

Response of Root and Shoot Growth of Three Grass Species to Decreases in Soil Water Potential

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Highlight: Native grass species show differences in leaf and root growth response to soil water potential. Soil water potential developed by blue grama at the time of leaf growth stoppage ranged from < -80.0 bars at 5 cm depths to -8.4 bars at 35 cm depths, while corresponding values for little bluestem were -24.3 and -3.0 bars, and -30.0 and -15.3 bars for western wheatgrass. Soil water potentials at the time of root growth cessation were somewhat lower with a minimum of -16.6 bars at the 5 cm depth of blue grama and a maximum of -5.0 bars at the 25 cm and 35 cm depths of little bluestem. The R^2 values indicate a lower level of correlation between soil water potential and root growth than between soil water potential and leaf growth. In ranking the three mixed prairie grass species as to their growth tolerance to decreasing soil water potential, blue grama ranks the highest followed by western wheatgrass and little bluestem, respectively.

In natural vegetation the position of plant species does not occur at random but the plants are intermixed or controlled by the impact of the environment over a series of years. Within the mixed prairie of central Montana, blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), and little bluestem (*Schizachyrium scoparium*) each appear to have different and distinct site requirements. The soil moisture requirements of these three species have been characterized as low for blue grama, moderate for western wheatgrass, and moderately good for little bluestem (U.S. Dep. Agr., 1971).

Daubenmire (1956) stated that each vegetation type differs from its neighbor in the degree of summer drought, except at the wet end of the climatic gradient, where low temperature is more the decisive factor. McMin (1952) supports this by showing that in the northern Rocky Mountains, where most precipitation occurs in the winter months and there are summer droughts, different plant associations are correlated with different extents of soil drought. The time and extent of summer drought serves to limit the spread of some species while favoring the spread of others.

The amount and rate of water uptake depends on the ability of the roots to absorb water from the soil with which they are in contact, as well as the ability of the soil to supply

and transmit water toward the root. These, in turn, are defined by properties of the plant: rooting density, root depth, and rate of root extension, as well as the physiological ability of the plant to increase its own water suction sufficiently to continue drawing water from the soil at a rate needed to avoid wilting; and by properties of the soil: hydraulic conductivity-diffusivity-matric suction-wetness relationships (Hillel, 1970). According to Brown (1970) the concept of the energy status of water in a system best explains the availability of the water. The free energy of the water in the soil can be expressed as the difference between the free energy of pure free water and the free energy of the water in the system at the same pressure and temperature, better known as water potential. Water potential is affected by factors that change the free energy of water molecules in the system. The presence of solutes, colloids, large particles such as sands, silts, and clays all decrease the water potential. The water molecules interact with these factors and decrease the free energy of the water below that of pure free water. Therefore, the total water potential is a combination of osmotic, matric, and gravitational pressures (Hillel, 1970; Brown, 1970).

There are implications that temperature and relative humidity of the atmosphere also play a significant role in the physiological ability of grasses to maintain water suction (Eddleman and Nimlos, 1972).

The thermocouple psychrometer method of measuring soil water potential is relatively new and is proving itself in many fields of science. Because the relative vapor pressure of soil water and plant tissue, which is directly proportional to water potential, lies very close to the saturated vapor pressure (95 to 100%), the method used to measure this must be capable of detecting very small changes in vapor pressure of water. This measurement can be made with small sensitive thermocouples (Spanner, 1951).

The objectives of this study were: (1) to test the hypothesis that there is a direct correlation between decreasing soil water potential and decreases in daily root and leaf growth, (2) to determine the water potentials of the soil system at the time of root and leaf growth cessation, and (3) to test the general hypothesis that differences exist between blue grama, western wheatgrass, and little bluestem in their ability to remove water from the soil.

Methods and Procedures

Specimens of blue grama, western wheatgrass, and little bluestem were collected from the Judith River valley 15 miles

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west of Lewistown, Mont. Clonal material was used to minimize the genetic variation between replications of each treatment. Specimens were collected in early spring before any evidence of new growth. Once growth started the plant clusters were removed from the sod and broken into smaller plants, which were used as individual replications in the study.

The study was conducted in a greenhouse using glass-front root observation boxes. Each root box contained approximately 6.5 liters of sandy loam soil (48% sand, 41% silt, and 11% clay).

Three replications of control and treatment plants of each species were used. The treatment plants were not watered after the initial saturation. Photosynthesis and respiration of the plant as well as evaporation were allowed to drain the soil of available moisture. The control plants were watered every 3 or 4 days to maintain a high water potential (greater than -1 bar).

The glass surface of the root boxes was divided vertically into four equal soil levels each 10 cm deep. Thermocouple psychrometers were inserted through the back of the boxes and centered at 5, 15, 25, and 35 cm in each of the four soil levels.

Soil water potential, soil temperature, root elongation, and leaf elongation measurements were taken at 24-hour intervals. All measurements started when the plant began to produce new visible roots along the glass surface of the root boxes. Measurements continued until there was no further elongation of roots in any of the four soil levels and no further leaf elongation in the treatment boxes.

Results

The soil water potential at the time of leaf growth cessation was used to rank the three species in their ability to extract moisture from a drying soil system (Table 1).

Blue grama extracted more moisture from the surface soil level than either western wheatgrass or little bluestem, to beyond the measuring capabilities of the thermocouple psychrometer (-80 bars). In the second soil level, blue grama and western wheatgrass developed lower soil water potentials than did little bluestem. In the lower two soil levels western wheatgrass extracted moisture to the lowest potential, followed by blue grama and little bluestem, respectively. As seen in Table 1, western wheatgrass extracted moisture more evenly from the entire soil profile than did the other two species. In all species the moisture was extracted first and to the greatest extent from the upper soil level and to a lesser degree from each successively lower level. Using various cool-season forage grasses and legumes, Bennett and Doss (1960) found that when plants wilted there usually was available moisture in the lower soil levels, but the plant was incapable of extracting this moisture. Such was the case with blue grama and little bluestem, where moisture was available in the lower soil levels at the time of leaf growth cessation.

Table 1. Soil water potential when leaf growth terminated.

Soil depth	Blue grama (Bars)	Western wheatgrass (Bars)	Little bluestem (Bars)
Level 1	<-80.0 b,c ¹ 2,3,4 ²	-30.0 a,c 2,3,4	-24.3 a,b 2,3,4
Level 2	-26.0 c 1,3,4	-23.6 c 1,3,4	-9.8 a,b 1,3,4
Level 3	-11.0 b,c 1,2	-16.8 a,c 1,2	-3.4 a,b 1,2
Level 4	-8.4 b,c 1,2	-15.3 a,c 1,2	-3.0 a,b 1,2

¹ Letters indicate the species that have significantly different water potential at the 5% level using a t-test of the replication means.
² Numbers indicate the soil levels within each species that have significantly different water potential at the 5% level using a t-test of replication means.

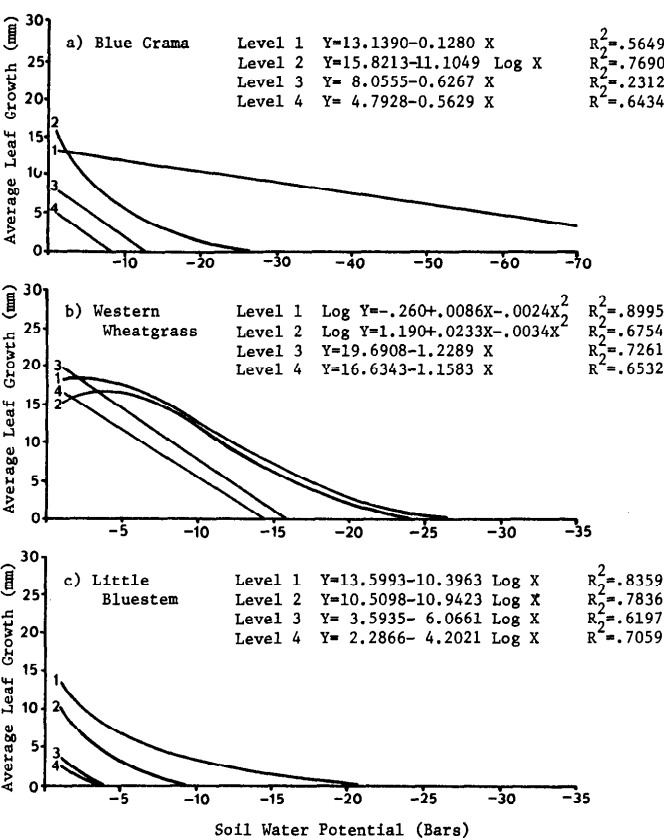


Fig. 1. Correlation between average daily leaf elongation and soil water potential in the four soil levels for all three species.

The correlation between soil water potential in all soil levels and leaf growth cannot be used to pinpoint the region of the soil that is the most critical in controlling leaf growth, but the slope and position of the regression lines can be used to support some theories (Fig. 1).

The decline in the soil water potential of the upper soil level corresponds with very small reductions in leaf growth of blue grama, suggesting that the upper soil level contributes little to the reduction of leaf growth (Fig. 1a). The leaf growth was reduced to nearly 50% of the original growth rate before the soil water potential dropped below -1 bar in the third soil level. Because there was apparent available soil moisture in the lower levels at the time of leaf growth cessation, the soil moisture availability in the second soil level seemed to have the closest correlation with decreases in leaf growth.

As illustrated in Figure 1b, all regression lines originated at points where leaf growth was at or near its maximum growth rate. This indicates that water potential decreased below -1 bar in all levels before any reduction in leaf growth occurred. The upward sloping of the first two lines indicates that leaf growth was actually increasing as the soil water potential decreased to as low as -5 bars in the upper soil levels. The similarity of the slopes of all four lines suggests that the water potential of all four levels contributed rather uniformly to the reduction of leaf growth.

The presence of decreasing leaf growth of little bluestem was apparent before there was any decrease in water potential of the second soil level (Fig. 1c). Leaf growth was reduced to one-third that of the original growth rate before the water potential decreased below -1 bar in the third soil level. The water potential reached in the lower two levels, before leaf growth terminated, remained very high compared to that in

Table 2. Soil water potential when root growth terminated.

Soil depth	Blue grama (Bars)	Western wheatgrass (Bars)	Little bluestem (Bars)
Level 1	-16.6 b,c ¹	- 7.8 a 2,3,4 ²	- 9.2 a 3,4
Level 2	-14.7	-10.6 1	-11.1 3,4
Level 3	-10.7 c	- 9.6 c 1	- 5.0 a,b 1,2
Level 4	-14.5 c	-13.8 c 1	- 5.0 a,b 1,2

¹ Letters indicate the species that have significantly different water potential at the 5% level using a *t*-test of the replication means.

² Numbers indicate the soil levels within each species that have significantly different water potential at the 5% level using a *t*-test of the replication means.

the upper soil levels.

The growth characteristic of the root system of many grass species is firmly fixed by their genetics. This, in turn, has an important bearing on the plant's ability to absorb water and, hence, survive drought. In most cases, upon encountering dry soil, root growth ceases and the roots become suberized to prevent moisture loss.

Blue grama developed similar water potentials at all levels at the time of root growth cessation (Table 2). For western wheatgrass the water potentials of the lower three levels were similar and significantly lower than that found in the upper level. The roots of little bluestem that tolerated the lowest water potential were in the upper two levels.

In the first soil level blue grama had the lowest soil water potential, which was significantly lower than the soil water potentials at the same level of the other two species. The soil water potentials of all three species were similar in the second soil level. In the third and fourth soil levels blue grama and western wheatgrass were similar but significantly lower than little bluestem. The total range of soil water potential at the

time of root growth cessation (-5.0 to -16.6) is quite small. Roots of the three species responded similarly to decreasing soil water potential.

The correlation between the soil water potential of each individual soil level and the root growth in that level is relatively consistent in all soil levels of the three species as indicated by the regression lines in Figure 2. The R^2 values indicate a lower level of correlation between soil water potential and root growth than between soil water potential and leaf growth. Some correlation between moisture and root growth may be purely coincidental, as indicated by a comparison of the growth pattern of the roots in the control and treatment boxes. Root growth, in both control and treatment, reached an early peak and decreased to a very low rate. The drying cycle developed in the soil of the treatment plants may have actually stimulated root growth to a greater rate than that for control plants. Canon (1926) and Weaver and Clements (1929) believed that a relatively low water content, provided there is enough to insure good growth, stimulates the roots to greater development, resulting in a greatly increased absorbing surface.

Summary and Conclusion

The three species involved in this study were deliberately chosen because of the habitats they occupy. Blue grama is usually the dominant species on low moisture sites. Little bluestem appears to thrive on damp, north-facing slopes. Western wheatgrass is found on a variety of sites ranging from xeric to mesic and appears to be an intermediate species in its moisture requirements. The soil water potentials that these species are capable of enduring, both in terms of leaf growth and root growth, appear to correlate with the apparent habitats they generally occupy.

One characteristic of these species that must be considered is their season of growth and maturation. Blue grama and little bluestem have both been termed "warm-season" grasses, while western wheatgrass is a "cool-season" grass. This, in part, may explain the different moisture extraction patterns, i.e., the relatively uniform moisture extraction by western wheatgrass and the inability of little bluestem and blue grama to effectively extract available moisture from the lower soil levels.

Soil water potentials at the time of root growth cessation varied no more than 6.1 bars throughout the soil profiles of these three species; blue grama ranged from -16.6 to -10.7 bars, western wheatgrass -13.8 to -7.8 bars, and little bluestem -11.1 to -5.0 bars. This indicates the need for a relatively moist soil profile to facilitate root penetration.

The increase in some species such as blue grama during extended dry periods can be partially explained by soil water potential tolerances found in this study, whereas higher precipitation and management systems that establish good soil moisture conditions appear necessary for maintaining western wheatgrass and little bluestem stands.

Literature Cited

- Bennett, O. L., and B. E. Doss. 1960. Effect of soil moisture level on root distribution of cool-season forage species. *Agron. J.* 52:204-207.
- Brown, R. W. 1970. Measurement of water potential with thermocouple psychrometers: Construction and applications. U.S. Dep. Agr., Forest Serv., Intermountain Forest and Range Exp. Sta. Res. Pap. INT-80. 27 p.

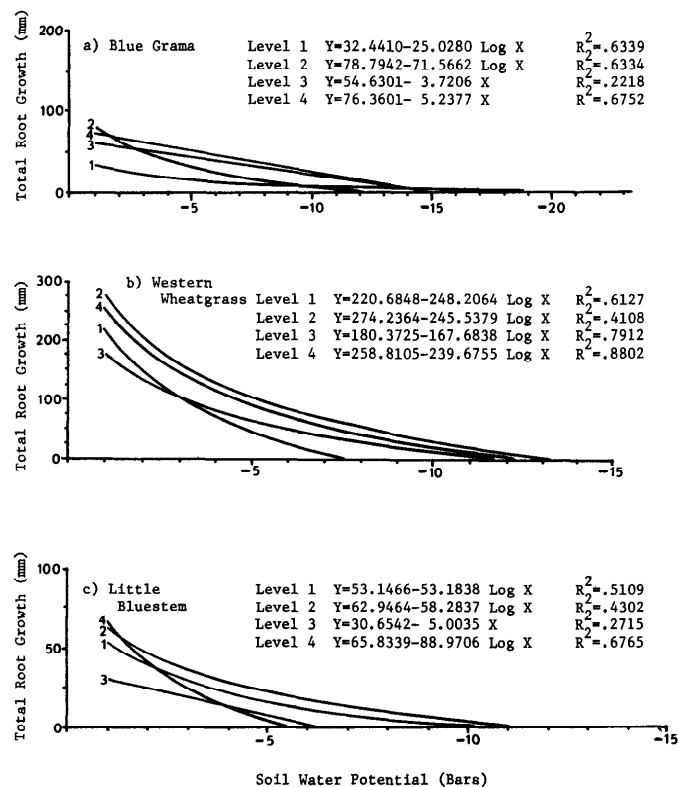


Fig. 2. Correlation between average daily root elongation in each soil level and soil water potential in each of the respective soil levels for all three species.

- Canon, W. A.** 1926. Studies on roots. Carnegie Inst. Wash. Yearbook 25:317-320.
- Daubenmire, R. F.** 1956. Climate as a determinant of vegetation in eastern Washington and northern Idaho. Ecol. Monogr. 26:131-154.
- Eddleman, L. E., and T. J. Nimlos.** 1972. Growth rates of native grasses and soil water potential as measured with thermocouple psychrometers, p. 231-236. *In*: R. W. Brown and B. P. Van Havern [ed.] Psychrometry in water relations research. Proc. Symp. on thermocouple psychrometry. Utah Agr. Exp. Sta.
- Hillel, D.** 1971. Soil and water. Physical principles and processes. Academic Press. New York and London. 288 p.
- McMinn, R. G.** 1952. The role of soil drought in the distribution of vegetation in the Northern Rocky Mountains. Ecology 33:1-15.
- Spanner, D. C.** 1951. The Peltier effect and its use in the measurement of suction pressure. J. Exp. Bot. 11:145-168.
- U.S. Department of Agriculture.** 1971. Soils of the Ashland and Fort Howes Ranger Districts, Custer National Forest. U.S. Dep. Agr., Forest Serv., Region 1, Missoula, Mont. 171 p.
- Weaver, J. E., and F. E. Clements.** 1938. Plant ecology, 2nd ed. McGraw-Hill Book Co., Inc., New York.

