SHRUB CONTROL


Soil Moisture Depletion in the Annual Grass Type

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The rate of soil moisture depletion from field capacity to permanent wilting percentage (PWP) is an important phenomenon of the soil-water-plant system. Its importance is not confined to the interest of the soil scientist and plant physiologists; it also attracts the attention of plant growers and managers, preoccupied with increasing plant yields.

Thus, range managers, interested in producing the highest amount and best quality of forage from their land, are very much concerned with the depletion of available soil moisture. That problem is of greatest practical importance in areas of typically Mediterranean climate, where the winter rainy season is followed by a long dry period.

Literature Review

The issue of soil moisture depletion through evapotranspiration has been a controversial one for many years. A detailed analysis of it would be outside the scope of this paper.

In general, there are four models of depletion curves supported by different specialists:

1. Soil moisture depletion rate is constant from field capacity down to PWP (Viehmeier and Hendrickson, 1955, 1961).

2. Depletion rate of soil moisture is almost constant for about the first eighty percent of available moisture, and then decreases rapidly (Gardner 1960).


4. Depletion rate of soil moisture is constant for about the first 20 percent of the available moisture, then decreases rapidly, and starts again to increase until it reaches the PWP (Penman 1941).

Long term, extensive field studies in the prediction of soil moisture to a depth of 12 inches, by the U. S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi, have shown an exponential depletion of soil moisture (1959). P. Zinke (1959) experimenting for 10 consecutive years with the San Dimas Experimental Forest lysimeters, came out with similar results: the soil moisture depletion under Coulter pine and barren soil was exponential when plotted against number of days. Similar conclusions were reached by Metz and Douglas (1959). K. Knoerr (1960) also stated that the depletion of available soil moisture was exponential when plotted against vapor pressure deficit times the relative length of day. M. Penka (1956) experimenting with arti-

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ficially prepared and natural soils concluded that the depletion curves “are distinguished by three characteristic phases: an initial phase, approximately linear; a second phase, forming a flexure; and a third, almost horizontal. These phases have been designated as the linear phase, the flexure phase, and the second linear phase.” As Penka describes them, his depletion curves are exponential, although he does not say so. However, he makes the statement that the transitions from one phase of the curve to another appear to be influenced by the quantity of organic matter and, generally, by colloidal substances present in the soil. In the case of sandy soils, the readily mobile capillary water, represented by the first linear phase, passes by way of a sharp curvature into relatively immobile absorptive (capillary) film water; this later is represented by this bend in the curve. Finally it passes into hygroscopic water which is indicated by the second linear phase of the soil drying curves. This sharp curvature that Penka is talking about with regard to sandy soil is what Weihmeyer and Hendrickson describe as range of the PWP. The first part of an exponential curve may be linear, and statistically R can be found to be highly significant especially when the number of soil samplings for that phase is large.

Research under way by the soil physics research section of the Southwest Water Conservation Laboratory, U.S.D.A., A.R.-S., at Tempe, Arizona, shows that the soil water diffusivity obeys the exponential equation. That may explain why in the Veihmeyer’s experiments with plants grown in tanks filled with Yolo sandy loam the moisture depletion is linear, provided the root system of the plant is very well developed and the soil is thoroughly permeated by roots.

Penka furthermore found that the plant growth was not affected during the first linear phase of soil moisture depletion. It was greatly retarded a little after following the flexure phase and completely stopped some half way between growth retardation and permanent wilting points. Proportional to total plant growth the growth during the retardation period was very small. This again may explain Veihmeyer’s findings (1961) experimenting with Guayula plants, in which growth was not affected by the soil moisture content between field capacity and PWP. It seems that plant growth is quantitatively affected only when the soil moisture falls below the permanent wilting point. Such are the conclusions of R. Campbell and R. Rich (1961), who found a linear regression between grass (herbage) production when plotted against number of days the soil moisture content was below the permanent wilting point.

**Methods**

In the annual grassland type of the California coastal range a cluster of three plots, 6 x 6 in. each, was established in 1959 in pastures representing three intensities of grazing: (1) None; (2) Light; and (3) Heavy. The three plots were about 15 meters apart, and the soil was the same for all three.

Each plot was divided into 225 little squares (40 x 40 cm), five of which were selected at random and used for soil moisture sampling. The procedure was repeated seven times throughout the year. From each little square a profile sample was taken; this was divided into four depth segments: (a) 0-10 cm; (b) 10-24 cm; (c) 24-40 cm; and (d) 40-90 cm. The soil moisture content by weight was determined by oven drying the soil samples at 105-110°C.

The mean values of the five squares per plot in each of the four depths were used for the following analysis. (Some times the number of samples of the deeper soil layer were less than five; small rocks prevented the sampling in that depth from a number of squares.) The distribution of the squares into the seven samplings, made throughout the year from October 1959

![Figure 1. Heavily grazed plot. Soil moisture drying curves by depth during the depletion phase.](image-url)
MOISTURE DEPLETION

Figure 2. Lightly grazed plot. Soil moisture drying curves by depth during the depletion phase.

The soil was a Los Osos clay loam of 80-95 cm in depth, developed on sandstone. It was classified as a non-calcaic brown grassland soil with some rendzina-like characteristics.

Findings-Discussion

Soil drying, following the winter rainy period, which coincided with the main plant growth season, proceeded differently in the three plots subjected to different intensities of grazing. However, drying of the upper 25 cm layer was similar in all three cases (Figures 1, 2, and 3). This seems very reasonable since the root systems of the plants in all plots were equally well developed to that depth. The differences in rate of depletion and in total amount of water lost were due to different depletion rates in the lower soil layers (Figures 1, 2, 3). In the case of the ungrazed plot, the moisture depletion rate was almost equal throughout the whole profile (Figure 3). Soil moisture on July 18, 1960, was unexpectedly high. Only two samples were taken from the lowest layer of 50 cm due to the occurrence of rock in the other three squares, and these were extremely high in moisture. Figure 3 shows this very clearly. Being unable to explain such a phenomenon a series of similar samples was taken during the soil drying period of 1961 (April 14, May 31, and June 20). The data this time, based on five samples,

Figure 3. Ungrazed plot. Soil moisture drying curves by depth during the depletion phase.

 Physical Conditions

The climate of the studied area is typically Mediterranean. The long-term annual precipitation is 595 mm (23.35 inch). During 1959, and 1960 when the present study was carried out, total rainfall was 663.13 mm (26.3 inches) distributed about normally. Ordinarily, temperatures do not vary much during the year; the coldest month (January) averages 9.5°C (49.1°F.) and the warmest one (September) 17.3°C (63.1°F). Temperatures during the period of main plant growth are very even (from 12.9°C (55.2°F) to 15.6°C (60.1°F) based on long term averages).

The vegetation of the three plots was composed primarily of annual grasses and broad leaved species. Some perennial forbs also occurred. In the ungrazed plot only perennial grasses were found in considerable number.

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gave a constant depletion rate in all four soil layers. Therefore, considering the soil moisture sampling of the fourth layer made on July 18, 1960 as biased, a correction was made by extrapolation of the depletion curve (Figure 3, 67.5 cm corrected).

Soil drying in the lower layers of the lightly grazed plot was between the two extremes, but closer to the ungrazed plot. This seems reasonable also, given that the plant roots were well developed under light grazing and yet the shoots had a fair amount of transpiring surface; so they withdrew the soil moisture from deeper layers rather effectively.

Moisture depletion throughout the entire profile (90 cm), as a function of time in days, was found to be of the exponential form in all three cases. This was true for the four depths of the soil profiles (Figure 1, 2, 3), with the exception of the 67.5 cm depth of the heavily grazed plot, in which there was practically no moisture loss.

Analysis of the data demonstrated that soil moisture during the depletion phase could be predicted at any time following the field maximum by the equation

\[ Q_t = Q_0 \cdot e^{-kt} \]

where: \( Q_t \) — soil moisture depth in mm at time \( t \) in days

\( Q_0 \) — soil moisture depth in mm at time 0, field maximum.

The rate of depletion varied with grazing intensity. The constant \( k \) was found to be .00421, .00925, and .00683 for the heavily, lightly, and ungrazed plots, respectively (Figure 4).

In the heavily grazed plot evapotranspiration losses by the dominant annual plants (mainly bear clover and Red-Stem filaree) were intense but, because of the continuous mutilation of areal parts and the consequent reduced root mass and length, those losses were considerably reduced considering the whole soil profile. In contrast, the evapotranspiration losses from the lightly grazed plot were the greatest with the fast growing and intensively transpiring annual plants. On the other hand, evapotranspiration losses were smaller on the ungrazed plot because the growth and activity of perennial grasses in the composition were delayed in the spring as compared with annuals. The drying period was consequently longer due mainly to the activity of the deeply rooted grasses. Soil moisture depletion was eventually complete even in the lowest layer (Figure 3).

Following the period of intense plant growth, which coincides with the time the soil moisture is close to the PWP (beginning of June for lightly grazed plots and July for the protected ones), the rate of soil drying was very low. It increased gradually from the heavily to the lightly and ungrazed plots. In the case of heavy grazing the depletion was
Table 1 Rates of soil moisture depletion.

<table>
<thead>
<tr>
<th>Degree of Grazing</th>
<th>Soil Moisture at Field Maximum</th>
<th>Rain During Depletion Period</th>
<th>Depletion Constant Rates k</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent of Total Maximum 112 mm</td>
<td>Without Adding</td>
<td>Adding</td>
</tr>
<tr>
<td>Heavy</td>
<td>401</td>
<td>112</td>
<td>27.9</td>
</tr>
<tr>
<td>Light</td>
<td>576</td>
<td>112</td>
<td>19.3</td>
</tr>
<tr>
<td>None</td>
<td>570</td>
<td>112</td>
<td>19.6</td>
</tr>
</tbody>
</table>

Due only to evaporation losses. (The same rate constant was found for the summer evaporation losses from barren soil in the depth of 3" by P. Zinke, 1959). The presence of still living and deeply rooted perennials in the lightly grazed and ungrazed plots, on the other hand, caused some transpiration losses. These losses were slightly greater under no use, whereas the constant rates k were comparatively higher (Figure 4).

During the soil moisture depletion period in 1959-60, scattered showers amounting to 112 mm were received on the experimental plots from March 15 to May 31. Those showers did not affect or disturb the constant rates of the exponential depletion. Apparently, when the showers were received, the actual rates of soil moisture depletion were temporarily increased to a level corresponding to a higher soil moisture content, but very soon afterward the rates returned to the long period constant rate. The same explanation has been given by others (U.S. A.E. Exp. Station 1959).

Figure 5 shows the constant rates k of soil moisture depletion when rain for the period is added to the soil moisture storage losses between samplings. It is important to notice that even in this case the depletion curves keep the exponential form. The calculated increases of the rate constants are proportional to the percent of soil moisture loss increase, as affected by the addition of the rain received during the depletion period. Table 1 shows the respective figures. With the exception of the lightly grazed plot, the percent increase of the rate constants is very close to the percent increase of evapotranspiration losses as affected by the rain.

Conclusions

1. Soil moisture depletion in this study followed an exponential form; it was proportional to the soil moisture available to plants. (Qt = Qo . e-kt, where Qt is the amount of water at time t, and Qo is initial water content.)

2. In Mediterranean climates soil moisture can be accurately predicted at any time following the field maximum soil moisture, which coincides with the end of the winter rainy season. Special studies can be conducted for the purpose of determining local constant rates k.

3. Given that plant growth stops when soil moisture is close to the permanent wilting point, the prediction of that point several months in advance is of great value to range operators. They can so determine, with good approximation, the green forage season on their range, and consequently make necessary provisions for keeping their livestock healthy. Marketing provisions and supplemental feeding arrangements made ahead would tend to avoid economic losses.

4. It might also be possible, by conducting new studies for the purpose of correlating available soil moisture content with the water content of the green plant material to develop formulas for proper range supplemental feeding. Knowledge of the water content of range herbage in relation to its bulk and finally to actual nutrient content may help greatly in developing a better balanced daily ration for high producing livestock.

Summary

A study was conducted in annual type grassland in the Berkeley Hills, California, to check soil moisture depletion rates.

Soil moisture depletion was found to follow the exponential form (Qt = Qo . e-kt, where Qt is the amount of water at time t, and Qo is the initial water content). This says that the rate of depletion is proportional to the soil moisture available to plants.

The rate of soil moisture depletion varies with the intensity of grazing. The constant rate k was found to be .00421, .00925, and .00683 for heavily, lightly, and ungrazed plots, respectively.

LITERATURE CITED


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An Appraisal of the Loop Transect Method For Estimating Root Crown Area Changes

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One of the most serious problems confronting the range technician, administrator, and user alike has been the lack of a suitable quantitative method for evaluating range condition and trend. Because of the heterogeneity of the flora on most ranges, the amount of sampling required to obtain a good estimate of the population with available techniques has been large.

Range technicians are constantly striving to improve their sampling techniques, and one of the most noteworthy efforts in this direction has been made by the Forest Service (Parker, 1951). As described by Parker this technique incorporates many ideas from other measurement methods and has been designated the "3-step Method." Step 1 of the 3-Step Method involves the use of a loop three-fourths of an inch in diameter to record hits on vegetation, litter, rocks, and other items. It is with this loop procedure that the present study is concerned.

The data obtained from the loop readings are intended to serve as benchmarks for future readings. Presumably, the changes recorded in the loop readings for a specific item over a period of time, coupled with other extensive wide-scale estimates, are indicative of trends. The reliance which the observer can place on his conclusions regarding trends depends largely on the magnitude of differences recorded by the loop and on his knowledge of and experience with the vegetal type under consideration.

Because the loop readings constitute an important part of the 3-Step Method, it is essential to have some knowledge of the sensitivity of the loop in detecting changes. Several observers have reported on investigations designed to test this matter of sensitivity. Parker (1955) used belt transects on which he counted plants of the rhizomatous sweet sagebrush (Artemisia discolor).

1. The author was at the Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Ogden, Utah, when this study was made.