Water Yield as Influenced by Degree of Grazing in the California Winter Grasslands[1]

LEONIDAS G. LIACOS

Service of Forest Technical Works, (Y.D.E.M.), Thessaloniki, Greece.

The increase of water produced by our watersheds is becoming more and more important. Particularly in countries with a deficiency in usable water, this problem constitutes one of the most important preoccupations of the administrators.

Almost always the problems of soil erosion and flood control are closely related to that of water production. Usually, increase of water yield and soil erosion-flood control are quite controversial items. Furthermore, in some countries one of these two items is the predominant one and the decisive factor in policy making. There are also cases (countries of Mediterranean-like climate) in which the critical thing may be the timing of water production throughout the year rather than the absolute increase of good quality water.

Long experience and detailed studies have established firmly the belief that the form and type of vegetation on the watersheds as well as how they are managed greatly affects water yield, soil erosion and flood control.

Numerous comparative studies have been made and a great deal has been written to date about the beneficial effect of forest, brush and herbaceous vegetation on water yield, timing of water production, soil erosion, and flood control.

The attention of research

[1] *The present study was carried out under the sponsorship of the National Academy of Sciences, Washington, D. C., Worldwide Research Program to which I express my acknowledgement.*

FIGURE 1. Soil profile taken with the aid of a metallic box.

workers has been mainly concentrated on the relative effect of the forest versus brush versus herbaceous vegetation, and there has been particular interest in the effect of forest manipulation upon water production, soil erosion and river regimen.

Relatively little has been done about the effect of grassland management practices upon water yield. Attention has been mainly centered around the hazard of soil erosion and range deterioration caused by overuse or misuse of grass cover by grazing animals. Particularly poor is the literature on annual rangelands, a characteristic formation of the Mediterranean climate.

The purpose of the present study was to contribute a better understanding of degree of grazing effects in the annual type upon soil, water storage and use by plants, and the opportunities for increased water yield.

Methods

In the Berkeley hills, just east of San Francisco Bay in California, a cluster of three experimental plots, 6 x 6 m each, was established in October 1959, one on range heavily grazed since at least 1925, another on range grazed lightly since 1928, and the third on range not grazed since 1935.

The plots were about 15 m apart and each was divided into 225 sub-plots 40 x 40 cm. In each large plot seven groups of five subplots each (35 in total) were randomly selected for seven soil samplings taken throughout the year 1959-60, with the provision that no two subplots would be touching on a side. From each subplot four soil samples were taken with an auger, representing four depth layers: a) 1-10 cm; b) 10-25 cm; c) 25-40 cm, and d) 40-90 cm.

On the same date, seven times during the year, 5 subplots x 4 (depths) soil samples were taken from each plot for soil moisture determination. At the second sampling, December 4, 1959, an additional series of soil samples was taken for soil moisture equivalent determination. In August complete soil profiles were taken with the apparatus shown in Figure 1. At the same time samples were carefully taken for bulk density determinations by the zinc chloride solution method (Perry 1949).

Water retention by mulch (dead plant material), left on the ground the year before, was evaluated. This is called rain interception in the following discussions.

Mulch collected separately from each of the three plots was used for a laboratory study as well as field study. In the laboratory, mulch proportional to the amount found on the ground for each plot, was placed in a 3 mm soil sieve with filter paper in the bottom and then thoroughly wetted by watering it for 30 minutes. By weighing the mulch before and after watering the

FIGURE 2. Wooden frame with mulch for testing rain interception losses.

percent by dry weight water interception was determined. The mean of three replications was used as the interception figures.

The field test was run to simulate natural conditions. Plastic screen of 5 x 5 mm mesh was put on three 40 x 40 cm frames. These were painted for waterproofing. After taking the tare of each screen, mulch was placed proportionally to the amount of mulch in each plot and the top of the frame was covered with a net of plastic string. So prepared, the frames were placed in the respective plots in direct contact with the ground (Figure 2). Twice, early in the morning after continuous night rains, the frames were weighed in the field. The difference of dry and wetted mulch weights was used to determine the percent field rain interception.

The weight of mulch cover in each plot was determined by collecting it very carefully from 40 x 40 cm squares. The means of five such squares taken on October 24, 1959 and May 17, 1960 were used in making a regression (mulch decomposition) line, relating the amount of mulch to time of year.

Local Climate and Soil

The climate is typically Mediterranean. The annual precipitation, all rain, amounts to 595 mm (23.35 inches, Berkeley long term average). This comes mainly during 8 months, October to May. Summer through the month of September is dry almost every year and herbaceous vegetation, except some late growing weeds and perennial grasses, is dry. The soil moisture, at least in the upper part of the profile, falls to or below permanent wilting percentage (PWP). This occurs at a depth of 15 to 25 cm and evaporation is very intensive during the summer.

Temperatures are very even throughout the year. Normal mean in Berkeley is 9.5°C (49.2°F) for January, the coldest month, and 17.3°C (63.2°F) for September, the warmest month. In the main growth period, (March through May) temperature varies from 12.9°C (53.9°F) for March to 15.6°C (60.1°F) for May.

The soil is a clay loam residual developed on sandstone in the Los Osos series. It is classified as a non-calcic brown grassland soil with some rendzina-like characteristics. The relief, on all three plots, is a gentle north facing slope (8 percent). The soil forming factors seem to have been the same for all three plots, with the exception of the different degrees of grazing by domestic livestock during the past 35 to 50 years.

Findings-Discussion

Soil Properties

Soil profile characteristics (Table 1) indicate the effects of grazing during the last 30 to 40 years on soil development.

Under protection from grazing, the undisturbed vegetation, microflora and microfauna of the soil apparently contributed to a granular structure and increased porosity of the soil. There also was evidence of an increase in infiltration, percolation and water storage capacity. These factors in turn affected vegetational changes, maybe a secondary succession towards the perennial grass climax. Thus, that portion of the soil profile which is actually utilized by the plants is deep under protection from grazing. The abundant roots go down more than 90 cm., permeating the soil very extensively throughout the profile and so improving greatly the porosity and aeration of the soil. At the same time the improvement of infiltration and percolation has increased the clay migration.

Under heavy grazing the soil

Table 1. Soil Profile Characteristics.

Soil Profile Plot	Layer from - to cm	Bulk density	Soil Structure	Color	pH
Ungrazed	0-10	1.40	Granular weakly block .5-1.5 cm	light brownish gray	5.4
	10-40	1.50	Blocky angular in squares .5-4 cm	light brownish gray	5.5
	40-72	)	Blocky angular 2-7 by 4-14 cm	light gray	6.0
	72-80	)2.00	Lightly blocky angular 2-5 cm	light olive gray	6.2
	80-90	)	Blocky angular 2-4 cm	light gray	6.5
Moderately to lightly grazed	0-18	1.50	Granular weakly blocky .5-4 cm	light brownish gray	5.5
	18-48	1.65	Blocky angular columnal 2-3 by 4-8 cm	light brownish gray	5.4
	48-80	1.60	Blocky angular columnal 3-4 by 10 cm	olive gray	5.6
	80-90	......	Decomposed bed rock (sandstone)	olive	6.0
Heavily grazed	0-15	1.60	Blocky more or less rounded 1-5 cm	grayish brown	5.7
	15-40	1.55	Blocky angular columnal 3-6 by 10 cm	grayish brown	5.6
	40-75	1.25	Blocky angular 2-4 by 10 cm	dark grayish brown	5.7
	75-90	......	Bed rock more or less decomposed	olive brown	6.4

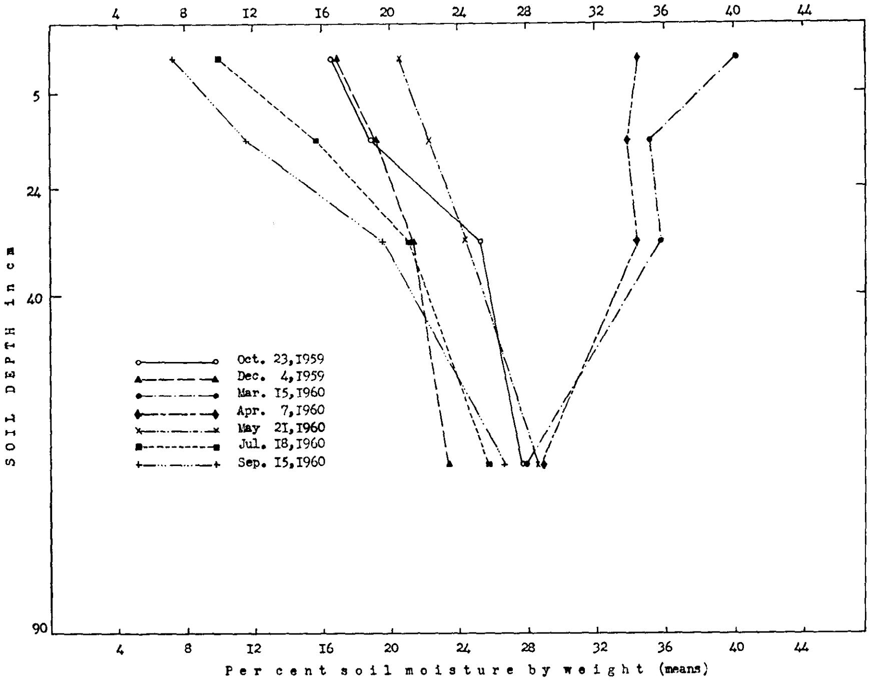

FIGURE 3. Heavily grazed plot. Soil moisture profiles throughout the hydrologic year 1959-60.

is shallower. Plant roots decrease greatly with depth. Trampling by the animals increased the bulk density of the upper layer. Water infiltration and precolation rates were apparently lowered and aeration was reduced. Earthworm activity was markedly lower than in ungrazed soil. The uppermost layers were darker in color, apparently because of the slow plant material decomposition process.

Under light grazing the situation was something between, but closer to the plot under no grazing (Table 1).

Soil Water Regime

The differences in soil physical properties were correlated with striking differences in the water regime in the three grazing treatments. Figures 3, 4, and 5 show the soil moisture profiles throughout the year for all three plots examined.

Under heavy grazing soil water storage was always low; its field maximum, reached by March 15 (end of the winter rainy season), amounted to 403 mm. The reason for that low moisture content must be the low rate of water infiltration and percolation. The soil moisture in the lower half of the profile practically did not vary during the year. It remained around 26 percent by weight. The water percolation was so slow that an increase of only about 3 percent was noticed. On the other hand the amount of plant roots was so small in the lower half of the profile that a moisture depletion of only 6 percent occurred.

The soil moisture content in the upper layers varied greatly, from 40 percent (very close to moisture equivalent=field capacity) at the end of the rainy season, down to permanent wilting percentage which was calculated to be around 15 percent. However, the moisture content of the uppermost layer went down to about 7 percent as a result of the intensive summer evaporation; this low soil moisture content of the uppermost layers—lower than the PWP—was a common phenomenon in all three plots. Moisture content of the third layer (24-40 cm) on October 23, 1959, was high. This was probably due to the good water storage during the first big storm

Table 2. Rain interception Losses by Mulch.

	Heavily grazed plot				Lightly grazed plot				Ungrazed plot			
		Interception Loss				Interception Loss				Interception Loss		
Month	Mulch	by evapotranspiration	Total amount	Period of water surplus	Mulch	by evapotranspiration	Total amount	Period of water surplus	Mulch	by evapotranspiration	Total amount	Period of water surplus
	Kgr/ha	— — — mm	— — —		Kgr/ha	— — — mm	— — —		Kgr/ha	— — — mm	— — —	
September	688	0.182			1,399	0,369			3,837	1.013		
October	688	......			1,399	......			3,837	......		
November	600	......			1,250	......			3,580	......		
December	525	0.257		)	1,050	0.277		)	3,262	0.861		)
				)				)				)
January	455	1.676		)	855	2.662		)	2,965	4.977		)
				)2.959				)5.055				)9.270
February	332	0.694		)	662	1.400		)	2,585	2.140		)
				)				)				)
March	315	0.332			470	0.716			2,250	1.292		
April	245	0.195			275	0.219			1,920	1.163		
May	165	0.129	3.465		68	0.954	5.697		1,555	1.072	13.018	

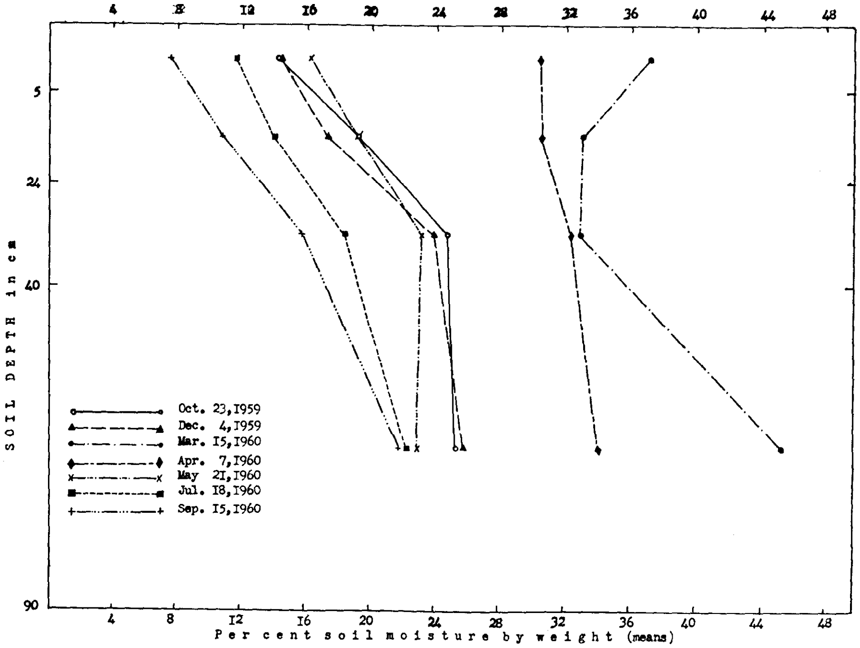

FIGURE 4. Lightly grazed plot. Soil moisture profiles throughout the hydrologic year 1959-60.

in September (Figure 6), facilitated by the deep fissures in the soil late in the dry season. The shallow rooted new seedlings had used the moisture of the upper layer only thus far, but the roots had not yet reached the 24 cm depth.

The soil water regime of the ungrazed plot was very much different, and soil moisture changes were equally drastic throughout the whole profile (Figure 5). A range in variation of 24 percent was found in all soil layers. The unexpectedly high moisture content in the lowest layer in May and July 1960 was due to a very high clay content in two of the five samples taken for each of them.

The ungrazed plot had high infiltration and percolation rates on the one hand, and heavy use of the stored moisture by abundant, deeply rooted plants (a considerable number of perennials) throughout the whole profile on the other hand. This can very easily explain the differences in its soil water regime and that of the heavily grazed plot.

As can be expected, the soil moisture regime of the lightly grazed plot showed a very similar picture. Soil moisture varied throughout the whole profile, but not as much as in the ungrazed plot (Figure 4). It is important to note, however, that in the lowest layer the percent soil moisture was not lowered very much, remaining around 23 percent at the end of the dry summer season. Thus, the lightly grazed plot was similar to the ungrazed one in soil moisture accretion and similar to the heavily grazed plot in soil moisture depletion. The very high soil moisture content in the lowest layer in the March sampling was due to the clay content of samples.

Rain Interception

Studies of rain interception by grasses, especially annual grasses, are rather limited (Burgy and Pomeroy 1958; Burgy 1958; Clark 1940). In a recent one, W. D. McMillan and R. H. Burgy (1960) found that rain interception by green grass leaves did not represent a net loss. Differences in evapotranspiration losses were very small under dry or wetted grass canopy (dry or wet leaf). In contrast, interception represented a net rain loss in the case of dry or wetted dead plant material.

Table 2 shows the amount of mulch in each plot for every month from September to May. The amount of mulch for Sep-

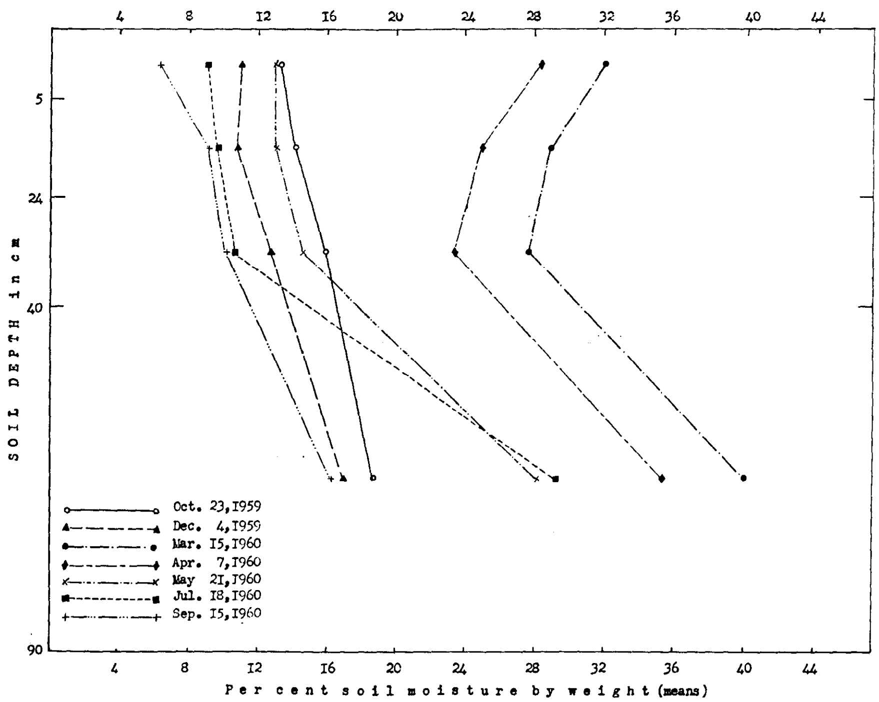

FIGURE 5. Ungrazed plot. Soil moisture profiles throughout the hydrologic year 1959-60.

tember was considered equal to that of October.

The mulch rain interception losses as a mean of the laboratory and field tests were found to be (percent by dry weight of mulch) as follows:

a. Heavily grazed plot 271 percent
b. Lightly grazed plot 260 percent
c. Ungrazed plot 261 percent

These figures are close to the results of other investigators (Kittredge 1955).

Based on the findings of McMillan and Burgy (1960) and taking as rain interception percentage for all three plots, 264 percent of dry mulch weight (mean of the above three figures), the net interception losses were calculated for each individual storm; the time interval between storms was taken into consideration for such calculations. The monthly net interception loss is given in Table 2. The net rain interception loss was about 10 mm greater in the ungrazed plot than in the heavily grazed one, and 7.5 mm greater than in the lightly grazed plot. (Although lightly grazed the cattle took a considerable amount of mulch during the early winter grazing).

Water Balance

It would appear from this study that intensity of grazing has a great effect upon the hydrology of a watershed. Although soil moisture differences may occur even at greater depth than the 90 cm (3 ft.) considered here, we can evaluate the hydrologic effect of grazing and its degree of intensity.

Figure 6 shows the trend in soil moisture content or water yield (depth of water in mm) throughout the year for each plot. The period of soil moisture accretion coincides, mainly, with the winter season of precipitation. Certainly, there is a variability from year to year but this does not greatly affect the general picture of soil moisture trend.

During the year 1959-60, when the experiment was carried out, the distribution of rain was very close to the "normal" one, based on weather record means, particularly during the period of soil moisture accretion (Figure 7).

Most of the rain comes during the period of seed germination and low growth. This is the period of soil moisture storage. By the middle of March, in general, soil reaches its maximum field moisture content, which is, we can say, the field capacity. Following the middle of March plant growth is very fast and a depletion of soil moisture begins. The small and scattered rain storms in the spring are ineffective in recharging the soil. All the rain coming during that period can be used by the plants at a faster rate than it is received.

In order to check the findings from field samplings, a daily water balance has been computed according to Thornthwaite's method (C. N. Thornthwaite and J. R. Mather 1957). The results of such water balance computations were rather close to those of actual sampling (Figure 6). It is important, I think, to notice that in the face of soil moisture depletion the method of Thornthwaite gives a smaller rate than the actual one in the case of the lightly and the ungrazed plots; in contrast this rate is higher in the case of closely grazed plots. In the face of soil moisture accretion the rate does not vary; the small differences, especially in the level of the accretion lines, are the result of similar variation in the rate of depletion during the late fall and early winter period (Figure 6). The low rate of soil moisture depletion in the early dry winter period in the case of the lightly grazed plot is actually due to heavy grazing by calving cows during that period, which

Table 3. Water yield under different intensities of grazing.

	Calculated by simple arithmetic							Computed by Thornthwaite's daily water balance method		
	Soil Moisture Storage									
Plot	On Dec. 4, 1959	On March 15, 1960	"Accretion" Difference in storage between the two dates	Actual evapotranspiration losses between dates	Rain received between the two dates	Water yield	Surface runoff	Gravitational water yield	Total water yield	Differences in water yield because of biased computed soil moisture content at the beginning of soil moisture accretion period
	(mm)									
Heavily grazed	266	401	135	98	468	235	59	226	285	+12
Lightly grazed	328	578	250	116	468	102	....	158	158	+33
Ungrazed	237	570	333	89	468	46	....	136	136	− 8

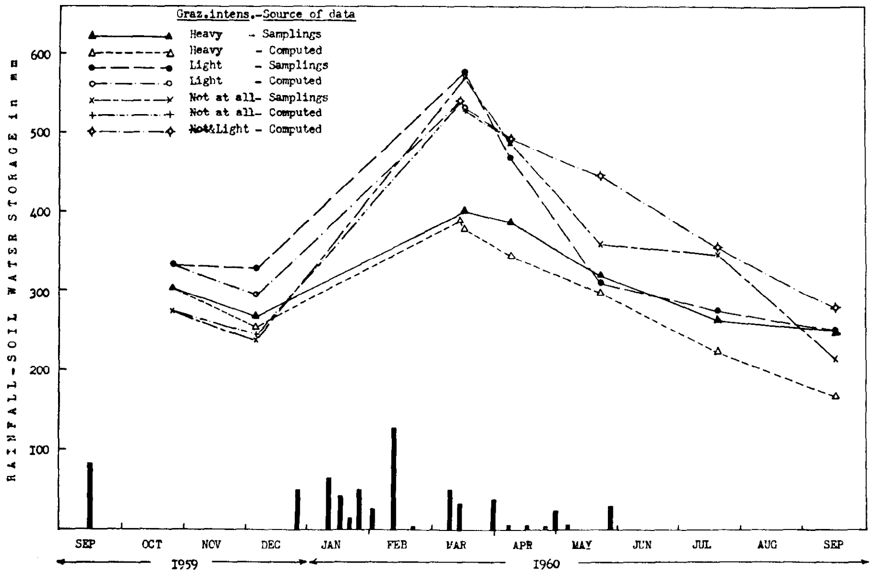

FIGURE 6. Rainfall and soil moisture trend throughout the year.

supports the statement made above.

Thus, we can say that the Thornthwaite's method is not a good one for water balance calculations in the case of grasslands subjected to different intensities of grazing. It can only be used for a general and average picture of the problem.

Coming back to the case of soil moisture accretion, we can see quite striking differences in the water regime from one plot to another. By substracting from the total rain received from December 4, 1959 to March 15, 1960 (period of soil moisture accretion) the difference of soil moisture between the above dates of sampling plus the evapotranspiration losses, one can easily find the water yield from each of the three plots. Table 3 summarizes the computations. For evapotranspiration losses, those computed by the Thornthwaite's method were taken. Although it may be argued that a portion of the soil water found on March 15 could be classified as gravitational water produced gradually later in the spring, yet nothing was added, considering the soil, on that date, to its field capacity. The soil samples were taken on March 15, and the last big storm was received on March 12, in other words, allowing some time for drainage. Table 3 also shows (see also Figure 7) the water yield from each plot according to the computations by the Thornthwaite's method. It must be noticed that, if the daily water balance computations had as starting point the sampling of Dec. 4, 1959 and not Oct. 24, 1959, the water yield would be increased for the heavily and lightly grazed plots and decreased for the ungrazed one; the last column of Table 3 shows the respective amount of increase or decrease in water yield.

The intensity of grazing, therefore, greatly affects the hydrology of our watersheds. Heavy grazing is responsible for more water production in areas similar in physical conditions to those of the Berkeley hills. The present study thus shows that the greater the grazing intensity the higher the water production. The figures in Table 3 also show that under heavy grazing a considerable amount of water produced down hill comes in the form of surface run-off (Martin and Rich 1948). That means that soil erosion hazard increases with the intensity of grazing, which is in accordance with the already well established experience. Although we have not noticed any erosion of soil on the heavily grazed plot, one feels that such a phenomenon will inevitably occur, especially when heavy grazing is practiced on steeply sloping grasslands. However, in case of heavy montmorilionite clay soils where shrinkage occurs, deep fissures open in the soil during the dry summer period which accept the rain water of the first storms in the fall very rapidly and so re-

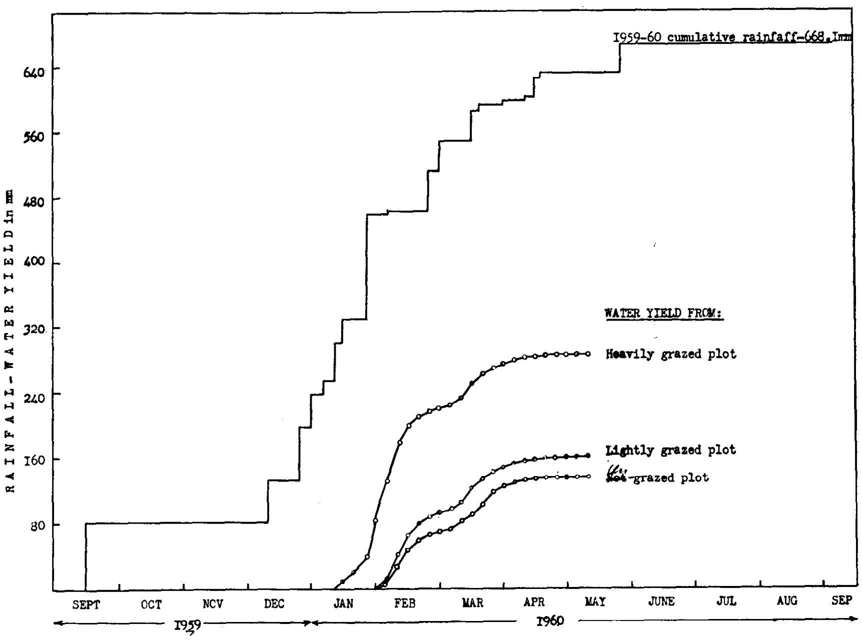

FIGURE 7. Water yield as related to degree of grazing by livestock.

duce greatly the erosion hazard on the soil surface. In that case internal soil erosion takes place during which soil particles are detached from the side walls of the open fissures and transported down to the bottom; this kind of erosion is not damaging. Following the first rains with favorable soil moisture and moderate temperature, many new seedlings (facilitated partly by the fact of low mulch cover), provide a very dense cover, especially when grazing is excluded for an adequate period of time. It is evident that in case of light and shallow soils, soil erosion with the first storms, when the soil is barren and with very poor litter cover, becomes the key problem in land management practices. In the case of the present study the surface run-off from the heavily grazed plot came during the main rainy period, when a good new growth provided cover to the soil. But the heavy trampling of the soil by livestock must reduce considerably the infiltration and percolation rates, thus causing the surface run-off.

The reduction of the infiltration and percolation rates is responsible, in the case of the heavily grazed plot, for the very low storage of rain water in the lower soil layer (Figure 3). On the other hand, the low, almost insignificant withdrawal of soil moisture from this lower layer by the shallow rooted plants does not create great opportunities for new storage.

The soil properties of the lightly grazed plot present good conditions for storage; the infiltration and percolation rates being high, facilitate the storage of the rain water even in the lowest soil layers. The more effective use of this water, on the other hand, by relatively deeper rooted plants creates good opportunities for water storage (Figure 4).

Finally, the soil water storage opportunities in the ungrazed plot are really very high, especially because of the total depletion of the soil moisture at the end of the summer by deeply rooted perennial plants. The soil moisture by the end of the dry season is at the P.W.P. (Figure 5). The extremely high infiltration and percolation rates prevent surface run-off. Thus, all the rain water is stored in the high storage capacity soil profile.

The total water production is also affected differently by interception losses. Those losses are significant in the case of the ungrazed plot (Table 2). Thus, if we took the most representative results of the simple arithmetic calculations (Table 3) and subtracted from them the respective mulch interception losses (from Table 2), the water yield from each plot would be as follows:

a. Heavily grazed plot 232 mm
b. Lightly grazed plot 97 mm
c. Ungrazed plot 33 mm

It is very reasonable to believe that under moderate grazing the water yield would be between 97 and 232 mm.

Thus, range managers have a very good tool in their hand to affect water production in quantity and quality.

Conclusion

1. When heavy grazing is practiced for a long time, the soil forming process is slowed down. Light or no grazing results in deeper soil, with good physical properties and high soil moisture storage capacity.
2. Water yield is many times greater from grassland under heavy grazing than under protection, when the major part of the rainfall comes during the winter period which coincides with very low growth.
3. The amount of net interception loss is about 6 mm higher in grasslands under no grazing than under heavy grazing and 4 mm higher than under light grazing.
4. The gravitational water does not seem to vary much with the degree of grazing.
5. The degree of grazing may be a practice for regulating water run-off. Protection from grazing may reduce the run-off and control the floods in small watersheds. In contrast, increased grazing intensity may be the right practice for increased water yield.
6. Where light to moderate grazing is implied, intense early winter grazing cuts down the evapotranspiration and reduces the soil water storage opportunity, resulting in increased water yield during the period of soil moisture accretion.
7. Thornthwaite's method gives higher evapotranspiration losses in the case of closely grazed grassland and lower in the case of ungrazed grassland.
8. Range managers must pay more attention to range influences and particularly to watershed management as affected by grazing management.

Summary

An experiment was established on the Berkeley hills, California, in 1959-60 to check the effect of the intensity of grazing upon the water balance.

Heavy grazing for more than 35 years had resulted in a shallower soil than where ungrazed during the same time.

Reduction of infiltration and percolation rates and increased shallow rooted plants, caused by heavy grazing, resulted in a considerable increase of water yield. Against only 33 mm, produced from the ungrazed plot there were produced 97 mm and 232 mm from lightly and heavily grazed plots, respectively.

The net interception losses from dead plant material (litter) were 3, 5, and 9 mm from heavily, lightly and ungrazed plots respectively.

LITERATURE CITED

Burgy, R. H. 1958. Water yield as influenced by watershed management. Pro. Am. Soc. Civil Engineers, pp. 10.

Burgy, R. H., and G. R. Pomeroy. 1958. Interception losses in grassy vegetation. Trans. Am. Geophysical Union, Vol. 39, No. 6, pp. 1095-1100.

Clark, O. R. 1940. Interception of rainfall by prairie grasses, weeds, and certain crop plants. Ecolog. Monogr. 10 (2), Duke University Press, pp. 243-277.

Colman, E. A., and G. B. Bodman. 1944. Moisture and energy conditions during downward entry of water into moist and layered soils. Soil Sci. Soc. Am. Pro. Vol. 9, pp. 3-11.

Kittredge, J. 1955. Some characteristics of forest floors from a variety of forest types in California. Jour. of For. Vol. 53, No. 9, pp. 645-647.

Liacos, L. 1954. Restauration des terrains au-dessus de la limite superieure de la vegetation forestiere — ameliorations pastorales dans les alpes maritimes. Triantaphyore & Sons Co., Thessaloniki, pp. 1-135.

Martin, W. P. and Rich, L. R. 1948. Preliminary hydrologic results, 1935-48, "Base Rock" undisturbed soil lysimeters in the grassland type, Arizona. Proc. Soil Sci. Soc. Amer. Vol. 13, 561-567, illus.

McMillan, W. D., and R. H. Burgy. 1960. Interception loss from grass. Jour. Geoph. Research, Vol. 65, No. 8, pp. 2389-2394.

Perry, E. P. 1942. A simple method of determining the apparent density of soil aggregates. Pro. Soil Sci. Soc. of Amer., pp. 409-411.

Thornthwaite, C. W., and J. R. Mather. 1957. Instructions and tables for computing potential evapotranspiraiton and the water balance. Drexel Inst. Techn., Publications in Climatology, Vol. X, No. 3, pp. 1-311.