Limits on Western Range Forage Production—Water or Man[1]

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Highlight

Water is generally regarded as the limiting factor in forage production on arid rangeland. If 800 lb. is taken as the water requirement for a pound of range forage, 12 inches as the average precipitation, and 400 lb. as the average forage production/acre, only 12.5% of the precipitation, or 1.5 inches, is used in producing the forage crop. If we estimate that in addition, ½ inch is lost to deep percolation, 1 inch to over-the-surface runoff, and 1 inch to undesirable vegetation, we account for 4 inches. Thus, the remainder, two-thirds of the total precipitation, is lost by evaporation, without benefit to man. The importance of the resource lost by evaporation is discussed in relation to the potential productivity of arid lands.

U. S. history during the 19th century was one of westward movement, characterized by buffalo hunts, Indian wars, cattle kingdoms on the plains, the sod busters, the pony express, the transcontinental railroad and telegraph, barbed wire, and range wars. In the westward migration, largely by people of European descent, there was no background experience to alert them to the low per-acre productivity of the arid West as compared to the humid East. In those days the range was thought of as an inexhaustible resource. That it was not, had to be learned the hard way, and by the time it was learned, much of the range had been seriously damaged.

The interesting, if tragic, story of the western range has been written by many and is common knowledge to all range-oriented people. Interested "outsiders" will get an account of range deterioration in central Texas from Bentley (1898). Barnes (1926) gives a comprehensive and fascinating treatment of the entire western range.

The concept of water as the limiting factor in range forage production developed naturally, once the limits of arid land productivity were realized. All one had to do was note the limited precipitation, compared to the higher precipitation in the Eastern States. Western soils were generally regarded as more productive than those in the East (less leached), and the western climate was less inclined to foster plant diseases. Certainly if the soils and climate were favorable, water had to be the limiting factor.

A written statement cannot alter the facts, and water is the limiting factor in the sense that if more water is provided, production is increased. This is amply borne out by the superior production of crops under irrigation in the West as compared with production under natural precipitation. But it may be profitable to take a fresh look at the water resource in the West and consider it in relation to the plant's need for water.

The intent is not to offer a precise analysis. The available information is too scanty—there are too many gaps. But, on the basis of the information we have, reasonable generalizations can be made. They sum up to a fairly startling picture, and suggest that the limiting factor is not so much water as it is man's ability to intelligently manage the water received.

The Water Requirement of Plants

A considerable body of information has been accumulated on the water needs of plants. For the arid West, Briggs and Shantz (1914) and Shantz and Piemeisel (1927) conducted some classic work at Akron, Colorado early this century. They found that different species of plants transpired from less than 300 lb. to over 1000 lb. of water/lb. of dry matter produced. Those with relatively high water needs included smooth brome (*Bromus inermis*), western wheatgrass (*Agropyron smithii*), and alfalfa (*Medicago sativa*). Those with a low water requirement included sudangrass (*Sorghum sudanense*), blue grama (*Bouteloua gracilis*), and buffalograss (*Buchloe dactyloides*). Crested wheatgrass (*Agropyron desertorum*) was in an intermediate position. Dillman (1931) verified the water needs of the above species in studies conducted at Newell, South Dakota and Mandan, North Dakota. McGinnies and Arnold (1939) reported the water requirement of many Arizona range plants. They also obtained values from less than 300 to over 1000. Water requirement studies have generally been conducted for short periods only, when growth is rapid. But some information is available for extended periods. McGinnies and Arnold (1939—Table 22) report for 12 warm season grasses a mean summer water requirement of 489, and a mean yearlong requirement of 567. On a yearlong basis these grasses used 16% more water/unit of dry matter produced than they did during the summer growing season.

Similar data have not been found for cool season grasses in the Intermountain Region. Since these grasses begin growth very early in the spring and enter dormancy when soil moisture is depleted, it does not seem likely that the difference in water requirement during the growing season and for the entire year

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would be greater than for the warm season grasses. It might well be less.

For the purpose of this study, 800 lb. will be used as the average water requirement for forage species on the western range.

Water Received Per Acre

If we assume the average acre of arid western range receives 12 inches annual precipitation, some allowance will be made for the small part of the total range that is at high enough elevation to receive appreciably higher precipitation, and also that this high altitude range generally shares the water with timber and has a short growing season.

Annual precipitation of 12 inches amounts to 2,613,600 lb./acre. Taking the plant's water requirement at 800 lb., this 12 inches would produce about 3200 lb. dry matter. What is the actual yield?

Forage Yield Per Acre

Average range depletion in 1936 (U. S. Forest Service, 1936) was estimated to be 52%. Thus, the western range was producing about half the forage it did in the virgin condition before occupation by the white man. Many excellent range improvement practices have improved the productivity of parts of the arid range since 1936 but the total area is so large that the response to improvement practices has not changed the overall productivity greatly. The areas where improvements have been effected are small, and largely offset by other areas where continued brush encroachment, erosion, and mismanagement have either lowered productivity or prevented improvement.

One of the present glaring deficiencies in our agricultural census is that it is almost totally lacking in meaningful statistics on the western range. But we know with reasonable accuracy the numbers of domestic and game animals in the West and the percentage of their total feed provided by the range. From these data we estimate 20 million animal units fed yearlong. If we take 728 million acres as the area of the western range (U. S. Forest Service, 1936) and assume an animal unit need of 20 lb. dry matter/day, the grazed forage crop would average 200 lb./acre. A policy of take half and leave half would indicate a total production of about 400 lb./acre.

Water Used to Produce the Forage Crop

An average production of 400 lb./acre is one-eighth of the potential of 3200 lb./acre arrived at earlier. This means that only about 12½% of the precipitation received, 1½ inches, is transpired or otherwise used to produce the forage crop. What happens to the remaining 87½%?

Avenues of Water Loss

Water is lost from the range by four obvious avenues: (1) that transpired by undesirable vegetation; (2) that lost by over-the-surface runoff; (3) that lost by deep percolation; and (4) that lost by evaporation from the soil or vegetation.

Undesirable Vegetation

Even with widespread herbicide use, the total amount of brush or other unwanted vegetation on western rangelands is probably increasing. The dramatic spread of mesquite in the arid Southwest (Buffington and Herbel, 1965) during the last 100 years is only one indication of the deterioration of the range resource and usurpation of the available water by unproductive vegetation. As much as 2 to 3 hundred million acres of arid range lose more water to unwanted vegetation than is transpired by the forage crop. On possibly a hundred million of these acres grass has been crowded out, and unwanted vegetation uses all the water. These hundred million acres must be cleared of the existing vegetation and seeded if they are again to become productive.

A reasonable estimate is that somewhere between ½ inch and 1 inch of water is lost to unwanted competing vegetation from an average acre of western range. This also is an extravagance we cannot afford. Corrective measures can be highly profitable to the operator as evidenced by many examples from all parts of the western range.

Over-the-Surface Runoff

Runoff occurs where the rate of precipitation or snowmelt is greater than the rate of water intake by the soil. It is thus the high intensity storms or rapid rates of snowmelt, that are responsible for most of the runoff. Runoff is generally intensified as slope of land increases. That runoff from rangeland occurs has been abundantly demonstrated. The amount of runoff is not easily determined.

Committee Print No. 21 (1960) of the Select Committee on National Water Resources, U. S. Senate, contains information on water yield from various vegetation types. Semiarid grass and shrub, comprising 330 million acres, is estimated to yield .1 to 1.0 inch/year to streamflow, averaging .4 inch. Pinyon juniper, with 61.4 million acres yields a range from 0 to 3 inches, averaging .5 inch. These types are in rainfall ranges of 5 to 20 and 10 to 20 inches, respectively. Langbein et al. (1949) calculated that the Great Basin (137 million acres) had an average runoff of slightly over 1 inch. Most of this originates on high elevation watersheds. Many runoff studies have been conducted on watersheds ranging in size from small plots to several square miles, and they also contribute substantially to our awareness of the importance of runoff. They indicate runoff from less than .1 inch to over 1 inch/year. Projection of these data to larger areas is hazardous because of the heterogeneity of the range and the tremendous influence of local conditions on the fate of the water. The size of the watershed alone has a severalfold effect on measured runoff. This is strikingly illustrated by research in Israel (Evenari et al., 1961) where a system of runoff farming in the Negev, believed to have been in use as early as the 8th to 10th centuries B. C., has been reconstructed. Watersheds as small as ¼ acre yielded 15 to 20% of total precipitation (there only 4 to 6 inches annually) while large catchment areas yielded only 1 to 5% of the precipitation. The Israeli studies suggest that we might look more closely at some of our desert areas to determine their potential for water harvesting for intensive production on selected adjacent sites. Waterspreading, practiced on many range sites (Monson and Quesenberry, 1958) is a crude form of water harvesting as practiced in Israel. A consideration of the available information leads us to the conclusion that a conservative estimate of loss of water from arid rangeland by runoff would be ½ inch annually and a more liberal estimate, 1 inch.

Deep Percolation

For much of the arid range, precipitation doesn't penetrate the soil below the reach of roots. Where it does, this water eventually contributes to stream flow or springs and is important downstream to man. Deep percolation occurs mainly on the higher elevation—higher precipitation rangelands where the value of the land may be greater as watershed than as range for forage production. On these watershed lands a healthy vegetative cover may be highly important for erosion control, and may contribute significantly during a very short summer season to the feed of game and domestic animals.

Although there are significant percolation losses at higher elevations, we estimate an average of not more than ½ inch a year lost to on-site productivity by deep percolation on an average acre of the western range.

Evaporation

Loss of water by evaporation is taken as the remainder, after the parts required to produce the forage crop, and those lost by the other avenues enumerated above are accounted for. We have the following:

Source of loss or use	Estimated inches	Percent of Total
Forage production	1.5	12.5
Undesirable vegetation	1.0	8.3
Runoff	1.0	8.3
Deep percolation	.5	4.2
Total accounted for	4.0	33.3
Remainder (evaporation)	8.0	66.7
Total	12.0	100.0

Since our estimations for losses to deep percolation and brush and weeds are generous, it is a reasonable assumption that the remainder, 8 inches, or 66.7% of the estimated 12-inch precipitation is lost by evaporation, primarily from the soil. Some percentage of the precipitation will be intercepted by the vegetation and never reach the ground, and another fraction will only wet the soil surface. These are not believed to be a very large part of the total precipitation. In winter-rainfall regions these fractions will be very small, but on the plains and other areas of summer precipitation, loss by evaporation of water that never reached the soil or penetrated it may be considerable. The potential for increased plant production by water now lost by evaporation primarily from the soil is so great that we cannot continue to permit it to go unexploited. If we are ever to realize the true productive capability of arid lands, we must learn to prevent, or sharply limit this loss.

Preventing Loss of Water by Evaporation

Experience up to the present time in reducing evaporation from the soil surface has not proven sensational, to say the least. Wheat farmers in many parts of the arid West practice alternate cropping and fallow. The water saved during the year of fallow is very important, but is a relatively small percent of the precipitation received. Bracken and Cardon (1935) from studies at Nephi, Utah, concluded that 30% of the precipitation was conserved by summer fallow. Mathews and Army (1960), from a survey of many locations in the summer rainfall region of the Great Plains, report less than 20% of the annual precipitation saved by fallow. Judging from wheat fallow, it is not likely that clean cultivation between rows of grass would appreciably lower loss of water by evaporation.

A thick vegetative mulch would lower loss of water by evaporation, but would also intercept precipitation that would otherwise enter the soil. Some vegetative mulch is highly desirable, but one thick enough to severely restrict evaporative loss is not likely to greatly increase water available to transpiration.

Sheets of plastic might conceivably cover the ground between rows of grass, and these would constitute a highly effective barrier to evaporative loss, but none are known that could be laid at a tolerable cost and that might withstand the hooves of grazing animals or the wheels of harvesting machinery. Unless lightproof, weed growth under the plastic would be difficult to control.

In recent years hexadecanol has been shown to restrict evaporation from small bodies of water. Anderson et al. (1963) tested hexadecanol on soil and concluded that on the basis of their procedures, hexadecanol did not offer great promise as an evaporation retardant. Olsen et al. (1964) applied heavy rates of hexadecanol to soil. When it was mixed into the surface ¼ inch, water loss was reduced 43% and the treatment was effective during the 14 months of the study. Hexadecanol is nontoxic to plants, does not break down readily, and when applied at the soil surface causes a rapid drying out, creating a diffusion barrier to water loss by vapor transfer. However, in earlier studies with corn, yields were depressed, apparently a result of lowered nitrate availability. If yields are going to be depressed, even though considerable water is saved, hexadecanol does not appear to be the answer.

In a greenhouse study, Keller (1954) found that a pea gravel mulch at the rate of 500 g/6-inch-diameter container (120 tons/acre) reduced evaporation by 66% compared to a bare soil surface. This was under conditions where bare soil lost only 23% less than a free water surface. The outside atmosphere in the West is probably drier than the greenhouse atmosphere but with drier soil beneath the gravel the saving should be greater (van Bavel et al., 1963).

There is insufficient evidence at present to recommend spreading 120 tons pea gravel on each acre of range, but some range soils contain sufficient gravel to provide an adequate mulch if that in the top 6 or 8 inches were brought to the surface. This might be accomplished with some modified version of a potato digger. Paltridge (1955) has shown that for some forage species cultivated rows 3.5 feet apart have some advantages over closer spacings. How would finer or coarser gravel, such as might be available, affect evaporative loss? How long would any evaporation retardant hold up under grazing by livestock or mechanical harvesting? What other substances might be more effective mulches or even cheaper, than gravel? Many questions arise which cannot now be answered. Much research is needed.

We can estimate what the consequences of a gravel mulch might be. If two-thirds of the water lost by evaporation could be diverted to transpiration, and if loss from runoff and by unwanted vegetation were stopped, production on our average acre would be increased nearly 4.9 times, or 1950 lb. additional forage, for a total of 2350 lb./acre. Under such conditions, rather than take half and leave half, we might well leave only about 800 lb. Thus we would harvest nearly 1600 lb. as compared with 200 or almost an eight-fold increase. In an environment providing moisture for such a level of production, use of fertilizer would be highly profitable and would further increase the efficiency of water use. The species used for range seeding would need to be reexamined.

Once the problem is recognized, and the potential benefits from its solution realized, industry would become seriously involved. Fabrication chemists may ultimately solve the problem by developing a substance which works like a one-way window. In cooperation with gravity when mixed into the surface soil it would let moisture move downward, but wouldn't let it come back. In addition to increasing forage for livestock on our arid rangeland, such a substance would greatly enhance the value of arid lands throughout the world, and would increase manyfold their contribution toward properly feeding the expanding world population.

Immediate Goals

Until some such revolutionary development, which may be one of the most significant scientific achievements of the next 100 years, every presently known range improvement practice needs to be put to work. Of particular immediate importance are measures which restrict or prevent erosion, so that we do not further undermine the inherent productive capability of arid soils. Erosion control is good range management. Brush control is good range management if there is an understory of grass or if grass can be established. Range seeding is good range management on potentially productive sites that cannot reasonably be restored to productivity by methods short of seeding. Regulating grazing, both time and intensity, with the welfare of the forage plants in mind, as well as the livestock, is good range management. Research has contributed greatly to our understanding of these and other good range management practices, and will continue to enhance the productivity of our arid lands. The opportunity for improvement remains great. Much additional research is needed to lower the cost of range improvement practices and to increase the likelihood of their success. For example with presently known methods we can control most brush and runoff—though if these processes were less expensive they would be greatly extended. By controlling brush and other unwanted vegetation and runoff, we could more than double per-acre production without doing anything about loss of water by evaporation. In the future years, breeders will provide better forage plants and these will be introduced in range seeding programs. There is no reason to consider this potential any less than with corn, rice, wheat, sorghum and other major food crops. Up to now, the impact of plant breeding has hardly been felt on arid rangeland.

Long Range Goals

An average acre of western range having some brush infestation, suffering also from average loss of water by runoff, produces, in round numbers, 1 to 2 lb. beef/100 tons precipitation received.[2] Research has shown that as little as 6 lb. of grass will produce 1 lb. of beef. If 800 lb. of water will produce 1 lb. of grass, 100 tons precipitation/lb. or 2 of beef is an efficiency of only about 2.5 to 5%. (Bonner, 1961, points out that 2% is the approximate efficiency with which plants utilize the energy of the sun—another fertile field for investigation.) Thus, in round numbers, and realizing some assumptions have been made, we have the potential to increase the production of our arid rangeland as much as 20 to 40 times. We have already determined that the water provided, if all were used by the plants, would increase production eight-fold (from 400 to 3200 lb./acre). To reach a 20 to 40-fold increase would thus require an increase of two and a half to five times the efficiency with which the forage was utilized. This may be unrealistic in practice because livestock must eat yearlong, but since our

[2] Suggested by Dr. Gerald W. Thomas in an address at the February, 1968 meeting of the Range Society at Albuquerque, New Mexico.

theoretical ideal was 6 lb. grass/lb. of gain, we may assume that at present, on the average, somewhere between two and a half and five times this amount, or 15 to 30 lb. grass are consumed per lb. gain. Based on a need of 20 lb./day per animal unit, this would amount to ¾ to 1½ lb. gain/day, yearlong. This appears to be a reasonable spread. Hyder and Sneva (1963) and Sneva (1967) have shown that forage can be managed so that livestock use it more efficiently. Their studies are only a beginning.

With the potential productivity of the arid range conservatively placed at several times the present level, perhaps it is time to quit rationalizing that water is the limiting factor and turn the spotlight on man.

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