Runoff from Pastures in Relation to Grazing Intensity and Soil Compaction[1]

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ONE of the chief difficulties encountered in the management of pastures is low production during hot, dry periods, particularly in July and August. This is especially true of the more intensively grazed pastures on the steeper and drier slopes. Results of studies with nitrogen fertilization, clipping treatments, and irrigation on a Kentucky bluegrass-white clover sod (14)[3] have shown that mid-summer productivity is closely associated with an adequate supply of available soil moisture. One of the conditions which affect the supply of soil moisture under actual pasture conditions is the amount of incident rainfall absorbed through the soil surface during the spring and summer months. Obviously, that portion of the rainfall which is lost as runoff is largely a loss of potentially available soil moisture.

It is now generally recognized that rainfall intensity is very important in determining the amount of runoff and erosion. In Pennsylvania, as well as in many other states, the most intense or heaviest rainstorms occur during the summer months. These storms very frequently occur during prolonged periods of high temperature, when soils are driest, and the need for moisture to maintain adequate plant growth is at a maximum. The precipitation records of the Soil Conservation Experiment Station, State College, Pa., reveal that for the 11 year period, 1935–45, inclusive, the percentages of the average total monthly rainfall which fell at rates of 1 inch or more per hour for a period of at least 15 minutes were as follows: January to April, 0%; May, 47%; June, 49%; July, 54%; August, 45%; September, 31%; October to December, 0%.

Runoff from pastures, except during periods of rapid snow melting on a frozen soil surface, is generally considered to be of little practical significance. The results of pasture runoff experiments in Ohio (5), New York (12), New Jersey (11), and Vermont (13) would tend to substantiate this view point. However, the results of investigations in Illinois (18), Missouri (16), Pennsylvania (2), and Virginia (7) show quite appreciable runoff losses from intensively grazed pastures during the summer. Soil losses from pastures, unless actively eroding gullies are present, are generally very small.

Most pasture management studies, in which runoff losses were measured, have dealt with means of influencing the amount of vegetative cover or forage through fertilization and controlled grazing.

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[3]Figures in parenthesis refer to "Literature Cited", p. 957.

Although the effect of soil compaction by cattle trampling has often been mentioned in accounting for the decreased productivity of continously, intensively grazed pastures, little direct evidence has ever been offered to support this contention. Auten (3, 4) and Chandler (6) studied the effects of grazing in forests and woodlands and showed that under grazed conditions the surface soil was more compact and had lower water-absorbing capacity than the ungrazed forest soils.

The structure of pasture soils has not as yet received much direct attention from investigators. That the structure of grazed and ungrazed grassland soils is different is very evident upon examination. The dense, compacted surface condition of many pasture soils is quite different from the porous, granular condition of undisturbed meadow or grassland soils. The greatest difference between the structure of grazed and ungrazed soils occurs at, or near, the surface. The compacting effect of cattle trampling appears to be most pronounced in the first inch of surface soil. From the standpoint of infiltration and runoff, it is this layer in the profile of well-drained soils which is most important in determining their absorptive capacity for rainfall (8). Of all the physical characteristics which regulate the moisture relationships in soils, noncapillary porosity is generally considered to be of the greatest direct importance in determining infiltration capacity and permeability (9).

The purpose of this investigation was to determine the amount of water lost as runoff during the summer from variously treated pastures on different soil types, and by analysis of the physical properties of these soils to attempt to determine the reason for this water loss, if and when it occurred.

EXPERIMENTAL PROCEDURE AND METHODS

Water was applied with a type F rainfall simulator at a rate of 1.4 inches per hour for a period of 60 minutes to plots 6 by 12 feet. Runoff was measured, and infiltration rates were calculated as the difference between the amount of water applied and that lost as runoff. Since it was impossible to make the initial runoff measurement on all sites at comparable soil moisture contents, a so-called "wet-run" was made 24 hours after the initial run. Additional wet-runs were made following clipping and removal of any mulch of dead plant material. These trials were conducted during a summer of unusually high rainfall, however, and in most cases the moisture content of the soil was rather high at the time the initial run was started. Thus, there are insufficient data for satisfactory comparisons of runoff from initially dry soil as compared with that from soil at field capacity. In the few comparisons that were obtained on heavily grazed pastures, runoff was as great in the initial run as in the corresponding wet-run. The data reported are for the wet-runs.

The mechanical analysis of the 0 to 6-inch soil layer from each site was determined by the modified pipette procedure of Alderfer and Merkle (1).

The volume weights of the 0 to 1-, 1- to 3-, and 3- to 6-inch soil layers were obtained using a sharpened steel volume weight sampling cylinder, 3.3 inches in diameter. Volume weight is expressed on the oven-dry (105° C) weight basis. From three to six separate samples were taken from each runoff site. Agreement between the volume weights of the replicate subsamples was generally very close, indicating that the degree of compaction due to cattle trampling was usually quite uniform. Volume weight samples were taken 24 hours following the wet-run so that the soil moisture content very closely approximated field capacity. Assuming that the soil at field moisture capacity had attained capillary saturation, the capillary porosity was, therefore, equivalent to the volume of water occupying the capillary pores. Assuming the density of this capillary water to be that of free water, the capillary porosity in percentage by volume was calculated from the amount of water contained in the soil at field capacity. Total porosity was calculated on the basis of volume weight of the respective soil layer. Noncapillary porosity was calculated as the difference between total and capillary porosity.

The soil organic matter content of each layer was determined by the chromic acid titration procedure of Schollenberger (15), as modified by Tiurin (17).

The pH values were determined potentiometrically on a 2 to 1 soil-water suspension, using a quinhydrone electrode.

DESCRIPTION OF EXPERIMENTAL SITES

The trials were conducted on Hagerstown clay loams and on Morrison sandy loams on the College farms. Hagerstown soil, derived from limestone, is an excellent agricultural soil when not too severely eroded. The Morrison soil is derived from sandstone interbedded with limestone. It is considered a poor agricultural soil but shows good response to the use of lime and fertilizer.

Ten different grassland conditions were represented in this study, each of which were designated with a site number. A description of the various pasture sites is presented in Table 1. For purposes of comparison, two ungrazed sods and an abandoned pasture area were included. In 6 of the 10 sites investigated, two locations were selected for study within each site area and were designated as replicate a and b. To give some quantitative characterization to the general terms heavy, moderate, and light in designating the intensity of grazing, estimates were made of the percentage of total ground surface which was covered with some form of vegetation whether living or dead. The botanical composition of the living vegetation was estimated. The amount of herbage above 1 inch in height was measured by clipping, and the surface mulch consisting of dead vegetation was removed by hand picking. All of the pasture sites studied were at one time used for the production of tilled crops. Each of the pasture sites except no. 6 had been grazed by dairy cattle for a period of at least 10 years. Site 6 had been plowed and seeded to orchard grass and Ladino clover in 1943.

The results of volume weight, porosity, and organic matter determinations are given in Table 2. The amount of compaction to which the various pasture soils had been subjected is reflected in the volume weight of the 0 to 1-inch soil layer. Compaction also decreased noncapillary porosity and total pore space. This is evident from the high correlation coefficient (–0.81) between volume weight and noncapillary porosity in the 0 to 1-inch soil layer. The compacting effect of cattle trampling seemed to be confined largely to the 0 to 1-inch surface layer, as shown by the difference in volume weight and noncapillary porosity of the 0 to 1-inch and the 1- to 3-inch and 3- to 6-inch layers. The soil on sites 2 and 3 was artificially compacted by walking heavily on the plot when the soil was at a moisture content approaching field capacity. The volume weight of the 0 to 1-inch layer was very much increased by this treatment. In the 1- to 3- and 3- to 6-inch layers the granular structure normally associated with grassland soils remained relatively undisturbed. Noncapillary porosity within these layers was usually very great.

It is not unusual that the organic matter content is greatest in the 0 to 1-inch layer. In addition to the accumulation of decomposed leaves and stems, it is in this 0 to 1-inch layer that the majority of Kentucky bluegrass and white clover roots are concentrated in pasture soils (10).

Mechanical analysis of the 0 to 6-inch surface layer from the sites on Hagerstown soil showed, in general, ranges of 18 to 32% clay, 35 to 45% silt, 20 to 25% fine sand, 3 to 10% coarse sand, and 5 to 10% gravel. The clay content was not correlated with volume weight. Hagerstown subsoil contains 40 to 45% clay. The Morrison soil was found to contain 13% clay, 27% silt, 21% fine sand, 34% coarse sand, and 5% gravel.

The pH determination showed that on all except No. 9 the soil had been adequately limed.

EXPERIMENTAL RESULTS

Runoff losses during 1 hour of simulated rainfall applied at the rate of 1.4 inches per hour ranged from none on sites 3, 7b, 8a, and 8b, none of which had been grazed, to 80% of the water applied on site 1b, a poor sod that was heavily grazed (Table 3). With 80% runoff, the effective rainfall was equivalent to only 0.28 inch.

Except on sites where little runoff occurred, the rate of water loss increased rapidly to a maximum and then remained relatively constant. This is illustrated in Fig. 1 for sites showing wide variations in rate of runoff. On site 1b, as shown in Table 3, the maximum rate of runoff amounted to 91% of the water applied.

TABLE 1.—*Description of the sites investigated.**

Site No.	Percentage surface cover	Botanical composition of surface cover†	Grazing intensity	Percentage slope	Dry weight of clipped herbage, lbs. per acre	Dry weight of mulch, lbs. per acre
			Hagerstown Soil			
1	55	10% white clover 25% Ky. bluegrass 20% weeds	Very heavy	30	None	None
2	90	20% white clover 10% black medic 30% Ky. bluegrass 30% weeds	Moderate	27	518	None
3	100	40% Ky. and Can. bluegrass 60% ground mulch	None Retired 5 years	25	1,070	3,090
4	85	30% white clover 35% Ky. bluegrass 20% weeds	Heavy	21	None	None
5	100	40% white clover 55% Ky. bluegrass 5% weeds	Light	20	710	Thin layer of decomposed manure not removed
6	85	20% Ladino clover 65% orchard grass	Moderate	23	380	None
7	100	45% red clover 55% timothy	None	15	2,900	1,950
8	100	100% orchard grass	None	12	2,530	3,000
			Morrison Soil			
9	50	20% redtop 5% bluegrass 25% weeds	Moderate	17	100	None
10	85	28% white clover 50% Ky. bluegrass 7% weeds	Heavy	17	None	None

*All sites except 2, 3, 9, and 10 are in duplicate.
†Sites 1, 2, 3, and 9 had not received fertilizer; all others had been fertilized.

TABLE 2.—*Soil properties of the sites investigated.*

Site No.	Site description and treatment	Depth of sample, in.	Volume weight	Porosity, %			Organic matter, %
				Non-capillary	Capillary	Total	
	Hagerstown Soil						
1	Bluegrass-clover, heavily grazed, 55% cover	0–1	1.80	6.1	26.0	32.1	2.89
		1–3	1.50	24.4	19.0	43.4	1.83
		3–6	1.26	33.7	18.8	52.5	0.62
2	Bluegrass-clover, moderately grazed, 90% cover	0–1	1.47	19.2	25.4	44.6	3.76
		1–3	1.19	37.7	17.4	55.1	2.53
		3–6	1.22	37.6	16.4	54.0	2.14
2	Same plot as above, trampled by foot	0–1	1.64	8.6	29.6	38.2	3.76
3	Bluegrass, ungrazed for 5 years, 100% cover	0–1	1.09	33.1	25.8	58.9	3.31
		1–3	1.36	25.9	23.8	49.7	2.34
		3–6	1.34	28.3	21.1	49.4	1.83
3	Same plot as above, trampled by foot	0–1	1.41	16.6	30.2	46.8	3.31
4	Bluegrass-clover, heavily grazed, 85% cover	0–1	1.61	9.2	30.0	39.2	4.63
		1–3	1.19	33.5	21.6	55.1	2.42
		3–6	1.28	30.5	21.2	51.7	2.18
5	Bluegrass-clover, lightly grazed, 100% cover	0–1	1.27	18.2	33.9	52.1	4.88
		1–3	1.29	26.1	25.2	51.3	2.13
		3–6	1.53	18.5	23.8	42.3	1.69
6	Orchard grass-Ladino clover, moderately grazed, 85% cover	0–1	1.55	10.9	30.6	41.5	2.57
		1–3	1.41	24.2	22.6	46.8	1.78
		3–6	1.48	22.3	21.9	44.2	1.40
7	Red clover-timothy, cut for hay; corn, oats, wheat, hay rotation; 100% cover	0–1	1.46	24.2	20.7	44.9	2.24
		1–3	1.41	27.2	19.6	46.8	1.89
		3–6	1.41	28.1	18.7	46.8	1.61
8	Orchard grass sod, ungrazed, 100% cover	0–1	1.44	17.7	28.0	45.7	3.15
		1–3	1.33	24.4	25.4	49.8	2.79
		3–6	1.36	22.6	26.1	48.7	2.67
	Morrison Soil						
9	Redtop-weeds, moderately grazed, 50% cover	0–1	1.96	5.1	20.9	26.0	2.06
		1–3	1.49	25.3	18.5	43.8	1.24
		3–6	1.54	24.0	17.9	41.9	0.78
10	Bluegrass-clover, heavily grazed, 85% cover	0–1	1.79	9.6	22.9	32.5	2.95
		1–3	1.54	23.6	18.3	41.9	1.34
		3–6	1.53	24.9	17.4	42.3	0.96

Runoff was greatest on the heavily grazed plots. The average water losses ranged from 33 to 80% on the five heavily grazed plots, 1 to

50% on the six moderately to lightly grazed plots, and 0 to 2% on the five ungrazed plots. In general, clipping the lightly grazed or ungrazed areas greatly increased runoff (sites 2, 5b, 7a, 7b, and 8a). In a few cases little or no water loss occurred even after clipping (sites 3, 5a and 8b). On these three sites, however, the soil was especially well protected. Site 3 had not been clipped or grazed for five years and had accumulated an excellent mulch of dead grass. Even after the mulch was removed, water loss averaged only 6% of the water applied, indicating a high degree of granule stability. Site 5a was covered with about ¼ inch of partially decomposed manure. (Site 5b was only partially covered with a thinner layer of manure.) Site 8b was covered with a heavy mulch of dead grass. In all cases, clipping the herbage and removing any mulch of plant material significantly increased runoff losses.

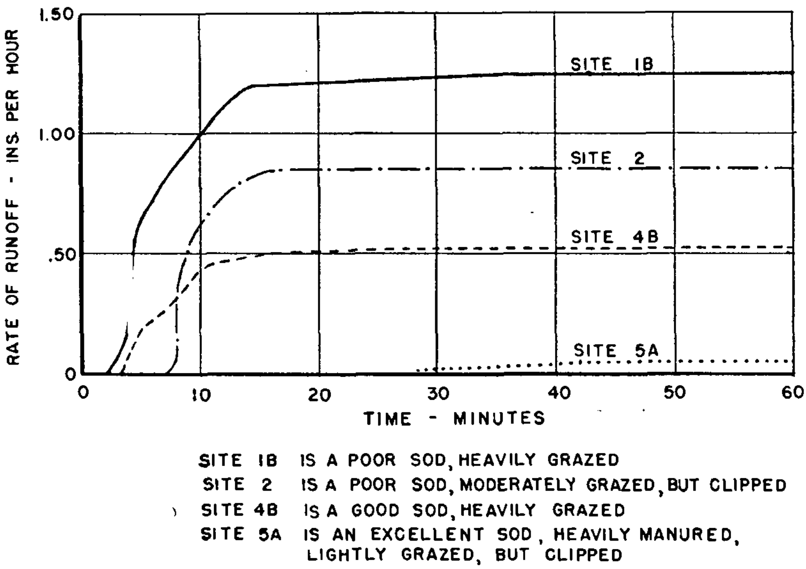

FIG. 1.—Runoff hydrograph, showing the rate of water loss from differently treated pastures on Hagerstown soil during a 1.4-inch per hour rain.

Heavy grazing not only reduced vegetative cover but decreased noncapillary porosity and increased the volume weight of the 0 to 1-inch layer of soil. In the 0 to 1-inch layer, noncapillary porosity ranged from 3 to 10% for the heavily grazed plots as compared with 15 to 33% for ungrazed and lightly grazed plots. Similarly, volume weights ranged from 1.54 to 1.91 on the heavily grazed sites and from 1.09 to 1.51 on ungrazed and lightly grazed sites. In the 1- to 3- and the 3- to 6-inch layers, on the other hand, volume weights apparently were not significantly affected by intensity of grazing.

The relationship between the volume weight of the 0 to 1-inch layer and the average percentage runoff for the sites on Hagerstown soil is shown in Fig. 2. To minimize the effect of vegetation or mulch

TABLE 3.—*Infiltration and runoff data from various pasture and grassland soils.*

Site No.	Site description and treatment	Runoff, %		Infiltration rate, in. per hour		Volume weight		Noncapillary porosity, %	
		Av.	Max.	Av.	Min.	0–1 in.	1–6 in.	0–1 in.	1–6 in.
	Hagerstown Soil								
1a	Bluegrass-clover, heavily grazed, 60% cover	71	75	0.41	0.35	1.69	1.41	9.2	28.1
1b	Bluegrass-clover, heavily grazed, 50% cover	80	91	0.28	0.13	1.91	1.31	3.0	31.2
2	Bluegrass-clover, moderately grazed, 90% cover	19	21	1.13	1.11	1.47	1.21	19.2	37.0
2	Same plot as above, but clipped to 1 inch	52	64	0.67	0.50	—	—	—	—
2	Same plot as above, trampled by foot after clipping	67	80	0.46	0.28	1.64	1.21	8.6	37.0
3	Bluegrass sod ungrazed for 5 years, 100% cover	0	0	1.40	1.40	1.09	1.35	33.1	25.3
3	Same plot as above, but clipped to 1 inch	0	0	1.40	1.40	—	—	—	—
3	Same plot as above, mulch removed after clipping	6	11	1.32	1.25	—	—	—	—
3	Same plot as above, trampled by foot after mulch removal	36	55	0.90	0.63	1.41	1.35	16.6	25.3
4a	Bluegrass-clover, heavily grazed, 85% cover	39	45	0.77	0.67	1.67	1.25	8.6	33.0
4b	Bluegrass-clover, heavily grazed, 80% cover	33	38	0.85	0.77	1.54	1.26	10.2	30.4
5a	Bluegrass-clover, lightly grazed, 100% cover	1	4	1.39	1.34	1.18	1.42	22.1	21.7
5b	Bluegrass-clover, lightly grazed, 100% cover	5	9	1.33	1.27	1.36	1.45	15.3	21.4
5a	Same plot as 5a above, but clipped to 1 inch	1	4	1.39	1.34	—	—	—	—
5b	Same plot as 5b above, but clipped to 1 inch	21	30	1.11	0.98	—	—	—	—
6a	Orchard grass-Ladino clover, moderately grazed, 75% cover	26	39	1.04	0.85	1.60	1.42	7.7	24.5

6b	Orchard grass-Ladino clover, moderately grazed, 90% cover	6	13	1.32	1.22	1.49	1.49	14.5	21.3
6a	Same plot as 6a above, but clipped to 1 inch	49	59	0.71	0.57	—	—	—	—
6b	Same plot as 6b above, but clipped to 1 inch	42	52	0.81	0.67	—	—	—	—
7a	Red clover-timothy meadow, 100% cover	2	7	1.37	1.30	1.45	1.37	24.2	29.2
7b	Red clover-timothy meadow, 100% cover	0	0	1.40	1.40	1.47	1.45	24.5	27.1
7a	Same plot as 7a above, but clipped to 2 inches	23	34	1.08	0.92	—	—	—	—
7b	Same plot as 7b above, but clipped to 2 inches	26	38	1.04	0.87	—	—	—	—
7a	Same plot as 7a above, but mulch removed after clipping	42	63	0.81	0.52	—	—	—	—
7b	Same plot as 7b above, but mulch removed after clipping	47	71	0.74	0.41	—	—	—	—
8a	Orchard grass, ungrazed, 100% cover	0	0	1.40	1.40	1.36	1.41	19.8	20.0
8b	Orchard grass, ungrazed, 100% cover	0	0	1.40	1.40	1.51	1.29	16.0	23.8
8a	Same plot as 8a above, but clipped to 1 inch	28	38	1.00	0.87	—	—	—	—
8b	Same plot as 8b above, but clipped to 1 inch	1	3	1.39	1.36	—	—	—	—
8a	Same plot as 8a above, mulch removed after clipping	47	64	0.74	0.50	—	—	—	—
8b	Same plot as 8b above, mulch removed after clipping	6	11	1.32	1.25	—	—	—	—
	Morrison Soil								
9	Redtop-weeds, moderately grazed, 50% cover	50	61	0.70	0.55	1.96	1.52	5.2	24.4
10	Bluegrass-clover, heavily grazed, 85% cover...........	41	48	0.83	0.73	1.79	1.53	9.5	24.2

cover, the runoff values used were those obtained after clipping and after removal of any mulch of dead vegetation. Included in Fig. 2 are the data obtained on sites 2 and 3, following tramping while the soil was wet. The correlation coefficient (0.80) for this relationship is highly significant (odds exceed 99 to 1). Site 8b is furthest out of line in this relationship. For some reason this soil, even after the removal of the mulch of dead grass, was highly resistant to dispersion and therefore runoff was low. Although sites 8a and 8b appeared to be very similar, the soil on 8a lacked this high degree of granule stability and runoff was much greater.

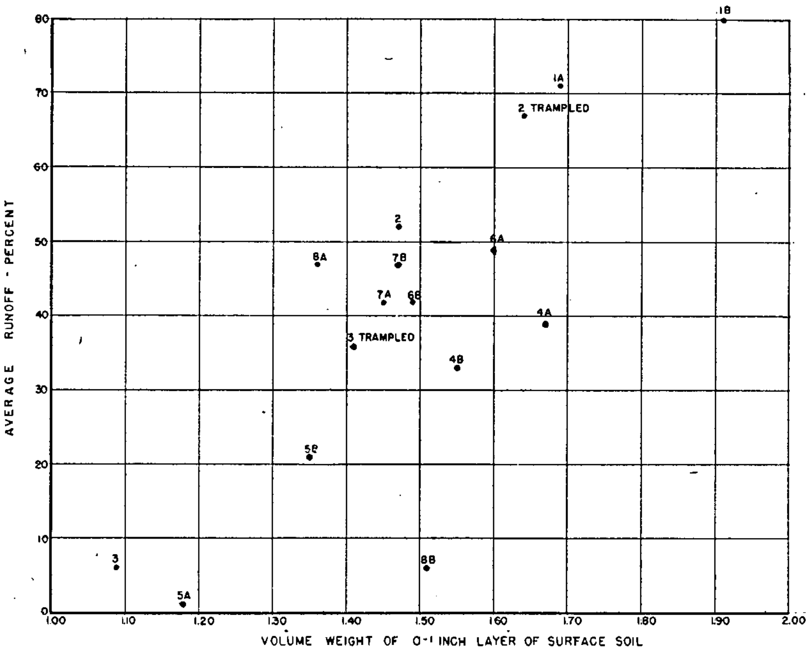

FIG. 2.—Relation between runoff and compaction of the 0 to 1-inch layer of surface soil. The numbers in the chart refer to sites.

Runoff was also highly correlated with noncapillary porosity. The correlation coefficient for this relationship is 0.76.

SUMMARY AND CONCLUSIONS

Runoff losses during the summer from various sites in pastures and grasslands on Hagerstown and Morrison soils were determined by means of a type F rainfall simulator. Water losses were supplemented by measurements of vegetative cover, percentage slope, volume weight, capillary and noncapillary porosity, organic matter content, pH, and the mechanical analysis of the soil.

Runoff losses ranged from none to 80% during a 1-hour period in which 1.4 inches of water were applied. In general, water losses were high from heavily grazed pastures, whereas ungrazed areas lost little if any water due to runoff.

The high rate of runoff from the heavily grazed sites was associated with lack of soil cover together with high volume weights and low values for noncapillary and total porosity in the 0 to 1-inch surface soil layer. Compaction was confined to the 0 to 1-inch layer even though this layer contained the greatest amount of organic matter. This is indicated by low volume weights and high noncapillary porosity in the 1- to 3- and 3- to 6-inch soil layers.

Since storms of high rainfall intensity are common during the summer months, it is suggested that water loss due to runoff may be an additional factor contributing to the low yields of closely grazed pastures during midsummer.

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