The Environmental Tolerance of the Seedling Stage of Sequoiadendron giganteum

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ABSTRACT: Studies of the environmental tolerance of the seedling stage of *Sequoiadendron giganteum* determined the influence of light intensity, soil moisture, and soil *p*H on the growth and survival of seedlings two to five years old. The young trees are more drought resistant than previously thought, and capable of growing and surviving under a wide range of soil moisture and shading conditions.

INTRODUCTION

The finite life and lack of vegetative reproduction of *Sequoiadendron giganteum* (Lindl.) Buchh. (Sierran redwood) means that slow natural reproduction is the key to maintenance of present stands. A first step in conservation or management activities is understanding the species' ecological tolerance to the available range of environmental extremes.

This study describes the range of ecological tolerance of seedlings of *S. giganteum* to some important environmental factors such as soil moisture, light intensity and soil *p*H. Another study discusses seed ecology (Stark, in press).

The scientific name of the species and its generic designation are still controversial (Buchholz, 1939; Dayton, 1943; Fritz, 1953).

DESCRIPTION OF THE HABITAT

Eighty or more groves of *S. giganteum* (Sierran redwood) occur on the west slope of the central Sierra Nevada of California at elevations of 1,350 to 2,280 m (California Department of Natural Resources, 1952). A few trees grow naturally above and below these elevations.

The range of groves extends a distance of 403 km from the middle fork of the American River in Placer Co. south to Deer Creek in Tulare Co. Although its natural distribution is limited, this species is planted successfully in at least 14 other countries (Stanford, 1958).

Summers in the natural range of the species are warm and dry with almost no precipitation except for occasional light thunderstorms. Most of the annual precipitation (ranging between 63 and 91 cm) falls as snow beginning in October or November and continuing through April or May. Annual snow accumulation varies from 1.2 to 4.7 m.

The warmest month of the year is August, when daily air temperatures may rise to 40 C, but often drop to 2 C at night. Intense summer solar radiation on exposed sites may heat the soil surface to 65 C while temperatures on shaded sites may be as much as 16 C lower.

The winters are cold; air temperatures seldom exceed 10 C during the day and sometimes drop to —23 C at night. The average annual frost-free period is 124 days.

Mountainous terrain with deep valleys and grassy meadows characterize the range. The main rock formations are granite, diorite, and andesite. Lava caps are common on the higher peaks.

Most of the groves are on unglaciated terrain but some can be found on glacial moraine. The soils are mainly shallow and rocky but include some deep sandy loams. They are weakly to moderately acid and are generally well-drained (Zinke and Crocker, 1962). The groves are not pure stands but contain other tree species: Incense-cedar *(Libocedrus decurrens* Torr.), White fir *(Abies concolor* (Gord. & Glend.) Lindl.), Lodgepole pine *(Pinus murrayana* Grev. & Balf.), Sugar pine *(Pinus lambertiana* Grev. & Balf.), Jeffrey pine *(Pinus jeffreyi* Grev. & Balf.), Ponderosa pine *(Pinus ponderosa* Laws.), Pacific yew *(Taxus bevifolia* Nutt.).

A check list of plants found in and around the groves provides a more complete picture of the flora (Stagner, 1951). Ferns, mosses, herbs, grasses, and shrubs are common in some groves. Continuous mats of vegetation once grew in most groves, but in some areas heavy recreational use has severely reduced the ground cover (Hartesveldt, 1962). The tests were conducted in the northern range of the species and the habitat description presented here applies to the Experimental Plot.

METHODS

CLIMATIC DATA

To understand the normal growth of *S. giganteum* in the environment of the Experimental Plot and elsewhere, it was necessary to maintain a constant record of climatic extremes combined with periodic growth measurements. A weather station adapted to the immediate needs of this research was equipped as follows:

1. A Moeller thermograph for 10 cm air temperature, and 1 and 20 cm soil temperatures.
2. A hygrothermograph set at 1 m above the ground for shelter air temperatures and relative humidity, checked by thermometers and a sling psychrometer.
3. A 3-cup anemometer mounted at 20 cm above the ground in summer and atop the shelter in winter.
4. A standard rain gauge.
5. Six's type maximum-minimum thermometers, used for recording maximum-minimum air temperatures at 5, 10, and 20 cm, and soil temperatures at 5 and 10 cm deep.
6. A 27.8 cm evaporimeter set in the open at 20 cm above ground. This instrument was devised from a flat-bottomed pan leveled on a board. Evaporation was measured daily in cm using a ruler set in the pan.
7. An electronic "Aquaprobe," which works on the principle of conductance, for soil moisture determinations. Gravimetric determinations were also made.

Instruments were serviced daily during the summer and weekly when possible during the winter. The 3-year weather record is not presented in this paper because of its length, but Table 1 summarizes the climatic extremes recorded for the three years of study.

FIELD STUDIES OF ECOLOGICAL TOLERANCE

The Experimental Plot at the Stanislaus Experiment Station, Old Strawberry, is located at 1,508 m elevation in a level, sunny flat near the south fork of the Stanislaus River (T 4N, R 18E, Sec 19 M.D.M., Tuolumne Co.). The soil is a deep sandy loam with good drainage. *Sequoiadendron giganteum* grows naturally north and south of the plot, although the study was conducted in the northern range of the species.

The soil was spaded and treated with 50 lbs 16-20-0 fertilizer per acre in the fall prior to planting. Tests and controls were planted in rows of 50 seedlings in several parts of the plot.

TABLE 1.—Characteristics of the climate of the Experimental Plot

Temperature	1960		1961	
	Max.	Min.	Max.	Min.
	degrees C			
Air				
20 cm	38.6	–15.3	38.4	–14.8
10 cm	37.8	–15.4	37.9	–15.3
5 cm	39.5	–19.9	39.5	–16.5
Soil				
1 cm	40.5	....	35.6	....
5 cm	37.1	– 7.9	36.8	– 0.5
10 cm	36.8	– 2.2	34.4	....
20 cm	22.2	....	22.2	....
Shelter air	37.2	– 3.2	36.8	–13.2
Wind at 20 cm (June-Sept.) Total km	4,203.4	....	1,140.6	....
Annual precipitation — cm	82.4	....	43.3[1]	....
Month of highest precipitation	Feb.	....	March	....
Month of highest evaporation	Aug.	....	Aug.	....
Lowest soil moisture reached at 15 cm — % on a wet weight basis, no water added	3.1	....	3.3	....

[1] For the first 10 months instead of the full year.

In March of 1960, 1,500 year-old seedlings (1-0) and 1,500 two-year-old seedlings (2-0) from the U.S. Nursery at Placerville, California (Merced Grove seed source) were planted at 30 cm spacing and 80 cm between rows. In April, a late shipment of 2,000 2-0 seedlings from the State Nursery at Magalia, California, was planted in tests identical with those of the Placerville trees. Mortality of the Magalia trees was high because of the late planting. (Mt. Home seed source.)

Unless otherwise stated, the seedlings were labelled and planted 50 1-0P, 50 2-0P (P = Placerville), and 50 2-0M (M = Magalia) for each treatment of the tests with five replications of 10 seedlings each. Height was measured in centimeters after planting and at the end of each growing season. In addition, 50 trees from each test were measured at the end of June, July, August, and September. Corrections were made for initial height differences. Root-shoot ratios were established at planting and again at the end of the tests to determine how the treatments influenced root and shoot growth. Root and shoot fresh and oven dry weights were taken in 1961 for 10% of the seedlings in each test. Percentage of survival was checked during the summer at monthly intervals and the causes of death determined for individual seedlings.

In 1960, several centimeters of pine litter was added to the soil surface to reduce losses from heat canker and high temperature soil fungi, particularly *Sclerotium bataticola* Taub., which was present in some stock. The litter reduced soil temperatures by 10 to 15 C and reduced moisture losses by 25 to 60% at 10 cm depth.

The plots were weeded regularly and water was added to trenches between the rows.

Controls.—(100 1-0P, 100 2-0P, 100 2-0M).—The growth and survival of these seedlings planted in several areas of the plot established a performance average for the environment of the plot and formed the basis of comparison for all tests. Controls were watered once every 7 days (75 liters per 50 seedlings as a group) as were all but the moisture studies.

Shading.—(250 1-0P, 250 2-0P, 250 2-0M).—There are conflicting reports on the tolerance of this species to shade (Schubert, 1957). This test was designed to study the influence of seven shading conditions on the growth, survival, and habit of the seedlings.

The treatments, checked with a G.E. light meter and based on readings at noon in August, are as follows:

A. Full sunlight (app. 10,000 + ft c—equivalent to but distinct from controls)
B. 75% full sun (cheesecloth shades)
C. 50% full sun (cheesecloth shades)
D. 25% full sun (burlap shades)
E. 2% full sun (burlap shades)
F. Full sun 5 hours per day, moderate shade 9 hours (lath)
G. Full sun 3 hours per day, moderate shade 11 hours (lath).

These trees were watered in the same manner as the controls and alterations of air temperature and relative humidity, and soil moisture and temperature by the shades was measured. Other modifications of the environment resulted from shading, but these could not be separated. Color differences of seedlings in the shading tests are based on the Munsell foliage color chart.

Soil Acidity.—(160 1-0P, 200 2-0P).—Seedlings planted in pure quartz sand in milk cartons were watered weekly with H_2SO_4 or NaOH solutions adjusted to *p*H 2, 3, 4, 5, 6, 7 (distilled water), 8, and 9. The cartons were set into the soil to avoid excessive root heating. Complete nutrient solution (Hoagland and Arnon, 1950) was added to the sand to insure that all essential ions were present. Soil moisture and acidity were checked weekly. The Hellige *p*H kit which was used as an indicator was not sensitive to *p*H 2 and 3.

Soil Moisture.—(475 1-0P, 475 2-0P, 650 2-0M).—The soil moisture tests were designed to show which range of soil moisture promotes the best height and root growth and survival, and what maximum and minimum soil moisture levels limit seedling survival. As the soil drains after watering, fresh air with oxygen moves into the pores. Soil moisture was regulated by the frequency of watering. Seedlings in groups of 50 received 75 liters of water at each watering. The time between waterings influenced the degree to which the soil was dried. Natural rainfall during the summer rarely exceeds 1 or 2 cm, which is lost by evaporation and seldom influences soil moisture. Moisture measurements at 15 cm were made just before each periodic watering using the gravimetric method to establish the range of soil moisture for each test.

The treatments (75 liters of water applied to the furrow adjacent to each of three groups of 50 seedlings) were:

A. Daily S* –S (+16.5%)
B. Every 2 days S–15.9%
C. Every 3 days S–14.7%
D. Every 4 days S–13.5%
E. Every 6 days S–12.2%
F. Every 7 days S–9.6% (controls, shading, *p*H)
G. Every 8 days S–9.2%
H. Every 10 days S–8.8%
I. Every 14 days S–7.5%
J. Every 16 days S–7.4%
K. Every 24 days S–6.2%
L. Every 30 days S–4.2%
M. Every 60 days S–3.3%
N. None all summer, except natural rainfall S–3.2%
O. Kept partly under water at all times S–S. In cartons under ± 5 cm water at all times, sun, shade.

* S means saturated, +16.5% soil moisture, on a wet weight basis. The second figure represents the average low soil moisture percent at the end of each watering cycle. S–9.6% indicates a range of soil moisture between +16.5% and 9.6% over a 7-day period.

RESULTS AND DISCUSSION

CONTROLS

Controls for the 1-0P stock grew well, averaging 20.1 cm growth in height in the second year. Root fungi interfered with the growth of the 2-0P stock, which averaged only 14.0 cm growth in the second year. Throughout the tests, the growth of 2-0P stock is not comparable to the growth of 1-0P stock. Nearly all 2-0P seedlings showed some damage to the roots so that differences between tests and controls within these groups of seedlings is meaningful (Tables 2, 3, 4).

The average 1960 growth of 1-0P stock was 9.5 cm compared to 20.1 cm for 1961 (Table 2). The 2-0P stock's seasonal height growth total averaged 6.1 cm in 1960 and 14.0 cm in the fall of 1961 (Table 3). The 2-0M stock averaged 13.5 cm height growth in 1961. The late-planted Magalia stock averaged 3.2 cm height growth the first year and 13.5 cm the second. In all cases, the second year's growth exceeded the first year's growth. The seedling crowns grew slowly the first year after transplanting.

SHADING

The most extreme microenvironment resulted from 75% of full sunlight, with air temperature 11.2 C higher than in the shelter. Soil temperatures were 1.3 C higher than those in the open, and soil

TABLE 2.—Average cumulative crown height increase of *Sequoiadendron giganteum* seedlings for 1960-1961 (1-0 Placerville stock)

Treatment[1]	1960 average growth (cm) Sept.	1960: % of Control	1961 average growth (cm) Sept.
Control	9.5	....	20.1
Full sun	10.0	103.4	23.1
75% full sun	4.5	49.5	10.7
50% full sun	7.0	77.3	14.1
25% full sun	8.9	97.7	13.6
2% full sun	3.8	42.2	6.1
*p*H 2	4.2	45.8	17.5
*p*H 3	4.9	53.5	16.4
*p*H 4	5.3	57.9	18.9
*p*H 5	4.0	44.3	17.8
*p*H 6	8.7	94.2	24.0
*p*H 7	4.6	50.5	23.4
*p*H 8	4.2	46.4	19.6
*p*H 9	3.9	43.0	18.3
M-daily[2]	9.4	109.4	27.3
M–2 days	13.7	131.6	27.6
M–4 days	12.4	136.4	23.2
M–8 days	10.9	113.5	22.3
M–16 days	8.3	86.2	21.4
M–1 month	8.2	89.4	20.4
M–2 months	9.9	....	....
M–none	5.2	52.4	14.3
Radiation	5.7	60.0	13.9
Root pruning	7.5	78.9	17.9
Flooding	2.2	23.1	4.8

[1] All tests began with 50 seedlings except for *p*H, which began with 20.

[2] M means moistened with 75 liters water per 50 seedlings.

moisture was lower (69.9% of control) than in any of the other shading tests. Air temperature maximums were 11.2 C higher and the minimums averaged 3.9 C lower than under control conditions. The thin cheesecloth shades used in this test excluded 25% of the measured visible radiation, and were effective in retarding reradiation, decreasing relative humidity, and may have limited wind movement. Height growth averaged 49.5% of control growth and only 73% survived under 75% full sun (Table 4). Under this treatment, seedlings averaged 13.6% of control crown dry weight and 21.9% of control root dry weight.

At the other extreme in 2% of full sun, the air and soil temperatures were lowest because the heavy burlap shades excluded nearly all radiation. Although the shades retarded reradiation, maintaining high night temperatures (at least 3.5 C higher than in the open), the maximum air temperatures averaged only 4.8 C higher than in the open because only a small amount of energy entered the system from above. This treatment maintained high soil moisture (151.5% of control); thus 7 days after watering, the moisture level was still near field capacity. The high soil moisture and relative humidity reflect the low

TABLE 3.—Average cumulative crown height increase of *Sequoiadendron giganteum* seedlings for 1960-1961 (2-0 Placerville stock)

Treatment	1960 average growth (cm) Sept.	1960: % of control	1961 average growth (cm) Sept.
Control	6.1	......	14.0
Full sun	6.3	103.0	13.9
75% full sun	3.5	57.4	11.9
50% full sun	6.3	103.2	12.6
25% full sun	5.1	83.6	16.0
2% full sun	4.5	73.7	14.9
*p*H 2	4.1	67.2	21.2
*p*H 3	3.4	55.7	21.6
*p*H 4	2.6	42.1	16.4
*p*H 5	2.9	47.7	14.8
*p*H 6	5.9	96.0	24.5
*p*H 7	4.1	67.2	20.6
*p*H 8	3.1	50.9	17.3
*p*H 9	3.4	55.7	13.3
M–daily[1]	4.6	75.9	14.3
M–2 days	6.2	102.5	14.9
M–4 days	6.2	102.5	14.3
M–8 days	5.2	85.9	14.8
M–16 days	3.7	60.3	11.1
M–1 month	3.4	55.7	9.9
M–2 months	2.6	42.1	11.3
M–none	2.4	55.7	12.7
Root pruning	4.2	67.2	19.4
Flooded	1.2	19.6	6.6

[1] M means moistened with 75 liters of water per 50 seedlings.

energy level of the system. Survival was high (90%) under protection from the environmental extremes. Seedlings grew slowly under 2% full sun, were etiolated, deformed, with lax, soft branches, and broad discolored needles (7.5 GY 5/4-greenish green yellow). These seedlings had tiny, weak root systems (5.8% of control root weight) and recovered poorly when exposed to full sunlight (Table 5). The crowns were dwarfed, and averaged only 2.7% of control crown dry weight.

The other shading treatments fell within the range of the two extremes with the best crown and root growth and form in full sun. Since not all environmental modifications produced by shading were studied, seedling response was influenced by some factors unknown.

Seedling growth and survival was slightly higher under 5 hours of sun (165.8% of control growth) than under 3 hours of full sun (154.1% of control growth). Growth in full sunlight was superior to that in any shading test, except among seedlings which had damaged roots. Seedlings receiving 5 hours of full sunlight appear undiseased and to have begun rapid growth aided by more soil moisture resulting from partial shade.

Litter placed on the soil surface for all tests reduced death from high temperature soil fungi and damage from heat canker. Few of the seedlings grown in shade showed signs of root rot.

Seedlings protected by shades from the dates of planting turned

TABLE 4.—Average cumulative crown height increase of *Sequoiadendron giganteum* for 1960-1961 (2-0 Magalia stock)

Treatment	1960 average growth (cm) Sept.	1961 average growth (cm) Sept.
Controls	3.2	13.5
Full sun	4.6	12.5
75% full sun	4.3	10.0
50% full sun	3.6	9.8
25% full sun	4.3	12.3
2% full sun	0.9	4.9
M–daily[1]	4.4	14.2
M–2 days	7.8	21.4
M–3 days	4.8	13.6
M–4 days	7.8	17.3
M–6 days	4.2	14.3
M–8 days	6.7	16.1
M–10 days	3.0	13.5
M–14 days	1.9	13.4
M–16 days[2]	5.6	13.6
M–24 days	1.9	7.5
M–1 month	4.8	14.1

[1] M means moistened with 75 liters of water per 50 seedlings.

[2] This test pirated water from another.

green much earlier and survived better than seedlings kept in full sun all winter. In winter, most seedlings develop a purple-brown cast, but shading maintains their normal summer color (7.5 GY 6/6 greenish green yellow). Six individuals of a physiological ecotype which remains green all winter, even in full sunlight, were discovered in the fall of 1960.

Healthy *S. giganteum* seedlings grow best in the central Sierra Nevada in full sunlight with a moderate litter cover on the soil. This same litter cover, if it becomes too deep, limits reproduction of the species.

SOIL ACIDITY

The soil acidity tests were beset with many difficulties. Seedling roots grew beyond the cartons and had to be cut back. It was nearly impossible to measure and maintain *p*H 2 and 3 under field conditions.

Seedling response was erratic to *p*H 2 and 3. There is no proof from these tests that *S. giganteum* seedlings can tolerate *p*H levels below *p*H 4.

The best height growth of all seedlings was at *p*H 6 (94.2% of control growth at *p*H 6, Tables 2, 3). The difference between controls at *p*H 6 and tests at *p*H 6 is probably the result of high soil temperatures in the cartons, which influenced root growth. All seedlings showed an unexpected reduction in height growth and survival at *p*H 5 (44.3% of control). This growth reduction may be related to the *p*H dependence of soil fungi. Since soil acidity influences ion uptake and also mycorrhizal activity, the real cause of poor growth and survival at *p*H 5 from these tests remains unknown. No deficiency symptoms were detected, but the extension of roots into untreated soil should have provided temporary access to extra nutrients.

TABLE 5.—Root-shoots data for *S. giganteum* September, 1961, 1-0P

Treatment	% of control (full sun) dry weight		Average dry weight in grams		
	Crown	Root	Crown	Root	Ratio
Saturated soil	4.9	14.5	2.9	2.3	1.2/1
Watered daily	128.2	124.8	76.0	19.8	3.8/1
Watered 2 days	180.4	178.2	80.2	24.1	3.3/1
Watered 2 months	91.2	110.9	65.7	14.5	4.5/1*
2% full sun	2.7	5.8	1.6	0.9	1.7/1
25% full sun	13.2	12.2	7.9	1.9	4.1/1**
50% full sun	22.6	20.0	13.4	3.2	4.1/1**
75% full sun	13.6	21.9	8.1	3.5	2.3/1
Full sun	100.0	100.0	59.3	15.9	3.7/1

* This ratio is based on data from 1961 when the seedlings had successfully sent roots to the capillary fringe of the water table resulting in an ideal balance of aeration and water.

** These seedlings were etiolated from the low light intensities. Those from 2% full sunlight were unable to grow or etiolate extensively.

Height growth declined from *p*H 7 through 9 (50.5% to 43.0% of control height growth). Differences in the 1960 and 1961 growth patterns probably result from the earlier application of treatments in 1961.

SOIL MOISTURE

These studies show that watering intervals of 2 to 4 days favor superior initial growth (131.6% and 136.4% of control height growth) and appear to maintain good oxygen-moisture relations (Tables 2, 3, and 4). Under a 2-day watering treatment, the crowns put on 180.4% of control crown dry weight and the roots put on 178.2% of control root dry weight (Table 5). By comparison, those seedlings watered every 2 months put on 91.2% of control crown dry weight and the roots put on 110.9% of control root dry weight (Table 5). The greater root weight of seedlings watered every 2 months indicates that at autumnal soil moisture levels of 3.3%, much summer photosynthate is diverted to roots.

Daily watering may not allow sufficient time for the soil to drain to field capacity and may not allow sufficient soil aeration. Seedlings constantly flooded grow slowly, but survival was good (19.6% of control height growth, 4.9% of control crown dry weight, Tables 3, 5). Seedlings receiving no added soil moisture during the summer grew nearly as slowly as the flooded seedlings (52.4% of control height growth, Table 2), until they were able to double the root dry weight resulting in faster crown growth. After the roots developed, growth of crowns was rapid.

Some seedlings scattered throughout the plot were 30 to 40 cm taller than the rest at the end of 2 years. Examination of the roots of these large seedlings showed an extensive mat at about 15 cm and a deep taproot. There is little reason to doubt that these seedlings have extended their roots into a zone of permanent and adequate soil moisture (about 60 cm deep in this soil). This, in part, explains their superior crown growth of 30 cm or more per year and their failure to respond to surface treatments. Since these trees did not show excessive growth until the second year, the calculations for percent of control height growth are based on 1960 when all seedlings were responding to surface treatments. Percent of control height growth for 1961, and examination of roots show that some seedlings were exceeding control growth partly as a result of the treatments and partly because of root extension into deep, moist soil.

With the exception of the 8-day treatment, survival and growth decreased from the 4-day interval to the unwatered treatment. Available soil moisture over this range decreased from 13.5% to 3.2%. At 3.2% soil moisture, only 27% of the seedlings survived, compared to 98% survival for seedlings watered every 4 days.

The Magalia seedlings responded poorly to all treatments the first year, but the 1961 data show superior height growth at the 2- and 4-day watering intervals (Table 4). These data agree with those from the Placerville seedlings, except for the peculiar height growth for the 3-day interval.

Aeration remains an important consideration in moisture studies. Where there is adequate soil moisture, aeration may be the limiting factor. When soil moisture is low, it acts as a limiting factor to growth. When soil moisture drops below about 6% (in sandy loam) growth and survival of seedlings is uncertain. Seedlings can survive in soil moisture as low as 5% provided they have extensive root systems, and levels of 3.0% can be tolerated in autumn when growth has subsided.

Seedlings withstand inundation for about a month, and shallow flooding for a week or two. If flooding continues for more than a month, seedlings will not grow, although they will survive in pure water for nearly a year. They can be frozen in ice with minor damage to roots. Seedlings in moist, bare soil in winter are often killed by frost heaving. Although the best growth occurs in soils near field capacity (16%), this species is poorly adapted to flooded sites that remain constantly at or above field capacity.

The most rapid growth for all tests came in July when soil moisture was still high in all areas. August growth slowed slightly over that in July in the higher moisture tests, but the slowing of growth was pronounced in September.

CONCLUSIONS

Tests of the ability of *S. giganteum* seedlings to survive extremes of soil moisture, light, *p*H, and other environmental conditions revealed the following:

1. Infection by high temperature root rot such as *Sclerotium bataticola* slows growth initiation, and limits growth and survival. Litter on the soil surface reduces damage from heat canker and root rot.
2. Shade in winter prevents the darkening and purpling of seedlings. Some natural physiological ecotypes remain green all winter.
3. Seedlings survive well but grow poorly in dense shade. Color, growth form, and roots develop abnormally in less than 25% full sun.
4. Seedlings grow best in height at *p*H 6, but they grow poorly at *p*H 5, and abnormally at lower *p*H levels. Growth decreases from *p*H 7 through 9.
5. Seedling height growth and survival decreases as soil moisture in the root zone drops from 16% to 5%.
6. Watering frequencies of 2 to 4 days seem to provide the ideal balance between soil moisture and aeration.
7. Once the seedlings extend taproots into zones of permanent and adequate moisture, growth is rapid.
8. *S. giganteum* can develop a two-storied root system well suited to summer drought.

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