Forage and Water[1]

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The subject of forage and water is indeed a broad topic, and for purposes of this discussion I shall restrict my coverage of the subject to the forage produced on non-irrigated and non-cultivated lands; in other words, to the ranges and forests that are sometimes classed as wildlands.

Vegetation of any sort may affect water in three principal ways. (1) It may intercept a portion of the rain or snow that falls and either temporarily or permanently keep it from reaching the ground, (2) it plays a role in the retention of water and soil, reducing runoff and erosion and, (3) it uses water directly in the growth process. I shall examine each of these effects briefly. Extensive timber stands or even windbreaks may modify the climate to some extent but forage probably has little or no effect on climate and I shall not go into that phase of the problem.

Water Use

One of the major studies of the amounts of water used by various kinds of plants was made at the University of Arizona during the period 1931 to 1936 (McGinnies, 1939). Water consumption of a number of forage grasses, as well as of several desert trees and shrubs was measured in this study. The results were expressed as the ratio between water used and the dry weight of aboveground plant material produced. Thus, the figures do not represent actual water usage. Neither do they indicate water use by the various species under field conditions of various degrees of water stress. Water was added to the cans in which the plants were growing whenever they indicated a weight loss of 1.5 kilograms. "A constant and uniform moisture supply was maintained through the year" As a uniformly mixed lot of soil with a moisture equivalent of about 12 was used in all cans, essentially the same amount of moisture was lost from each can before water was added.

The perennial grasses were clipped periodically; annuals were clipped at the end of their life span. Shrubs and trees were harvested "when they became too unwieldy to handle."

Although the grasses that were studied were all native to the area, they were divided into the following three "geographical" groups

1. *Desert Grassland*
   Rothrock grama
   Curly mesquite
   Slender grama
   Black grama
   Santa Rita threeawn
   Poverty threeawn
2. *Plains Grassland*
   Blue grama
   Hairy grama
   Sideoats grama
3. *Southern Tall Grasses*
   Tanglehead
   Cottongrass
   Feathergrass

It was concluded that the water requirements of the perennial grasses were fairly uniform; also, that there was less difference between the geographical groups than within the groups. Winter annuals were about as efficient in their use of water as the perennial grasses during the same season. This could be expected, however, since these annuals make all of their growth during the winter, while the perennial grasses make most of their's during the summer. Summer annuals were more efficient than perennials, but this would appear due to the fact that these annuals make their entire growth during a few weeks when temperatures are high.

The most significant fact obtained from the study was that the trees and shrubs produced much less dry matter on a given amount of water than either the annuals or the perennial grasses. Mesquite, for example, required almost five times as much water as Rothrock grama. Other shrubs tested, all of which were very efficient (though slightly less so than mesquite) in their use of water, were jojoba, Mormon tea, burroweed and catclaw. Only foothill paloverde approached the grasses in efficiency and even this tree was somewhat less efficient than the perennial grasses.

Craddock (1954) cites water-use figures obtained from four kinds of cover in central Utah. The results were expressed in terms of pounds of forage produced per acre-inch of water by each kind of forage. Smooth bromegrass produced most efficiently with 350 pounds, Kentucky bluegrass was next with 218, timothy was third with 135, and a mixture of weeds, largely dandelion and sweetsage, produced the least with 80 pounds. Craddock suggests that information of this sort might be useful in meeting certain objectives of watershed management. For example, when maximum forage production is the primary objective, a high-forage-producing

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species such as smooth bromegrass might be planted. Or, when high forage production is not of paramount importance, and more runoff (though still with erosion control) is desired, a species such as Kentucky bluegrass might be used. A cover of weeds on the other hand, that produces little forage and provides poor erosion control, would seem to have no place in any watershed management program.

Fredricksen (1938) measured the water used by native prairie vegetation near Lincoln, Nebraska, and compared it with that used by a field of alfalfa. He found that the alfalfa used 72.5 percent more water daily than the native vegetation. Each of the two kinds of vegetation used about the same amount of water to produce a given weight of dry matter. Weaver and Crist (1924) in a somewhat similar study, found that alfalfa used approximately 30 percent more water than a stand of upland prairie vegetation.

Studies on the Sierra Ancha Experimental Forest in southern Arizona (Anonymous, 1953), although not providing specific figures on water use, do furnish interesting relative data from a chaparral-grassland area. For example:

1. The amount of water lost from bare soil by evaporation was nearly as much as that lost by plants, plus evaporation.
2. Shrubs used more water than grass.
3. Water was used by plants at different times during the year, depending upon when they were growing and/or when water was available for use.
4. Shrubs and half shrubs used water most heavily in the spring and again during late summer.
5. Perennial grasses used little water until late summer, primarily during August and September.
6. Winter annuals used little water during the winter, hit a peak for about six weeks during the spring, and then tapered off to none for the balance of the year.

Blaney, Taylor and Young (1930) made a study of evaporation and transpiration losses from chaparral in the San Bernardino area. They concluded that "out of a total of 32 inches of natural and artificial rain during the 1927-28 season, 27 inches were lost by evaporation and transpiration." Facilities did not permit determination of the actual amount lost by transpiration as contrasted with evaporation. It is significant to note, however, that approximately 84 percent of the total precipitation was lost as water vapor.

At a second location, all of the precipitation that fell during the three successive years 1927-28, 1928-29 and 1929-30 either evaporated or transpired. Again, these two sources of water loss were not separated. As a result of their studies the authors concluded: "A seasonal rainfall of less than nineteen inches is usually consumed by the brush cover before any portion of it reaches the ground water." In contrast with this, a total of 10 to 12 inches was utilized by a cover of weeds and grass. The brush cover involved in this study, therefore, apparently used 7 to 9 inches more water than the weeds and grass.

In the same study, measurements were made of the consumptive use of water by native vegetation along stream channels. During the 30-day period from April 28 through May 27 there was a total water loss of 12.9 acre-inches per acre. This was three times the amount lost from a free-water lake surface. The vegetation in this instance had ample water available and, as a consequence, the rate of loss was presumably higher than would be the case during periods of water stress. However, even in the Sonoran desert of the Southwest, soil moisture is adequate over extended periods to permit unrestricted loss by transpiration.

Reliable measurements of moisture used by individual trees or by whole forests are very difficult to obtain. One study that attempted to get information of this sort was made in southern California (Anonymous, 1940). Streamflow was used as an index of water use in this instance. By comparing the flow from similar, adjacent watersheds, one of which supported riparian vegetation of alders, sycamores, bay, oak, and an understory of herbaceous species, and another that had been cleared of vegetation, water use of the plants was calculated. It was determined that water consumption by the plants amounted to 45 inches per acre during the 6-month summer period of 1931.

In a somewhat similar study Croft and Monninger (1953) recorded annual evapotranspiration losses in an aspen-herbaceous type of 18.70 inches, 14.83 inches where the aspen had been removed, and 11.21 inches on bare ground. More than half of the total loss, therefore, was as evaporation from bare ground.

Forage plants such as tules *(Scirpus)* and meadow grass, that grow in a high water table where their roots may be immersed in water much of the time, appear to transpire only slightly more water than is evaporated from an open water surface (Young and Blaney, 1942). A Colorado study indicated that during the growing season from June to November consumptive use by tules was 126 percent and by meadow grasses 118 percent that of evaporation from open water. It should be kept in mind that these figures are for the 6-month growing period. Similar data, but for a 12-month period, obtained at Victorville, California, showed that a stand of tules used only 95 percent as much water as evaporated from an open pan.

A somewhat similar study was conducted in central New Mexico. In this investigation cattails were found to use 63 percent more water during a 4-month growing period than evaporated from an open water surface, and sedges 18 percent more. Saltgrass and willows used only 57 and 46 percent as much respectively as was evaporated. It would seem that removal of these kinds of vegetation from these study areas would have resulted in a reduction of water loss essentially equivalent to the amounts transpired.

Veihmeyer (1951) reviews the observations of a number of workers on the effect of different kinds of range vegetation on runoff and streamflow. In this review he cites Croft as saying that "deep-rooted aspen trees take more water from the soil than shallow-rooted herbaceous plants. Cutting aspen trees and leaving only herbaceous plants increased the amount of water available for streamflow." The herbaceous cover on the other hand was as effective as the aspen in preventing erosion. Replacement of deep-rooted plants by shallow-rooted ones is suggested as one method of increasing streamflow.

Veihmeyer *(idem)* also cites the farming practice common in some parts of the West of summer fallowing or letting the land lie idle in alternate years, thus conserving the moisture that would otherwise be lost as transpiration. Even with this practice, moisture continues to be lost by evaporation from the soil but, as the fields are kept free of weeds, none is lost as transpiration.

Veihmeyer *(idem)* studied the effect of removing brushy vegetation in a California chaparral-covered area and permitting natural revegetation to grasses. He found that soil moisture losses were in proportion to depth of rooting of the vegetation and its persistence through the growing season. Shallow-rooted or short-lived grasses used much less moisture than the deeper-rooted shrubs. He concluded that transpiration was the principal cause of soil moisture loss below the surface layer.

Veihmeyer (1953) used soil moisture records from burned and unburned California brush ranges as an indication of relative amounts of water used by brush as compared with grasses and forms. He obtained no specific data on the actual amounts of water used by the different kinds of vegetation. He did conclude, however, that (1) "losses by evaporation directly from the soil surface are small compared to transpiration," and (2) "water use by grasses and forbs was less than by the brush."

It should be noted that the first of these conclusions is not in agreement with observations made in a similar type in southern Arizona (Anonymous, 1953), where it was concluded that almost as much moisture was lost by evaporation alone as by evaporation plus transpiration.

Except in a general way it is difficult to summarize the results of these studies on water use. It is evident that the information on water use is at best inadequate and often completely wanting. For example, almost nothing is known on the amounts of moisture that our range plants use. Neither yearlong or seasonal use figures are available on individual species, although some general relative data are available on water use by vegetation types. Although large amounts of water are lost as transpiration, much is lost also as evaporation from the soil. Evaporation losses may be greater than those from transpiration or they may be less, the relative importance of these two depending on amount and kind of vegetation and amount of bare soil exposed.

The volume of water lost as transpiration depends on total leaf surface, the length of time the leaves remain green and amount of available water. As one or all of these increases, so too, does transpiration. Thus, evergreen trees and shrubs use more water than broadleaf herbs and these, in turn, than grasses. Perennials, which remain alive throughout the year, use more moisture than annuals, which may grow actually for only a few weeks.

The plant cover of a watershed may be modified with the end in view of conserving moisture to produce additional overland flow or for storage in the soil and eventual use as spring, well or stream water. The amount that can be stored depends first of all on amount and distribution of precipitation and, when it falls as snow, on the rate of snow melt and depth of frost in the soil. Secondly, it depends on the water-holding capacity of the soil layer. This is in part a function of soil depth.

On the basis of a study made in southern California (Anonymous, 1955), workers at the California Forest and Range Experiment Station concluded that in the mountains of southern California (1) brush used more water than grass, (2) forbs used almost as much, and (3) of these growth forms, grass used the least. These facts were related to soil-moisture storage in the following terms: (1) Where the soil mantle was less than 4 feet deep the storage capacity was inadequate to make any appreciable difference regardless of plant cover, and no additional water could be stored if the vegetation were converted from brush to grass. (2) Where soils are deeper than 4 feet and in years when rainfall is adequate to wet the soil below this depth, additional water would be made available for storage if the brush were converted to grass, but only if the growth of forbs was prevented.

One hydrologic viewpoint of soil is that it constitutes a storage reservoir for water. As water is removed by evaporation or transpiration the soil pore spaces are emptied and become available for storage of additional water. Relatively little water is lost by evaporation; the principal losses are from transpiration (Lassen, Lull and Frank, 1952). Consequently, anything that alters the rate of transpiration has a major effect on the capacity of the soil to store additional water.

Transpiration ceases when plants are killed; it may be markedly reduced when they are seriously injured. This reduction stems from two causes, as pointed out by Lassen, Lull and Frank; (1) there will probably be a reduction in total leaf area or transpiring surface, and (2) since development of the root system depends upon maintenance of an adequate photo-synthetic area, total root volume may be decreased. As a consequence, fewer and shorter roots will be available to draw water from the soil. As water movement within the soil is extremely slow, absorption by roots is highly dependent upon their being where water is available. On overgrazed ranges, therefore, where grass roots have been stunted by heavy use, moisture removal by transpiration is greatly curtailed. The extent to which root growth may be reduced by grazing was shown by Biswell and Weaver (1933). In this study typical perennial prairie grass dominants were clipped at 14-day intervals during the summer. When the roots were examined at the end of this period, 5 of the 9 grasses had a total root volume less than 5 percent that of those that were unclipped. This drastic a reduction would undoubtedly have a marked effect on the ability of the plants to extract water from the soil.

Water use by vegetation may be sufficient to affect spring and stream flow to a marked degree. Biswell and Schultz (1958) studied the effects on springs and streams of removing trees and brush in Madera and Lake Counties, California. Shrubs and low-growing trees were the principal plants in the areas, though annual weeds were abundant in season. The flow was measured from one creek and nine springs. Conclusions of the study were in part as follows: "Where the spring water is dependent on the local watershed, it is not unreasonable to expect some increase in flow as a result of manipulation of the plant cover." This conclusion was based on flow measurements from three springs that served as a check, and on which there was no manipulation of cover, and from six nearby springs on which the cover was either burned or cut. During the period of study the trend of flow from the untreated springs was consistently downward. On 5 of the 6 where cover was manipulated, there was an immediate increase in flow, but with continued drought the flow often soon decreased again. In some instances the increase was immediate and large. Grapevine Spring, for example, immediately increased from 1.5 gallons per day to 360; Tank Spring from 198 to 486; and Willow Spring from 31.5 to 122.

The authors concluded that the increase in spring flow that might be expected would vary considerably, "depending on such factors as the size of the watershed, density and kind of plants on the watershed, type and depth of soil, geologic formation, amount of rainfall, and source of water."

Interception

Rather large amounts of precipitation, both snow and rain, may be intercepted by vegetation. These amounts are roughly proportional to the denseness and volume of the plant cover. In dense evergreen forests or brush much of the snow may never reach the ground but may evaporate from the leaves and twigs. Dense vegetation with a large surface area of leaves and branches may intercept much of the precipitation that falls as rain and may retain it until it has evaporated. Portions may run down the stems and ultimately reach the ground, but in light, scattered showers this amount will usually be small.

Grass, as a forage species, intercepts little snow as compared with a stand of lodgepole pine. Dunford and Niederhof (1944), concluded that interception of snow in dense pine stands is probably responsible for the loss of more moisture than either transpiration or evaporation from snow or ground surfaces.

The earlier classic Wagon Wheel Gap study in Colorado also indicated much the same relationship (Bates and Henry, 1928). Both of these studies also showed that aspen, which can be classed as a forage species, intercepted only slightly more of the total annual precipitation than grass.

Croft and Monninger (1953), in a more recent study of aspen forest in Utah, found that 15.8 percent of the annual precipitation was intercepted in an aspen-herbaceous cover type and 10.5 percent where the aspen had been removed and the herbaceous cover remained. Runoff down the stems does not seem to have been measured.

A California chaparral study (Rowe, 1948) indicated that about 19.5 percent of the precipitation was intercepted by the brush but that most of this ultimately reached the ground by flowing down the stems. Only 5.2 percent was lost from the stems and leaves as evaporation. When the vegetation was destroyed by burning there was a great increase in runoff as flash floods following heavy rains and a decided decrease in infiltration capacity of the soil. The slight reduction in evaporation losses was much more than offset by the increase in runoff losses. These flood waters were heavily laden with silt and debris. In contrast, runoff from the vegetated area was negligible, and the water was clear.

Rowe, Storey and Hamilton (1951) studied the rainfall interception effect of chaparral and ponderosa pine in California. They found that in a total of 50 storms measured, 81 percent of the precipitation reached the ground directly, 8 percent reached the ground as stemflow, and 11 percent was intercepted by the canopy and evaporated.

Veihmeyer (1951) also measured interception in California chaparral. His figures are based on differences in amount of precipitation caught in rain gages placed in the open and under bushes on adjacent plots. They do not measure water that may have run down the stems. The precipitation thus intercepted amounted on the average to 20.11 percent of the annual rainfall. Note that this figure is in essential agreement with the 19.5 percent obtained by Rowe (*loc. cit.*) but that Rowe found that only 5.2 percent was lost as evaporation, the balance reaching the ground by running down the stems.

Little information is available on interception of precipitation by vegetation other than trees. One study, however, designed to measure interception by corn, alfalfa, and clover, was conducted in Iowa (Anonymous, 1940). This study showed that approximately 22 percent of the rain that fell was intercepted and never reached the ground in the stand of corn, 21 percent was intercepted by alfalfa and 18 percent by clover. In light rains the fraction of the total that was intercepted was greater than during heavy rains. Because of this, it was concluded that these kinds of vegetation would have little effect on the control of floods resulting from severe storms.

Runoff and Sedimentation

No phase of the forage-water picture has received more attention than the relationship between ground cover and the runoff-erosion complex. Since biblical times and before, destruction of forage by grazing animals has exposed the soil to erosion and excessive runoff. Many studies have been made to determine the relationship between various types of plant cover and the runoff-erosion complex.

Kind and amount of vegetation as related to runoff and sedimentation was investigated on the Wasatch Plateau near Ephraim, Utah (Forest Service, 1950). This study showed that area A, with a 16 percent ground cover, yielded 4 to 5 times more storm runoff and sediment than adjacent area B, which had a cover of 40 percent. Area A was subsequently protected from grazing and parts of it were reseeded and parts planted to shrubs. The ground cover increased from 16 percent to 40 percent. The moderate grazing on area B was continued during this period. These treatments reduced the runoff from area A by about half.

Subsequently, area B was heavily grazed while area A was totally protected. The ground cover on "A" increased to 50 percent, and the runoff decreased to ½ to ⅓ of that from "B". In this instance, ground cover of forage plants clearly played a decisive role in controlling the amount of water that was lost as runoff.

Runoff as affected by ground cover was also studied in an Illinois experiment (Gard *et al.*, 1943). In this study the forage on different plots was modified by variable grazing intensities and by fertilizing. Runoff from a 2-day rain of 4 inches was measured from one plot that had been fertilized but severely grazed and from a second that had been similarly fertilized but moderately grazed. Thirty percent of the rain ran off from the overgrazed plot as contrasted with 4 percent from the one that had been moderately grazed. The water that did not run off soaked into the soil with the result that soil moisture in the moderately grazed plots was higher than those that were heavily grazed.

In a Utah study Croft and Monninger (1953) found that surface runoff was negligible in a stand of aspen (0.16 percent of the total annual rainfall) and not much more (0.30 percent) where the aspen had been cleared and only the herbaceous cover remained. In contrast with these low figures, 5.45 percent ran off from bare soil areas.

The investigators concluded that removal of the aspen, *i.e.* leaving only the forage species, provided essentially as good protection against erosion as when the trees were present, yet saved about 13 percent of the total annual precipitation falling on such sites that would be added to natural streamflow. Although removing all the vegetation would have saved 27 percent, erosion losses were severe and would not permit consideration of this more drastic treatment.

Southern Arizona measurements made during a 50-hour period during which 6.0 inches of rain fell, showed that 7.7 percent ran off as surface flow from a well-grassed watershed, 17.6 percent from a similar watershed with fair cover, and 16.3 percent from one with poor cover (Anonymous, 1953). The difference between the last two figures does not appear to be significant, and their similarity is probably due to factors other than cover that affected the runoff.

Soil erosion losses from these same watersheds are of interest. Soil losses for the good, fair, and poor covers were respectively as follows: 44, 188, and 1,114 tons per square mile.

When vegetation is destroyed by burning or other means there may be an increase in surface runoff and erosion. This is particularly true if the destroyed vegetation is not replaced by a substitute ground cover. Veihmeyer (1950) set up a study in which he burned the brush on a number of plots and kept a second set as untreated checks. Some of the burned plots became largely covered by a stand of grasses; on others there was a mixture of grasses, forbs, and resprouted brush. He found that in no case had burning adversely affected the infiltration capacity of the soil. This observation was based on the fact that in the burned plots, "the entire soil profile of the primary soils, and to the depth of the sampling of the secondary soils, was wetted as soon as that in the covered plots. In all but a few cases, the soil in the burned plots was raised to its field capacity before that in the adjacent covered areas."

In these experiments, burning did not seem to have any particular effect on runoff. In some instances runoff was greater from the burned than from the unburned areas, in others the reverse obtained. The average for the entire period of study, which covered several calendar and 71 plot years, indicated essentially the same runoff under each treatment.

Similarly, there were no appreciable differences in erosion under the two treatments. A yearly average of 8.2 pounds of soil was lost from the unburned plots as opposed to 9.3 pounds from the burned. In terms of soil depth these amounts correspond to 0.00049 and 0.00056 inches respectively.

Summary

Water Use: Water use varies approximately in proportion to (a) length of time a plant is actively growing or is producing a crop of green leaves; (b) depth and extent of the root system; and (c) amount of water available. Thus, trees generally use more water than shrubs; shrubs than grasses and grasses than forbs.

Water efficiency, or dry matter produced per unit of water consumed, is a highly variable figure and one about which little is known. It is highly possible that efficiency for a given species under moisture stress may be quite dissimilar from a figure for the same species where moisture is not deficient. Desert trees appear to be less efficient than associated perennial grasses.

Spring flow may be increased by removal of trees and shrubs from a watershed when the spring flow originates on the treated watershed.

Interception: Large amounts of precipitation may be intercepted by vegetation, these amounts being roughly proportional to denseness and volume of the plant cover.

Grass intercepts little precipitation in comparison with trees and shrubs.

Runoff and Sedimentation: Runoff and sedimentation are in rather direct proportion to forage plant density or ground cover.

A dense stand of brush or trees that intercepts appreciable amounts of precipitation, although not necessarily contributing much in the way of forage, may be highly effective in reducing runoff and erosion.

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