Pine Plantation Survival Related to Calculated Moisture Deficits on the Huron National Forest (1929-1976)

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Soil moisture deficits are an important cause of seedling mortality on the sandy outwash plains typical of the Huron National Forest. Red and jack pine planting survival records from 1929 through 1976 were examined, and those years with two or more planting sites and consistent survival were chosen for study. Growing-season water deficit, expressed as the difference between precipitation and potential evapotranspiration, was significantly related to percentage survival using simple linear regression. Survival ranged from 30 to 95 percent, while moisture deficits ranged from + 0.40 to - 8.31 inches during the growing season. With a mean moisture deficit of - 3.82 inches during the growing season, the expected seedling survival is 80 percent. Based on available water contents in the sandy outwash soils, moisture deficits commonly exist during the growing season, and site preparation and planting practices should attempt to preserve surface organic layers. Tree Planters' Notes 37(3):17-22; 1986.

Obtaining acceptable survival of planted pine seedlings is often a challenge for regeneration foresters. Although competition with neighbors and pest attacks are the chief causes of mortality of older trees (2), a myriad of factors, including stock quality and handling, soil moisture and nutrient conditions, seed source, and pests influence planted seedlings (1). Proper attention to these details and appropriate planning for the reforestation effort have proven to be useful in reducing seedling mortality (5).

Of the many site factors that influence seedling survival, soil moisture is often critical. This fact has been well-documented for a number of tree species, including Douglas-fir (7), ponderosa pine (6), and loblolly pine (3).

The Huron National Forest has had an active reforestation program for over 55 years, and because of the sandy, droughty, glacial outwash soils that are common on the forest, much attention has been paid to the relationship between soil moisture and seedling survival. Several years ago an investigation was begun to determine if seedling survival could be adequately predicted by soil moisture or some other readily measurable climatological factor. A prediction equation would be useful to determine how much of the variation in seedling survival is attributable to soil moisture/climatological factors and how much remaining variation is attributable to other factors. Planting site management recommendations may be varied on certain sites to preserve organic matter, prohibit prescribed burning, or modify site preparation and planting practices.

Methods

First year planting survival records for the Huron National Forest were examined for the years 1929 through 1976. The survival data base consisted of those years for which there were two or more red pine and/or jack pine planting sites with consistent survival. The planting seasons selected represented 137 planting sites, 8,576 acres, and approximately six million seedlings.

Climatological data from the U.S. Department of Commerce, Environmental Science Services Administration was obtained for the study years, and potential evapotranspiration (PET) was calculated using the method of Thornthwaite (10). Thornthwaite's method for computing PET integrates the factors of vapor pressure, temperature, wind, humidity, evaporation, and transpiration and involves a series of calculations using monthly temperature values (9). Veihmeyer (11) presented Thornthwaite's equations as follows:

$$PET = 1.6 \cdot \frac{10\ T^a}{TE} \qquad (1)$$

$$a = 0.000000675(TE)^3 - 0.0000771(TE)^2 + 0.01792TE + 0.49239 \qquad (2)$$

$$i = T^{1.514} \div 5 \qquad (3)$$

where:

PET = potential evapotranspiration (cm)

T = mean monthly temperature ºC)

TE = temperature - efficiency index, equal to the sum of 12 monthly values of heat index, *i.*

In order to compute PET for a given location:

- ?? mean monthly temperature (T) is used to compute a heat index *i* using equation 3
- ?? the heat indexes are summed over a year to obtain a temperature - efficiency index (TE)
- ?? the temperature - efficiency index is used to compute the variable a using equation 2
- ?? mean monthly temperature (T), temperature - efficiency index (TE), and the variable a are used in equation 1 to compute PET
- ?? the PET computed by equation 1 may be adjusted for day-length and number of days per month (because the number of days per month varies between 28 and 31 and the number of hours of active evapotranspiration per day varies with latitude) (4).

A plot of monthly PET and precipitation is commonly used to display a water balance for a given location.

There is a water deficit when PET exceeds precipitation. If the soil moisture is depleted during this period, seedlings may die. Moisture deficits were calculated for the growing season months of May through August for each year and were used as an independent variable in a simple linear regression analysis with percentage seedling survival as the dependent variable.

Results and Discussion

Water deficit during the growing season and percentage seedling survival were significantly (P<0.01) related as follows:

$$\%\ \text{survival} = 99.1137 - 5.3836\ (\text{water deficit in inches}) \qquad (4)$$

$$r = -0.795$$

$$SE = 12.2\%$$

Although many factors, such as competition for sunlight, insect and disease damage, limited soil nutrients, and poor stock quality and handling, also contribute to seedling mortality, calculated moisture deficit during the growing season was correlated with percent survival on the Huron National Forest (table 1). During 1934 the growing season moisture deficit was -8.31 inches, and during 1940 a moisture surplus of +0.40 inches occurred. On the average the moisture deficit during the growing season was -3.82 inches, however. Seedling survival ranged from 30 percent in 1933, when there was a moisture deficit of - 7.00 inches, to 95 percent in 1940.

Equation 4 is used to predict expected survival rates at varying moisture deficits. Table 2 displays the actual and expected survivals, as well as the relative occurrence of moisture deficits during the 47year study period. Eighty-four percent of the years had moisture deficits between 0.0 and -5.0 inches. Actual and expected survival rates were in reasonable agreement except at the - 7.0 moisture deficit, which had only a 30 percent seedling survival. For that year some factor other than moisture must have contributed heavily to seedling mortality. According to Ohms (8), a seedling survival rate of 70 percent is normal for the Lake States region, assuming good quality planting stock and proper planting procedures. A water deficit of about -5.0 inches should result in about 73 percent of seedlings surviving their first year. Water deficits below -5.0 inches may result in objectionable levels of mortality.

Thornthwaite's PET equation is useful for integrating the climatic factors of precipitation, temperature, wind, relative humidity, and evapotranspiration into a reliable

Table 1—*Descriptive statistics of regression data*

	Growing-season moisture deficit[1] (in.)	Percentage seedling survival
Mean	−3.82	80
Range	−8.31 to +0.40	30 to 95
Standard deviation	2.96	20

[1]Computed as the sum of the moisture deficits (precipitation − PET) for May through August

Table 2—*Actual and expected survival and relative occurrence during the study period for various moisture deficits*

Growing-season moisture deficit (in.)	Relative occurrence during study period (%)	Percent survival	
		Actual	Expected
−10	2	—	45
− 9	0	—	51
− 8	4	58	56
− 7	2	30	61
− 6	8	—	67
− 5	11	86	72
− 4	11	83	78
− 3	15	92	83
− 2	25	90	88
− 1	11	91	94
0	11	95	99
+ 1	0	—	100

index that is significantly related to seedling survival. In addition, PET can be used to indicate specific periods of moisture stress. The dominant soils planted to red and jack pine on the Huron National Forest are Typic Udipsaments of the Grayling, Graycalm, and Rubicon series. The average available water content for these soils is 5 percent, and the bulk density ranges from 1.3 to 1.7 grams per cubic centimeter for the surface 10 inches.

The available water holding capacity is computed by multiplying the percentage of available water content by the bulk density by depth of the horizon. Therefore, the available water holding capacity for the surface 10 inches ranges from 0.65 to 0.85 inches. The 47year mean daily PET's for the months of May through August for the Huron National Forest are 0.09, 0.14, 0.15, and 0.12 inches, respectively. Therefore, the available soil water would be depleted in May in 7.2 to 9.4 days, in June in 4.6 to 6.1 days, in July in 4.3 to 5.7 days, and in August in 5.4 to 7.1 days. Unless the top 10 inches of soil gets recharged during these time limits, the planted seedlings will experience moisture deficits with a resultant increase in mortality.

Summary

Agencies and organizations that are heavily involved in artificial regeneration recognize the importance of factors such as proper stock handling, correct planting practices, planting site condition, and soil moisture to early seedling survival. The simple linear regression equation presented here has proven useful in providing expected seedling survivals at various moisture deficits. If the survival rate is less than expected during a season with a relatively low moisture deficit, other factors may be implicated. Although foresters are unable to manipulate climatic conditions, and irrigation is infeasible, other site preparation practices such as preserving surface organic layers while removing competing vegetation may aid in reducing evapotranspiration losses.

Literature Cited

1. Boyd, R.J. The biology of planting. In: Baumgartner, D.M.; Boyd, R.J., eds. Tree planting in the inland Northwest. Pullman: Washington State University; 1977.
2. Buchman, R.G. Survival predictions for major Lake States tree species. Res. Pap. NC-233. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983.7 p.
3. Cannell, M.G.R.; Bridgewater, F.E.; Greenwood, M.S. Seedling growth rates, water stress responses, and root-shoot relationships related to eight-year volumes among families of *Pinus taeda* L. Silvae Genetica 27:237-248; 1978.
4. Griddle, W.D. Methods of computing consumptive use of water. Proceedings of the American Society of Civil Engineers 84:1-27; 1958.
5. DeYoe, D.R.; Cleary, B.D. Reforestation planning guide: helping insure reforestation success for woodland owners. EM 8241. Corvallis: Oregon State University Extension Service; 1983. 89 p.
6. Feret, P.P. Effect of moisture stress on the growth of *Pinus ponderosa* Dougl. ex Laws seedlings in relation to their field performance. Plant and Soil 69:177-186; 1982.
7. Krueger, K.W.; Trappe, J.M. Food reserves and seasonal growth of Douglas-fir seedlings. Forest Science 13:192-202; 1967.
8. Ohms, O.J. Increase planting survival through better management. In: Artificial regeneration of conifers in the Upper Great Lakes Region, 1982. Houghton, MI: Michigan Technological University; 1982:383-390.
9. Spurr, S.H.; Barnes, B.V. Forest ecology. New York: John Wiley & Sons; 1980. 687 p.
10. Thornthwaite, C.W. An approach toward a rational classification of climate. Geographical Review 38:55-94; 1948.
11. Veihmeyer, F.J. Evapotranspiration. In: Chow, V.T., ed. Handbook of applied hydrology. New York: McGraw-Hill Book Co.; 1964: 11-1 to 11-38.