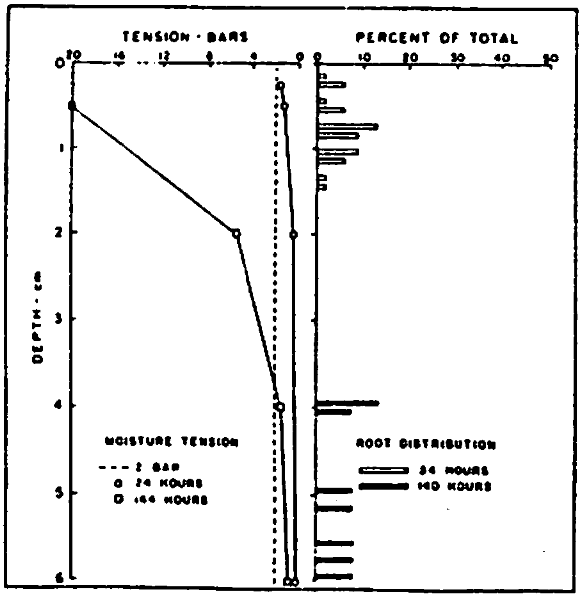

Figure 4. Soil drying and root distribution for sideoats grama.

Similar data are presented in figure 5 for Cochise lovegrass. Root elongation rates were slower than the soil moisture drying front which, if some other adjustment (physiological) wasn't made by the plant or if the soil didn't receive a water addition, the seedling would die.

SUMMARY

The rate of root elongation is critical to seedling establishment. As the soil dries downward from the surface, the root must be able to maintain contact with moist soil or the seedling will die. A simple model was developed that combined root elongation rate to soil moisture availability during drying. There is little information on the rooting characteristics of range grasses. Root elongation data from a simple laboratory study was combined with soil moisture tension drying data derived from a bare soil area following irrigation. It was shown that with root elongation faster than the rate of soil drying there was a good probability that the seedling would survive. If the soil moisture drying front moved into the soil at a faster rate than the root elongated, the seedling would be expected to die. This approach can be used to assist in estimating, based upon soil, climate, and species rooting properties, the chances of achieving successful seedling establishment.

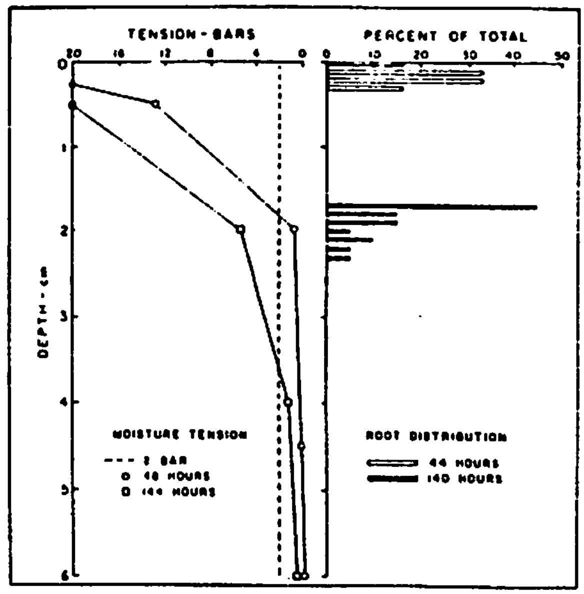

Figure 5. Soil drying and root distribution for Cochise lovegrass.

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