1935

COMPARISON OF RUNOFF AND EROSION IN PRAIRIE, PASTURE, AND CULTIVATED LAND

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DEPARTMENT OF BOTANY
THE UNIVERSITY OF NEBRASKA

BULLETIN 11
CONSERVATION DEPARTMENT
OF THE
CONSERVATION AND SURVEY DIVISION
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As defined by law, the Conservation and Survey Division of the University includes the following state departments and surveys: Soil, Geological, Water, Biological, Industrial, Conservation, and Information Service. Its major purpose is to study and describe the state's resources and industries for use in development. Reports of the Division are published in three series, i.e., Nebraska Soil Survey, Nebraska Geological Survey, and the Conservation Department.

CONTENTS

Comparison of Runoff and Erosion in Prairie, Pasture, and Cultivated Land

INTRODUCTION

Soil erosion resulting from runoff water has come to be recognized as a national menace. The determination and evaluation of all factors influencing runoff and erosion are studies of fundamental importance, especially insofar as they may be made to yield information upon methods of control over this insidious tendency of washing away the land.

"Fully 75 per cent of the crop-producing and grazing areas of the United States is sloping enough to set in motion, moderately or violently, these wasteful processes of accelerated soil-removal and excessive runoff. That 35 million acres of formerly cultivated land have been essentially ruined by erosion and that an additional area of about 125 million acres, still largely in cultivation, have lost all or most of the topsoil, with another 100 million acres of crop-land heading in this direction, should be sufficient evidence that the problem is one of profound economic importance. Especially must this be considered true since the wastage is now proceeding faster than ever, owing to the fact that considerable time was required to strip off the more absorptive surface-layer from millions of acres, and to the further fact that the subsoil is generally more erosive than the soil. The cost runs into hundreds of millions of dollars annually, in the way of direct depreciation and essential destruction of fields and pastures, the silting of reservoirs, stream-channels and ditches, damage to highway and railway fills and embankments, choking of culverts, covering of valuable valley-lands with relatively unproductive erosional debris, and pollution of former clear-water streams with excessive loads of silt and clay washed out of the hills" (Bennett, '34).

Much experimentation has been carried on and numerous papers have been written on the effects of a forest cover in promoting absorption of rainfall and controlling erosion. But a study of grass as a stabilizer of lands and a means of increasing absorption and diminishing runoff has just begun. It has resulted from the present physical crisis in land use within the United States and especially in the west. This crisis is a consequence of the period of exploitation resulting from the rapid occupation of the whole country by a civilized people. The story of American agriculture has been one of breaking new soil, farming it hard, and then, when yields began to fall off, moving west to repeat the cycle. The time has gone, however, when worn out lands can be abandoned for virgin soils, with their stored fertility, and undepleted ranges lying to the west. These changes have occurred rapidly. As stated by Lowdermilk ('35[a]): "Soils which had been thoroughly protected through thousands of years of time by unbroken mantles of vegetation, and, for this reason, had weathered to fine textures with high organic contents so favorable to 'mellowness' and good fertility, were suddenly exposed to the dash of torrential rains characterizing the climate of extensive regions. . . . Topsoils have been literally washed away, leaving raw, comparatively unproductive, unabsorptive, intractible subsoil exposed at the surface. . . . . of the greater part of the crop and grazing areas of the West."

The natural cover of prairie vegetation has nearly all been removed by breaking, or sorely depleted by continued overgrazing. This effective preventive of erosion has been replaced by poorly sodded pastures and lands covered only temporarily with crops. Overgrazing on the one hand and cultural practices on the other have exposed much of the surface of both to the destructive action of rain and runoff waters.

With a widespread erosion control campaign going on throughout the United States with the object of the best type of soil conservation, it is peculiarly desirable to take full account of the influence of plant cover. Moreover, in examining the effects of disturbances wrought by man, his implements and machines, and his domestic animals, it is desirable to begin investigations with undisturbed natural condition of the land. Fortunately many limited areas of natural grassland, especially prairies kept for the production of hay, remain to facilitate such comparative studies.

INTERDEPENDENCE OF VEGETATION AND SOIL

That vegetation is a product of the soil is generally understood; that soil is likewise a product of vegetation is not so widely comprehended. The remarkable rôle that vegetation plays in soil development must be considered for a proper understanding of the evil effects of a disturbance or removal of a plant cover. Throughout the centuries soils have undergone a process of development, the controlling factors being climate and vegetation. Vegetation, prairie for example, accelerates weathering of rock into fine soil by the excretion of acids and mechanical effects of roots; it supplies food for myriads of microörganisms, both plants and animals, which live within the soil, as well as food for numerous burrowing animals. By making the soil porous and adding humus, plants increase absorption and percolation of rain water, thus preventing rapid removal of soil by runoff waters. The cover of vegetation by absorption and transpiration removes large amounts of water from soil and subsoil, and thus increases their potential water absorbing and water retaining powers for the next rain.

Vegetation profoundly affects soil structure, that is, the arrangement of the individual grains and aggregates that make up the soil. The irregularity in size and shape of the rock particles prevents tight packing and affords open, irregular spaces through which air and water can circulate, while their weight and mutual pressure furnish the necessary resistance for firm root anchorage. The structure of a soil determines its porosity. This in turn, affects the absorption of water and, therefore, runoff and the consequent erosion. Roots, and especially grass roots, are extremely important in maintaining a good soil structure. As a result of the interlacing and clutching of earth particles by myriads of roots, the soil is compressed into granules whose identity, stability, and permanence are established by a surrounding colloidal film of humified root materials. Hence the virgin prairie sod is mellow, moist, and rich. The soil is filled with pores of old root channels; the humus from the decaying roots and tops adds much to its productivity.

A remarkable dependence of long standing has existed between soils and their natural vegetation. Indeed the development of the soil and the plant cover have gone hand in hand from the beginning of rock weathering to the production of mature soil covered with climax vegetation. Thus it should be clear that "soil is as much a product of vegetation as vegetation is a product of the soil. The development of soil, given proper basic materials and a proper climate, is inconceivable without vegetation" (Shantz, '35). Since there has been a delicate interdependence between vegetation, soil, soil water, and, consequently, stream flow throughout the centuries, small wonder is it that removal of the cover of vegetation may cause disastrous results.

NORMAL AND ACCELERATED EROSION

Normal erosion may be defined as the rate of soil removal that occurs under an undisturbed natural plant cover. It has occurred throughout the ages and in a geological sense it is always going on. But it is only recently in America that it has come to exceed the processes of weathering and the decay of plant materials which build up and improve the soil. This has resulted from the destruction of the native mantle of plants through fire, destructive lumbering, heavy grazing, smelter fumes, railway and highway cuts, clearing and cultivating lands for crop production, and in other ways.

EXPERIMENTAL METHODS

The earlier experiments on runoff and erosion were concerned with entire watersheds. Such was the case in measuring the effects of forest on stream flow at Wagon Wheel Gap, Colorado, an experiment initiated in 1909 and continued throughout a period of sixteen years (Bates and Henry, '28). This was a beginning in America for numerous similar experiments now installed in various hilly and mountainous areas to determine the efficiency of various types of forest and chaparral in influencing absorption and percolation and protecting the soil from erosion.

One of the first studies on the effects of grassland cover was made on the high mountain lands of the Manti National Forest in Central Utah (Reynolds, '11). These studies on the effects of a reduced plant cover in promoting runoff and erosion have been continued (Sampson and Weyl, '18) to the present time (Forsling, '31; Stewart and Forsling, '31). These researches showed the great increase in runoff following the partial removal of natural cover of grasses and herbs by overgrazing, and afforded a pattern for similar studies elsewhere.

A new method of attacking the problem, the runoff-plot method, was employed in Missouri in 1917 for comparing the influence of different crops and methods of cultivation on runoff and erosion (Duley and Miller, '23; Miller and Krusekopf, '32). These researches have had a profound influence upon similar quantitative studies. The plot method is extensively used at the ten soil erosion stations throughout the United States that resulted from the National program inaugurated by Bennett in 1928 for research in soil and water conservation under the Bureau of Chemistry and Soils.

The plot method consists in enclosing limited areas of land (one-eightieth or other fraction of an acre) on selected slopes, catching the water that runs off in appropriate interceptometers, as well as the soil that is carried away by the runoff water.

The present studies are the outgrowth of field experiments performed by classes in plant ecology (Figs. 1 and 2). The erosion traps used by Bates and Zeasman ('30), in their study of runoff rates under different conditions of forest, pasture, and cultivated fields, furnished the idea for those described in this paper (Weaver and Noll, '35).

THE INTERCEPTOMETER

The interceptometer consisted of a box made of No. 22 galvanized iron, 3 feet long, 8 inches wide, and 18 inches deep. Larger boxes, 18 inches wide and 2 feet deep, have been found more convenient on steep slopes and in cultivated fields. The boxes were well braced inside and furnished with a hinged, sloping top, open in front.

After selecting the station for installment, an excavation slightly larger than the interceptometer was made at right angles to the slope. This was just long enough to receive the container, about 10 inches wide and 18.5 inches deep, with the front (upper) wall perpendicular and smooth. The front side of the interceptometer was then fitted tightly against this wall with the upper edge about 0.5 inch below the soil surface. Soil was then tightly tamped, in filling the excavation, against the entire back wall of the container, which was thus held firmly in place. During rains the water running from the backwardly sloping top kept this soil wet and

FIG. 1.—Measuring the runoff on a 5-degree slope in upland prairie by the direct application of an inch of water during every 30 minutes.

FIG. 2.—Class in plant ecology measuring the runoff and soil erosion on a 10-degree slope in a pasture and bared area. The runoff plots are 3 feet wide and 33.3 feet long. Runoff from a single inch of water is shown in the settling tanks in the foreground.

firm. But during long periods of dry weather it was necessary to retamp the soil to keep the front wall tightly in place.

An area 3 feet wide and 33.3 feet long and parallel with the slope was enclosed by planed boards 6 inches in width. These were placed on edge in the soil to a depth of 3 to 4 inches and held firmly by nailing them to stakes driven into the soil just outside the area. The framework was thus securely placed and run-in water excluded without disturbing the enclosed area.

Water running down inside the plot found its way into the interceptometer, entering under the top which was about five-sixteenths inch above the soil surface. The accumulated water was removed and measured each day or after every rain. Interceptometers that were found to be too small to hold the runoff were supplied with a spout 0.5 inch in diameter and 2 inches long soldered to an opening in the back about an inch from the top. This was connected by rubber tubing to a covered overflow tank sunk in the soil just back of the interceptometer. Where the roily or muddy water indicated soil erosion, the contents of the interceptometer were transferred to a settling tank. The clear water was later siphoned off, the sediment air dried, and the quantity of eroded soil determined.

STUDIES IN PRAIRIE, PASTURE, AND BARE AREA

A number of interceptometers have been used during the past two years. Although the precipitation has been light, some illuminating results have been obtained. One interceptometer was installed in April, 1933, in prairie on a hillside of Carrington silt loam, a mature upland soil of rolling topography. The slope was 10°. Another one was placed 30 feet distant on a similar slope in a pasture. The climax prairie of little bluestem had been mowed annually; the pastured area was similar only that it had been closely grazed for two years and also during the period of the experiment. Not only was the vegetation removed close to the soil but the soil itself was trampled. Close grazing in the pasture outside the experimental area was continued during the dry year of 1934 and resulted in nearly denuding the soil of all vegetation. Hence in the early spring of 1935 a third interceptometer was installed in a bared area in the pasture only 10 feet from the experimental plot. This area also had a slope of 10°. During 1935, conditions in each area were as follows:

1. Prairie: unmowed the previous year but mowed at a height of 2 inches and vegetation removed in early spring and also on July 6, 1935. Approximately 95 per cent foliage cover.
2. Pasture: native bluestems mostly killed by grazing and replaced by a half-stand of bluegrass in 1935. Bluestems recovered in part in June and July. About 50 per cent foliage cover. All grasses kept mowed closely with grass shears.

3. Bare area: only a few blades of grass and annual weeds were left. The weeds were removed and the grass continuously cut at the soil surface until it finally died. There was practically no growth after midsummer.

Losses from these areas are shown in Table 1. They are continuous from June 8, 1934, to September 8, 1935, but, with one exception, the table does not include showers that caused no runoff. A torrential shower of .47 inch on April 29, 1933, resulted in heavy runoff. This amounted to 13.4 per cent in the prairie and 41.1 per cent in the pasture. Heavier rains on July 7 and 8, but falling over a period of several hours, resulted in 3 and 6.6 per cent runoff, respectively, in the pasture but less than 1 per cent in the prairie in both cases. Showers of equal amounts but of different intensities on June 8 and 14, 1934, resulted in considerable differences in runoff and showed that under certain conditions practically all of the water may be absorbed even on a 10° slope.

On August 31, .25 inch and .32 inch of rain fell, each during one hour in a rainstorm totaling .82 inch. Runoff was high. A day later, .47 inch of a .51 inch rain fell in an hour. It resulted in 11.3 per cent runoff in the pasture but only 2.4 per cent in prairie (Table 1). During an .84 inch rain two days later, when .4 inch fell during a single hour, the pasture lost 10 per cent but the prairie less than 1 per cent.

The consistently greater losses from the pasture during both fall and spring are marked. On April 11, when a .38 inch shower of a .91 inch rain fell in an hour, runoff from the bare area was over 10 times as great as that from the prairie and 7.5 times as great as that from the pasture. Forty-four times as great a loss from the bare area as from the prairie occurred on May 12. On May 27, when the hourly rainfall[1] was only .14 and .17 inch respectively, the bare area sustained 29 times as great a loss as the prairie, and more than twice that of the pasture. On the next day, when the hourly rainfall was .19 to .23 inch, differences between pasture and bare area were even greater. With .34 inch rain falling in a single hour on May 31, losses in both pasture and bare area were in striking contrast to the small runoff in prairie (Table 1).

Throughout the entire period runoff water from the prairie was clear, except for rains following dust storms. That from the pasture was often turbid, and even muddy during 1935. Usually the sediment remained suspended in the water, except on July 23 when 5 oz. of soil were washed away. In this storm over 2 inches of rain fell in 2.5 hours. Runoff water from the bare area was always roily and often carried much sediment as is indicated in Table 1.

[1] Data obtained from the U. S. Weather Bureau Station on the campus of the University of Nebraska at Lincoln, only 1.5 miles distant from the experimental tract.

TABLE 1.—*Runoff from prairie, pasture, and bare area.*

Date	Rainfall, inches	Percentage of runoff			
		Prairie	Pasture	Bare area	
April 29 1933........	.47	13.4	41.1		
July 7 ”	.65	0.5	3.0		
” 8 ”	.54	0.7	6.6		
June 8 1934........	.64	2.6	4.6		
” 14 ”	.64	0.9	1.2		
” 17 ”	.27	0.0	0.0		
” 22 ”	.57	0.6	1.3		
Aug. 31 ”	.82	4.2	7.4		
Sept. 1 ”	.51	2.4	11.3		
” 3 ”	.84	0.8	10.0		
” 25-26 ”	2.32	5.8	11.3		
Oct. 18-19 ”	1.62	1.4	4.8		
Nov. 2-3 ”	1.00	0.8	1.3		
March 3 1935........	.21	32.8	98.0		Eroded
” 7 ”	.32	0.6	8.4		soil,
” 17 ”	.38	1.1	2.9	4.2	lbs.
April 11 ”	.91	3.1	4.4	33.6	2.19
May 11-12 ”	.69	0.3	1.3	13.2	1.13
” 15-16 ”	.42	0.0	0.0	0.6	
” 19 ”	.67	0.0	0.0	0.0	
” 21 ”	.45	0.0	0.0	0.7	
” 23 ”	.33	0.0	0.0	9.0	
” 27 ”	.48	1.9	21.5	55.0	
” 28 ”	.51	0.8	0.3	27.5	
” 31 ”	.91	3.2	29.3	49.2	4.37
June 1 ”	.63	2.7	12.4	60.2	1.13
” 2 ”	.69	6.1	38.6	51.0	6.56
” 17 ”	.40	0.5	2.0	15.8	
” 20 ”	.91	0.8	5.3	21.5	
” 26 ”	.65	3.1	19.1	53.7	0.56
” 27 ”	.18	0.0	0.3	0.6	
July 4 ”	1.64	1.9	11.0	29.3	1.13
” 23 ”	2.15	3.4	4.8	12.2	3.25
Aug. 17 ”	.36	0.6	0.4	1.1	
” 20 ”	.56	3.0	8.8	11.1	0.31
” 22 ”	.46	0.2	0.3	0.2	
” 30 ”	.36	0.4	4.2	11.4	
Sept. 1 ”	1.65	2.4	14.7	19.4	1.60
” 8 ”	.73	1.4	8.2	35.2	1.10
June 8 1934 to Sept. 8 1935—Total...	26.88	2.5[1]	9.1	15.1	23.33

[1] Total inches runoff divided by total inches rainfall.

The total runoff from the prairie amounted to only 2.5 per cent of the rainfall recorded in Table 1. There was no measurable erosion. Runoff from the pasture was 9.1 per cent, and there was a small amount of erosion. From the bare area, runoff was 15.1 per cent of the rainfall, and 5.08 tons of soil per acre were washed away.

EXPERIMENTAL WATERING

Since little rain fell during the extremely dry summer of 1934, some experiments were made by adding water from sprinklers to the run-off areas, thus imitating rain. In these experiments the water was hauled in 55 gallon steel barrels and sprinkled uniformly over the 100-square-foot enclosure by 5 students, each watering an area of 20 square feet. Such experiments have numerous advantages over natural rainfall. By the co-operation of several workers, water may be applied at any desired rate and during any desired period of time. The behavior of the soil surface in relation to the intake of water may be directly observed under favorable conditions, the time when runoff or erosion begins ascertained, the relative turbidity or clearness of the water observed, and the period of runoff after cessation of watering determined.

The results of an initial experiment where 2 inches of water were applied to the prairie and 3 inches to the pasture are recorded in Table 2. A study of these data shows that in the prairie runoff began later, was smaller in amount, and ceased sooner after the total amount of water or any portion of it was applied. This resulted partly because of the greater interference to water movement afforded by the denser ungrazed vegetation, but perhaps chiefly to the greater porosity of the untrampled soil. The pasture had been grazed (or cut) so closely for three years that the weakened plants had partially lost their power of binding the soil, some

TABLE 2.—*Runoff from pasture and prairie.*

July 7, 1934

Place	Time	Amount, inches	Per cent runoff	Remarks
Pasture	2:00- 2:30	1	8.3	Runoff began after 5 min. Finally ran from top to intake. Ceased 3 min. after watering.
"	2:35- 3:05	1	14.1	
"	3:05- 3:20	1	30.1	Ceased 4 min. after watering.
Prairie	3:20- 3:50	1	3.8	Runoff began after 15 min., ceased at once after watering.
"	3:55- 4:25	1	4.3	Runoff ceased 1 min after watering.
July 19, 1934				
Pasture	9:20- 9:35	1	8.5	Runoff began at once, ceased 5 min. after watering. Water roily, ran from top to intake.
"	9:45-10:15	1	8.5	
"	11:20-11:25	.5	16.4	Water roily, slight erosion.
Prairie	10:20-10:35	1	2.6	Runoff began in 9 min., ceased 2 min. after watering.
"	10:45-11:15	1	1.6	Water clear.

of which would have been removed by torrential rains. On July 7, the runoff from the 2-inch watering in the pasture was 11.2 per cent, but that in the prairie only 4.1 per cent. The third inch of water in the pasture gave a runoff of 30.1 per cent. On July 19, runoff from the two inches of water added to the pasture and prairie was 8.5 and 2.1 per cent, respectively.

Further comparison of runoff and erosion was made with prairie, bluegrass, and bare area on April 13, 1935. As shown in Table 3, 2.5 inches of water were applied to each area. The experiment was preceded two days earlier by .91 inch of rain. In the prairie, which had been cut two inches high in early spring, the new growth of the earlier vegetation was about 3.5 inches tall. The most abundant grasses, the bluestems, had not resumed growth. About one-third of the pastured area was covered with bluegrass, otherwise the soil was bare. Weeds had been removed from the bare area a week previously.

TABLE 3.—*Runoff and erosion from prairie, bluegrass, and bare area (10° slope), on April 13, 1935.*

Place	Time	Water, inches	Runoff, per cent	Soil eroded, pounds	Remarks
Prairie	1:30-2:00	1	0.0	None	
"	2:00-2:30	1	0.0	"	
"	4:30-4:45	0.5	0.0	"	
Bluegrass	2:30-3:00	1	21.2	.38 (first two periods)	Runoff began in 5 min., ran from top after 10 min.
"	3:00-3:30	1	30.4		Water muddy from beginning of experiment to end.
"	4:45-5:00	0.5	36.4		
Bare area	3:30-4:00	1	52.6	8.56	Runoff began in 5 min., ran from top after 7 min.
" "	4:00-4:30	1	48.4	7.13 (last two periods)	Water very muddy.
" "	5:00-5:15	0.5	50.2		

The runoff from each area was as follows: prairie 0, bluegrass 29.3 per cent, and bare area 50.4 per cent. No erosion occurred in the prairie; in the pasture and bare area the losses were 165 pounds and 3.42 tons per acre respectively.

The loss of water to the soil is also of interest. While the prairie soil was wet to a depth of 42 inches 5 days after the watering, in the bluegrass area water had penetrated to 22 inches, and in the bare area to only 19 inches.

A fourth experiment was conducted on October 12, when the soil was very dry. Two inches of water were applied, at the rate of an inch each

FIG. 3.—Detail of plant cover in runoff-plot in upland prairie, September, 1935.
FIG. 4.—Detail of plant cover in runoff-plot in overgrazed prairie, September, 1935.

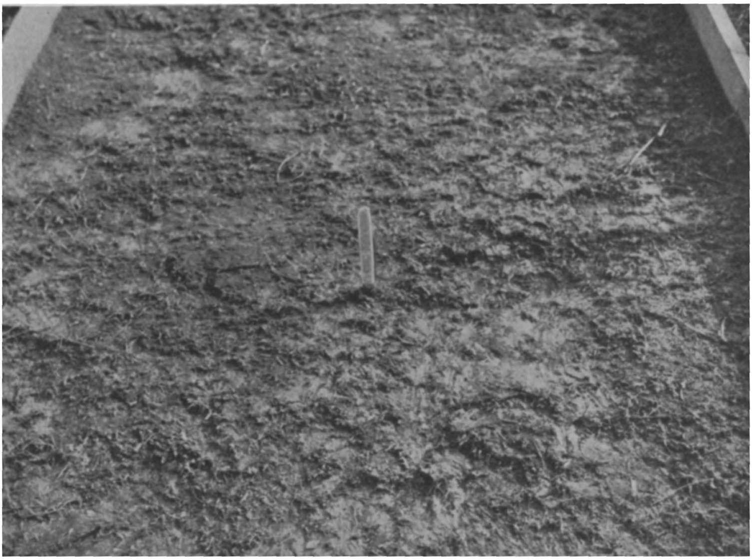

FIG. 5.—Close view of soil surface in runoff-plot in area bared by continuous overgrazing and trampling. The dead crowns of the grasses have decayed and are disintegrating.

half hour, to the prairie, pasture, and bare area, successively. Immediately following, a third inch was added in the same sequence and at the same rate to each plot (Figs. 3, 4, and 5, and Table 4).

TABLE 4.—*Percentage of runoff and soil erosion resulting from the application of three inches of water on October 12, 1935.*

Water applied	Percentage of runoff				Erosion per acre		
	Prairie	Pasture	Bare area		Prairie	Pasture	Bare area
						Lbs.	*Tons*
First inch............	14.6	45.0	63.2		0	218	2.19
Second inch..........	12.0	52.8	74.0		0	98	1.43
Third inch...........	7.4	53.6	77.6		0	39	1.05
Average..........	11.3	50.5	71.6	Total	0	355	4.67

The rather large runoff from the first inch of water in the prairie resulted from the dry condition of the soil. After the soil was moistened, a decrease in water loss was determined. Just the reverse occurred in the other plots where more water was lost upon the application of each successive inch, until in the bare area it was more than three-fourths of the amount applied.

Immediately before watering, soil samples were taken in duplicate in each area, the holes being refilled and the soil tightly tamped. Samples were again taken 24 hours later. The total water contents are shown in Table 5.

TABLE 5.—*Water content in the several plots before and after watering.*

Depth of sample	Prairie			Pasture			Bare area		
	Before	After	Per cent increase	Before	After	Per cent increase	Before	After	Per cent increase
0″- 6″	11.0	35.9	24.9	11.9	28.0	16.1	14.0	23.3	9.3
6″-12″	13.2	25.7	12.5	13.8	15.2	1.4	17.3	19.7	2.4
1′- 2′	14.6	21.4	6.8	15.1	16.2	1.1	16.2	17.1	0.9
2′- 3′	17.2	17.0	—0.2	16.8	17.0	0.2	16.0	16.1	0.1

The hygroscopic coefficients of the soils for the several depths, from the surface downward, are approximately 9.5, 8.7, 8.6, and 7.1 per cent, respectively. Examination of Table 5 shows that before watering, the grasses of mowed prairie and clipped pasture had, by absorption, dried the soil almost equally, but that the bare area had 2 to 3 per cent greater water content to a depth of two feet. It also shows that the prairie soil, 24 hours after watering, increased in water content to a depth of two feet. This agrees with the apparent water penetration determined at the time of sampling. Likewise, both pasture and prairie showed water penetration to only 13 to 14 inches. The decreasing water content in the first foot from prairie to bare area is in accord with the increase in runoff in the same sequence.

Many of the stem bases and roots in the bare area were so disintegrated that they were washed away with the soil. The great loss of soil, 4.67 tons per acre, resulting from one rain only would indeed be alarming to the owner if it were understood that this loss of top soil really occurred and that it resulted from only a few years misuse of the pasture.

DISCUSSION

In all studies on runoff and erosion there are numerous variable factors. One of these is rainfall. While erosion begins only when water acts upon an exposed surface, the intensity, duration, direction, distribution, and nature of the rain are all significant. Direct sprinkling imitates certain types of rainfall, just as forcing the water into the air and letting it fall under the pull of gravity imitates other types. Often the rainfall is gentler than in the sprinkling employed; sometimes rain beats upon the ground with much greater force and the volume of falling water is also greater per unit of time.

The effect of length of slope on runoff has been a subject of investigation. Measurements have been made in Kansas, on silty clay loam soil, on similar areas 3 feet wide and 10, 20, 40, and 100 feet long, by sprinkling the soil and catching the runoff water (Duley and Ackerman, '34). Under both light and heavy rains there was a larger percentage of surface runoff from the shorter plots than from the longer ones. Under light erosion short plots gave the larger amounts; under heavy erosion the reverse condition prevailed. In comparing results from a large number of widely separated stations, Bennett ('34) finds that on some slopes both erosion and runoff are greater on uniform slope cross-sections of short length, while corresponding losses are greater on the longer slopes of other soils.

The degree of slope has been found to exert little effect upon soil loss when grass covers the soil, but profundly affects the losses when the grass cover is replaced by a tilled crop. On Shelby loam in Missouri an increase of slope from 3.7 to 8 per cent trebled the loss of soil (*i.e.* increased it from 20 to 61 tons per acre per year) when corn was grown. When the two slopes were covered with grass the losses were 0.3 ton per acre per year in both cases. At Tyler, Texas, a very steep slope of 16.5 per cent on fine sandy loam soil lost scarcely no soil when under Bermuda grass, while the loss was 35 tons per acre per year when planted to cotton (Uhland, '35).

"It has been assumed generally that slope is the most powerful factor affecting soil erosion and runoff. The available data do not bear out this point of view. They indicate instead that the character of the vegetative cover is the most pertinent factor in this connection, and after that the character of the soil appears to have the most potent influence" (Bennett, '34).

A study of the relative effectiveness of grass as compared with forest cover shows that both give practically complete protection from erosion on many important types of soil. In fact little difference is found. In California, moreover, it has been shown that a cover of grass is quite as efficient in preventing soil erosion as is a growth of chaparral. Grassland binds the soil more effectively than any other type of vegetation.

THE ROLE OF PRAIRIE VEGETATION IN PREVENTING EROSION

The natural cover of grassland reduces runoff and prevents erosion. It breaks the impact of the raindrops before they reach the soil. In fact, much of the water is intercepted. Forests are efficient in this manner because of the cover of trees, undershrubs, herbs, and other plants on the forest floor. Tall-grass prairie has three distinct layers (Weaver and Fitzpatrick, '34). The rain first encounters the tall forbs which overtop the thick layer of grasses. Below the taller grasses are numerous shorter ones and an abundance of rosette and mat-like plants that further protect the earth. A single acre of normally developed prairie supports a total leaf surface of 5 to 10 acres. This extensive foliage loses large amounts of water through transpiration, frequently 30 to 40 tons per acre per day in midsummer (Flory, '34). This results in decreased water content of soil and consequent increased power of absorption.

Fallen plant materials form miniature dams and terraces which hold the water momentarily and thus promote percolation. The bases of plants, especially the bunches and mats of sod, constantly divert the runoff water of torrential rains and spread it evenly over the surface, thus hindering sheet erosion.

As a result of the earlier studies in forests, it was believed that the great value of litter was its power of imbibing large amounts of water as does a huge sponge, thus delivering rainfall slowly to the soil. Recent experimental studies have shown that the chief function of the forest litter is keeping surficial water clear and thus preventing the sealing of the soil pores at the surface. This condition maintains the soil at maximum capacities for absorption (Lowdermilk, '30). Litter in natural grassland is much less abundant than that in forest but the amount is considerable and it undoubtedly plays a similar important rôle. The surface soil is rich in leaf mold and organic matter. Pore space is great, often occupying about half of the volume of the soil (Weaver, Hougen, and Weldon, '35). Myriads of closely associated stem bases occur underground; branched rhizomes extend everywhere; tiny roots of great tensile strength entwine the soil particles and anchor them firmly. These are all factors that help maintain the wonderful structure known as grassland soil. In the surface 4 inches alone, three to four tons per acre of living underground plant parts occur (Weaver and Harmon, '35). Thus in prairie many factors combine to prevent the throwing of soil particles into suspension, even during the heaviest rains, and thus clogging the pores as the water sinks into the soil.

On soils denuded of their cover and robbed of accompanying protecting influences, dashing rains churn the bared soil into muddy suspensions. As the water percolates into the earth, the suspended soil particles filter out, close the soil pore spaces and finally seal the soil to such a degree that it scarcely absorbs. Water collects on the surface and in running away carries with it a load of topsoil. Accumulating into rills and streamlets its eroding and transporting power is increased many fold.

OVERGRAZING A CHIEF CAUSE OF EROSION

Every agency that destroys the cover of vegetation and exposes the surface gives opportunity for erosion in proportion to the completeness of the destruction (Figs. 6 and 7). Overgrazing is a chief cause. Over a large portion of the West the amount of runoff is approximately proportional to the sparsity of the plant cover, the loss of surface litter, and

FIG. 6.—Bluegrass in a 3-year-old native pasture killed by the drought of 1934, leaving a scattered growth of big bluestem (*Andropogon furcatus*). Such areas are readily invaded by weedy prairie forbs.

FIG. 7.—Same area a year later showing a rank growth of Missouri goldenrod (*Solidago glaberrima*), horseweed, (*Leptilon candadense*), and other weeds.

the compacting of the soil. As stated by Clements ('35), the partial or complete loss of plant cover is more portentous in areas of relatively low rainfall, where conservation of the soil is the critical need and where recovery of the vegetation by natural or artificial means is less rapid and complete. Overgrazing is probably responsible for much more abnormal erosion on unbroken land than all other causes combined.

On the elevated grazing lands of central Utah, surface runoff and resulting sedimentation have been studied since 1915. Two adjacent experimental watersheds of approximately equal area were used. One of these with a considerably eroded soil supported (period 1) from 1915 to 1920, inclusive, a plant cover of 16 per cent. From 1921 to 1923 (period 2) the plant cover was increased to 40 per cent, and has been maintained thus until the present (period 3). The other watershed, with little eroded soil, had a well developed plant cover of 40 per cent throughout the entire period of study. Although rain gauges on the two areas showed a slightly greater summer precipitation on the area that was well vegetated, yet the runoff and soil erosion were less. Approximately 3 to 5 times as much water ran off the area with the poorer plant cover. For the three periods of years the runoff was 10.33, 8.74, and 5.49 per cent respectively, from the area with the poorer cover as compared with 4.10, 2.88, and 1.05 per cent for the continuously well-vegetated one (Stewart and Forsling, '31).

"The increase in the density of the vegetation from 16 to 40 per cent of a complete cover, and the replacement of certain plants by others with more extensive and more fibrous root systems reduced the rainfall surface runoff 64 per cent and rainfall erosion 54 per cent. It reduced melted-snow erosion 57 per cent, but did not influence melted snow run-off" (Forlsing, '31).

The greater runoff and decreased penetration of water from the overgrazed and bared plots leads to an immediate understanding of the reports by ranchers in the West that during the past decade many springs have ceased flowing and that numerous streams which formerly ran continuously have gone dry, now carrying water for only short periods after heavy rains. As the soil is bared the rate of accelerated erosion increases and the eroded land suffers a great loss in productivity. Finally the soil becomes extremely droughty and even if ungrazed will support only a meager cover of weeds and the poorer forage grasses.

It is of the utmost importance that on areas once bared by overgrazing or otherwise, nature sets to work at once to repair the cover. As pointed out by Shantz ('35), secondary plant successions mark the scar tissue necessary to heal the wound. There are well recognized steps in recovery (Clements, '16). In the prairie the "storm troops" against

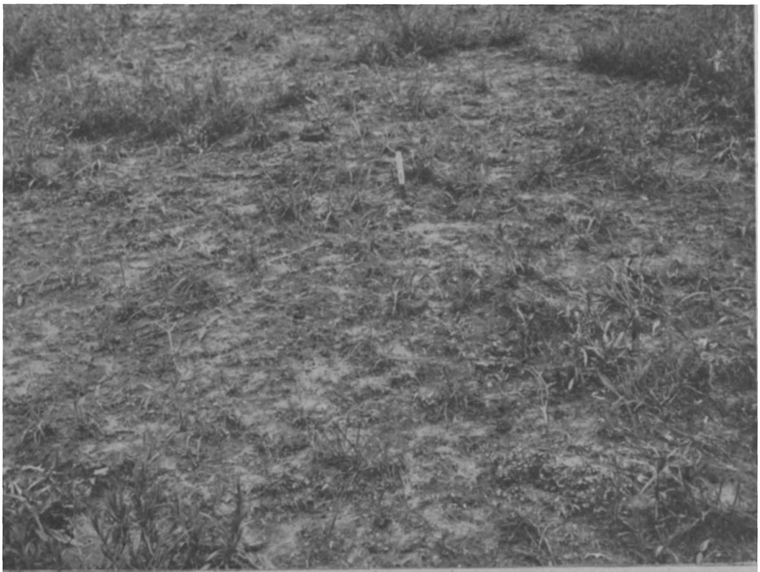

FIG. 8.—Slope in a badly overgrazed pasture. Many of the best grasses (little and big bluestem and bluegrass) have died. The bare ground is readily eroded both by wind and water. Weeds quickly invade such bare areas.

FIG. 9.—Same slope a few months later invaded by western ragweed (*Ambrosia psilostachya*) in foreground and horseweed (*Leptilon canadense*) and other weeds in background. Even a cover of weeds affords considerable protection against erosion.

erosion are annual weeds, the supporting troops the perennial weeds and short-lived grasses (Figs. 8 and 9). These are gradually replaced by more permanent grasses and forbs and final rehabilitation is established with the coming of the bluestems and other plants of climax prairie.

"While cover and succession must be employed as the major tools in the control of erosion and flooding, it is obvious that engineering works are indispensable complements in many instances, though it is unfortunate that trust has too often been placed in them alone. The more progressive engineers are coming to realize that the proper place to control runoff and erosion is at the start and that the check-dams and debris basins are temporary or supplementary devices chiefly needed during the period when . . . . the restoration of the natural cover is barely under way. Many small check-dams at the heads of small rillways or gullies are far preferable to much larger ones in ravines . . . . and valuable as debris basins may be in halting or diminishing the momentum of flood materials, it can not be denied that the adequate protection of the native cover will render them unnecessary" (Clements, '35).

STUDIES IN PRAIRIE, WHEAT FIELD, AND FALLOW LAND

A second installation, including a rain gauge, was made for the purpose of comparing runoff in a virgin prairie of little bluestem and in an adjoining area that had been broken and cropped for a period of 30 years. The crop of winter wheat was removed from a part of the field by hoeing and the area designated as fallow land. The soil was Carrington silt loam and in all cases the slope was 5°. Readings were made only when the soil was unfrozen, and rainfall data are given only when runoff occurred (Table 6).

TABLE 6.—*Runoff from prairie, wheat field, and fallow land.*

Date	Rainfall, inches	Percentage of runoff		
		Prairie	Wheat field	Fallow land
Dec. 2 1933........	1.30	2.0	0.8	
" 3 "	1.47	2.5	5.2	
Feb. 24 1934........	.28	1.3	4.0	
June 8 "	.58	1.0	0.1	0.3
" 14 "	.87[1]	0.2	7.0	1.1
" 22 "	.54	0.0	0.0	0.4
Aug. 7 "	.80	1.0	3.4	12.8
" 31 "	.74	0.1	7.9	18.4
Sept. 1 "	.65	1.8	48.2	55.3
" 3 "	1.01	0.4	15.5	30.5
" 10 "	.37	0.0	0.3	4.2
" 18-23 "	.86	2.0	13.9	19.5
" 25-26 "	1.54	1.0	31.6	42.5
Oct. 20 "	1.88	0.3	12.3	28.8
Dec. 2, 1933 to Oct. 20 1934—Total	12.89	1.0	12.1	17.8

[1] Wheat harvested on June 9.

On December 2, when the crop of winter wheat stabilized the dry, loose field soil, the runoff from a 1.3 inch rain was less than that in the mowed prairie. A rainfall of 1.47 inches, on December 3, after the surface soil had been thoroughly wet, resulted in more than twice as much runoff in the field of wheat as in the native grassland. When the soil was again very dry (June 8, 1934), the small loss in the prairie exceeded that in the field during a .58 inch rain. But on June 14 a rain of .87 inch resulted in greater water loss from both the field and fallow land. This was the dry summer of 1934 and the wheat grew so poorly that the mature crop was only 18 inches tall. Growth in the prairie, however, was also far below normal.

The relatively heavy rains of August 31 and September 1 resulted in high runoff except in the prairie. The water lost from the fallow land considerably exceeded that lost from the wheat stubble (Table 6). During the inch of rain on September 3, practically all of the water was absorbed in the prairie, 15.5 per cent ran off the stubble field, and twice this amount from the fallow land. Losses by erosion from these rains in the two field plots aggregated 296 pounds and 1,085 pounds per acre, respectively.

The fallow land had not been cultivated since spring but it was kept entirely free of weeds. The soil became compacted and runoff during late summer was high. For example, on September 25-26, 1.54 in. of rainfall resulted in a loss of 42.5 per cent from the fallow land and 31.6 per cent from the stubble field, but only 1 per cent from the prairie. Moreover, 605 pounds of soil per acre eroded from the stubble and 1.29 tons from the fallow land.

On October 20, a rain of 1.88 inches resulted in slight runoff from the prairie (0.3 per cent), 12.3 per cent from the stubble, and 28.8 per cent from the bare area. While the water from the prairie was clear, that from the stubble carried away 152 pounds of soil per acre, and .78 ton of soil per acre was washed from the bare area.

Summarizing, the percentage of runoff from the rains recorded in Table 6 was 1, 12.1, and 17.8 from the prairie, wheat and stubbble field, and fallow land, respectively. While there was no measurable loss of soil from the prairie, that from the wheat field was .52 ton per acre and that from the fallow land 2.6 tons.

EXPERIMENTAL WATERING

In one experiment 6 inches of water were applied to the runoff plot in the prairie soil during a period of three days and 5 inches to the plot in wheat stubble. Four inches were applied to the fallow field. The results are summarized in Table 7.

TABLE 7.—*Runoff and erosion from prairie, wheat stubble, and fallow field, July, 1934.*

Place	Time	Amount, inches	Percentage runoff	Remarks
	July 3			
Prairie	2:30-3:00	1	0.6	Water clear.
"	3:00-3:30	1	1.7	Water clear, no erosion.
"	3:30-4:00	1	2.3	Runoff ceased at end of watering.
	July 4			
"	9:15-9:45	1	3.1	Runoff began after 15 min.
"	10:00-10:30	1	7.8	Runoff ceased in 3 min. after watering. Water clear.
	July 5			
"	10:25-10:55	1	4.1	Water clear, no erosion.
	July 4			
Wheat stubble	11:05-11:35	1	4.9	Stubble 2.5 to 3 in. high. Few weeds.
"	11:35-12:05	1	18.3	Water muddy.
"	12:05-12:35	1	27.1	Muddy, total erosion 40.2 oz.
	July 5			
"	8:45-9:15	1	30.9	Water muddy, erosion 15 oz.
"	9:30-10:00	1	56.7	Muddy. Channels formed. Erosion 40.2 oz.
	July 3			
Fallow field	4:00-4:30	1	0.3	Bare soil just hoed 4 in. deep, rough.
"	4:30-5:00	1	18.1	Water very turbid till end of watering.
"	5:00-5:30	1	35.8	Runoff ceased 5 min. after watering. Total erosion 77 oz.
	July 4			
"	10:00-10:30	1	38.6	Runoff began after 5 min.; ceased 5 min. after watering. Eroded soil 52 oz.

The watering on July 3 showed that the very dry surface soil of the prairie (with a water content below the hygroscopic coefficient) absorbed the three inches of water during 1.5 hours with only 1.5 per cent runoff. There was no erosion. The fallow field absorbed even better than the prairie during the first half hour, but soon the soil pores became partially blocked so that 18.1 per cent of the total three inches of water was lost, as well as 1.04 tons of soil per acre. Sampling on the following morning showed that the water had penetrated to an average depth of 14 inches in the prairie.

The two inches of water applied on July 4 were absorbed by the prairie with only 5.5 per cent runoff and no erosion. The following morning the soil was wet to a depth of 16 inches near the upper end of the area and 21 inches near the foot. The fallow field lost 38.6 per cent of the water from the single inch applied and .71 ton of soil per acre.

Water was applied to the wheat stubble on July 4 in the same amounts and at the same rate as in the prairie on July 3. The original water content of the first foot was quite as low as that in the grassland. It may be noted in Table 7 that the runoff was very much greater in the field after each inch of applied water; the runoff for the three inches was 16.8 per cent. Moreover, .54 ton of soil per acre was removed from the surface of the field. The following morning the water had penetrated 11 inches at the lower end of the slope but only 7 at the upper end of the enclosure. This averaged 5 inches less than in the prairie.

With the application of a fourth inch of water to the wheat stubble on July 5, runoff was greatly increased, and 43.8 per cent of the fourth and fifth inch was lost in this manner. Also the additional two inches of water removed .75 ton of surface soil per acre. While 5 inches of water wet the prairie to an average depth of 18 inches, average water penetration in the wheat field did not exceed 12 inches.

Soil samples showed that the field soil held 4 per cent more water in the surface 4 inches five days after the 5 inches of water were applied than did the prairie after a single day. But in the 4 to 12 inch layer the prairie soil had 7 per cent more water than the field soil. The higher water content of the portion of the second foot of soil that was moistened was also significantly greater in the prairie.

The prairie soil had been so thoroughly depleted of its moisture that 7.5 inches of water increased the water content only in the first 3 feet. Samples of dry soil taken during the experiments to depths of 3 feet at a distance of 3 inches outside of the enclosed areas showed that there was little lateral movement of the soil water.

Summarizing, the total runoff resulting from the application of 5 inches of water was 3.1 per cent in the prairie, 27.6 per cent in the stubble field, and 23.2 per cent in the fallow land (where only 4 inches were applied). Erosion from the prairie was practically nil; 1.29 tons of soil per acre were eroded from the stubble field, and 1.75 tons were washed away from the fallow land.

STUDIES IN PRAIRIE AND ALFALFA FIELD

The field about the preceding runoff areas was plowed in early fall and a crop of alfalfa sowed on September 8. Soil moisture was favorable and the plants made an excellent fall growth. Late in October two new runoff areas of 5° slope were installed in the alfalfa field and an additional one in the prairie. The most distant were only 50 feet apart. Water losses from these areas, until a first cutting of the crop on June 25 the following summer, are shown in Table 8.

TABLE 8.—*Runoff from prairie and alfalfa field.*

Date	Rainfall, inches	Percentage of runoff	
		Prairie [1]	Alfalfa [1]
Nov. 2-3 1934	.54	0.3	0.0
" 17-18 "	.28	0.0	5.7
" 22 "	.40	0.1	10.5
March 3 1935	.21	50.4	15.2
" 7 "	.32	2.3	17.5
" 17 "	.38	1.1	3.4
April 11 "	1.20	0.2	0.1
May 11-12 "	.73	0.0	2.6
" 19 "	1.03	0.0	0.4
" 21 "	.82	0.0	6.6
" 27 "	.54	0.7	33.3
" 28 "	.26	0.3	0.4
" 30 "	.46	0.0	3.8
" 31 "	1.42	18.0	43.4[2]
June 1 "	.42	0.0	36.0
" 2 "	.57	0.6	2.8
" 3 "	.63	2.5	88.3
" 4 "	.06	0.0	1.3
" 6 "	.34	0.2	34.1
Nov. 2 1934 to June 6 1935—Total	10.61	3.8	19.2

[1] Average from two similar areas.
[2] Runoff exceeded the capacity of the interceptometers.

Water losses from the November rains were much greater in the alfalfa field than in the grassland. The greater loss from the prairie sod on March 3 was due to the fact that the grass-covered soil remained frozen or partly frozen longer than the much exposed soil in the field. Examination of Table 8 shows that, with few exceptions, the loss of water was greater in the field of young alfalfa after every rain. This occurred notwithstanding the fact that the crop made an excellent growth in spring and was 5 inches tall on May 1. On June 1 when no runoff occurred in either prairie area, an average of 36 per cent was lost from the field. On June 3, a rain of .63 inch resulted in a water loss of 88.3 per cent from the alfalfa field, but only 2.5 per cent from the prairie.

A total runoff of 3.8 per cent of the 10.6 inches of precipitation was determined for prairie and 19.2 for the field of alfalfa.

EXPERIMENTAL WATERING

On May 2, 1935, the alfalfa was 5 inches tall and free of weeds. The soil was checked and cracked to a depth of 1.5 to 2 inches. The early prairie grasses, viz. bluegrass (*Poa pratensis*), June grass (*Koeleria cristata*), and needle grass (*Stipa spartea*), as well as certain sedges and forbs had also reached a general height of about 5 inches (Figs. 10 and 11).

FIG. 10.—View of prairie in a runoff-plot on a 5-degree slope on May 2, 1935.
FIG. 11.—Alfalfa five inches tall in a runoff-plot on a 5-degree slope on May 2, 1935.

Sprinkling gave the results shown in Table 9. It is of interest that despite the rough surface of the alfalfa field, runoff began a little earlier, and for every inch of water applied it was greater in amount than in the prairie. Water ran from the top to the bottom of the area after 18 minutes, the cracks having been fairly well sealed by the swelling of the wetted soil and by the shifting of the soil particles. In the prairie, runoff from the top to the bottom of the area began only after seventy-five minutes. Both alfalfa and native vegetation stood erect throughout the experiment, although some channels were formed in the alfalfa field. In the prairie runoff stopped 1 to 5 minutes after watering; in the alfalfa only after 9 to 11 minutes. Runoff in the prairie was 5.9 per cent; that in the field 40.8 per cent. Moreover, 3.3 pounds of soil (.72 ton per acre) were washed away from the alfalfa plot.

EXPERIMENTAL WATERING IN BURNED PRAIRIE AND CORN FIELD

A study of the comparative runoff and erosion from a burned prairie and a cultivated field was made on May 10, 1935. The soil was Lancaster sandy loam, the slope 7°. The prairie had been burned in the spring for three consecutive years. The new cover of little bluestem (*Andropogon scoparius*) and big bluestem (*A. furcatus*) was about 4 inches high. The corn field occupied a portion of the prairie that had been broken six years

TABLE 9.—*Runoff and erosion from prairie and alfalfa field (5° slope), May, 1935.*

Place	Time	Water, inches	Percentage runoff	Soil eroded, ounces	Remarks
Prairie	May 2 9:10-9:40	1	0.9	None	Water clear, runoff began in 20 min.
"	9:40-10:10	1	3.1	"	Water clear, trickled slowly from middle to lower end.
"	10:45-11:15	1	15.4	"	Water clear, runoff began in 12 min. Finally ran from top of enclosure.
"	May 3 4:00-4:30	1	4.3	"	Water clear, runoff began in 18 min.
Alfalfa field	May 2 8:10-8:40	1	4.8	3.0	Water turbid, runoff began in 15 min.
"	8:40-9:10	1	46.8	14.0	Water muddy, constant stream from top to bottom of enclosure.
"	10:15-10:45	1	56.8	16.0	Very muddy, runoff began in 1.5 min.
"	May 3 4:30-5:00	1	54.8	20.0	Very muddy, runoff began in 3 min.

previously and continuously cropped to corn. The soil had been disked and harrowed in preparing the ground for a seventh crop.

Three inches of water were applied to each area during a single period of one and one-half hours. There was no runoff in the prairie, which apparently could have readily absorbed another inch or more of water.

In the field, runoff began in 20 minutes and in 28 minutes water was running the full length of the area. Runoff totaled 3.2 per cent and loss by soil erosion 697 pounds per acre. A rill began to form at the beginning of the second 30-minute period. In 25 minutes it was about 2 inches deep and 3 inches wide and had worked back 7 feet from the lower end of the enclosure. Of this inch of water 24.2 per cent was lost in runoff, and 4.43 tons of soil were washed away. During the application of the third inch of water the small gulley cut back two feet farther and there was formed a shallow channel throughout the entire length of the area. Runoff was 32.6 per cent, and soil eroded 7.41 tons per acre.

Thus of the three inches of water 20 per cent was lost in runoff. Moreover in running off it carried with it 12.2 tons of soil per acre.

DISCUSSION

These experiments are illustrative of differences between the effect of prairie and certain cultivated crops as regards runoff and erosion. The time of experimentation was too short for final conclusions. Because of the light precipitation during this period of relative drought, the differences are probably not as great as they would be over a period of years with normal rainfall. A single intensive rain sometimes causes more loss in an hour or two than may occur during an entire year. Bennett ('34) cites the following example from Bethany, Missouri. A rain of 3.7 inches fell on corn-plots on April 3, 1934, 3.03 inches falling at the average rate of 2.36 inches an hour. Sixty-nine per cent of the water was immediately lost as runoff, although only 27 per cent of the total rainfall of 1933 was lost from the same plot. The loss of soil resulting from this one rain was 46 tons as against 56 tons per acre from the 76 rains that fell during the preceding year.

It has been conservatively estimated that it requires more than 400 years to produce a single inch of surface soil. This is clearly too slow a rate to keep pace with soil removal under artificial disturbance such as is incurred by cropping. Experiments at Columbia, Missouri, have shown the relatively short time required to remove the surface 7 inches of soil (Miller and Krusekopf, '32). In cultivated corn land this is 50 years; in fallow land cultivated 4 inches deep only 24 years; land continuously cropped to wheat, 100 years; but on land under a cover of bluegrass it would require at least 3,000 years.

Studies on the effectiveness of various plant covers in preventing runoff losses show that alfalfa is a great stabilizer of soil. The large foliage cover in well established fields protects the soil from driving rains and its great usage of water keeps the soil receptive to moisture. Losses from fields of alfalfa are usually much less than from other crops and often do not exceed those from a cover of bluegrass or other grass crop grown from seed or transplanted as sod in cultivated land.

The efficiency of a grass cover and the great losses suffered when the land is replaced by crops is well illustrated at Hays, Kansas. Under a meager annual precipitation of 22.18 inches, fields rotated to wheat, Kaffir corn, and fallow have suffered an average annual loss of 16.34 per cent of the rainfall and 15.79 tons of soil per acre. But under the protection of a cover of native grass the runoff equalled only 0.64 inch of rain and eroded soil only .09 ton per acre (Lowdermilk, '35).

Mean annual losses during a period of four years were determined at the Red Plains Soil Erosion Experiment Station at Guthrie, Oklahoma. The average rainfall is 33 inches, the slope 7.7 per cent. Runoff from Bermuda grass sod was 1.5 per cent of the precipitation as compared with 14 per cent from cotton cultivated in rows. The erosion was .04 and 26.7 tons per acre respectively (Bennett, '34[a]).

At Spur, in northwestern Texas, the average annual loss of water by runoff from a 2 per cent slope on a clay loam soil was 6.1 per cent for buffalo-grass sod, 19.5 per cent where the soil was continuously cropped to cotton, and 32.6 per cent on fallow land. Under this annual rainfall of 17 inches, average annual losses of topsoil were 3.8, 12.6, and 18.6 tons per acre respectively (Conner *et al.,* '30).

"The results of careful measurements of the runoff and erosion from representative areas of 12 major soil types throughout the country show on the average that where grass, or a similar dense crop, is grown 5 times more rain water is absorbed and 65 times less soil is washed away as compared with the losses of soil and water from exactly the same kind of land, occupying the same slope, and receiving the same rainfall, where clean-tilled crops are grown. These measurements have been made from about the average slope of the soil types involved, and they represent annual losses over a period ranging from 2 to 4 years" (Bennett, '35).

General erosion, such as occurred in the field of corn, increases following removal of the surface soil by sheet washing, and it is at this stage of progressive erosion that gulleying occurs. This is the beginning of the final stage of land destruction. Lowdermilk ('35[a]) states that "Gully erosion is the death stage in the cancer-like eating process of water erosion. Rills, if neglected, develop into gullies which cut into the soil and the subsoil beneath like ripsaws". But in the tilled fields, cultivation following rains obliterates the rills and the farmer soon forgets that he has lost a considerable part of his limited capital of rich topsoil.

More than all other physical agencies with which man has any causative association, accelerated erosion is responsible for soil impoverishment and eventual soil destruction. Shantz ('35) points out that on agricultural land the success or failure of cultural practices should be judged not alone by the crop produced, but by the absence of erosion damage to the soil and the maintenance of physical tilth and fertility.

Since it is necessary to clear land for the production of food and textile crops, the first problem is to determine what lands may be safely used. Properly terracing the slopes where farming is too profitable to be abandoned and growing strips of long lived, deeply rooted crops following the contour lines will prevent the gulley cutting, down hill drainage. In the employment of crop rotations, fertilizers, and other modern methods of erosion control, emphasis should be placed upon a continuously protecting plant cover. One of the chief essentials of erosion control is the increased use of grass crops. Grass is invaluable to permanent and successful agriculture.

SUMMARY

Soil erosion is a national menace. It is a complex problem in which the pertinent factors of climate, slope, soil, and vegetation must each be analyzed and evaluated for different areas and regions. A full understanding of the scientific principles underlying the process will be had only after long continued research.

Erosion is one of the interactions between climate, vegetation, and soil, in which the plant cover is a decisive factor.

There was no problem of accelerated soil erosion in the West until much of the grassland was broken for cropping or weakened by continuous overgrazing.

Soil is as much a product of vegetation as vegetation is a product of soil. Throughout the centuries vegetation has favorably influenced the development of soil. Its presence in the soil, whether alive or dead, profoundly affects soil structure, water absorption, percolation, and water retention, while the mantle of grassland above ground protects the earth like a garment.

Runoff and erosion have been measured from entire watersheds and, more recently, by the runoff-plot method.

Enclosed plots 3 feet wide and 33.3 feet long were used in these studies. Natural rainfall was supplemented by artificial watering.

Runoff on a 10° slope from 26.88 inches of rainfall during 15 months was 2.5 per cent from prairie, 9.1 from overgrazed pasture, and 15.1 per

cent from a pasture entirely bared by close grazing. The soil was Carrington silt loam. No measurable amount of soil eroded from the prairie, only a small amount from the pasture, but 5.08 tons per acre were lost from the bare area.

Both 1934 and 1935 were years of drought and consequently runoff and erosion were light.

Runoff from 4 inches of water applied to pasture and prairie, respectively, in July, 1934, at the rate of 2 inches per hour (including 1 inch applied in 15 minutes) at intervals two weeks apart, resulted in 3.1 and 9.8 per cent runoff. In April of the next year 2.5 inches were applied at the same rate to prairie, pasture, and bare area. Runoff losses were 0, 29.3, and 50.4 per cent, respectively, and losses by erosion 0, 165 lbs., and 3.42 tons of soil per acre.

In October, after another summer of close grazing and root deterioration, three inches of water were applied in 1.5 hours to each area. Runoff from prairie, pasture, and bare area was 11.3, 50.5, and 71.6 per cent, respectively, and soil losses from erosion 0, 355 lbs., and 4.67 tons per acre. Water penetration was nearly four times as great in prairie as in pasture.

Where there is a good cover of grass there is no serious problem of erosion. But where the cover of grass is broken or removed by excessive grazing, erosion is the inevitable sequel. Nature, unhindered, will repair the cover if soil erosion has not progressed too far. But once the good topsoil is washed away, restoration of former conditions requires very long periods of time. Pasture improvement is a chief weapon against erosion.

Runoff on a 5° slope from 12.9 inches of rainfall during a period of 11 months was 1 per cent from prairie, 12.1 per cent from wheat field, and 17.8 per cent from fallow land. The soil was Carrington silt loam. No measurable erosion occurred in prairie, .52 ton of soil per acre eroded from the wheat field, and 2.6 tons from the fallow land.

Five inches of water were applied to prairie and wheat stubble, and 4 inches to fallow land during a period of two days. Runoff was 3.1, 27.6, and 23.2 per cent, respectively, and soil erosion was nil, 1.29 tons, and 1.75 tons per acre, in the same sequence.

Runoff from prairie and young alfalfa on Carrington silt loam with a 5° slope during a period of about 7 months was 3.8 and 19.2 per cent, respectively, from a total rainfall of 10.6 inches.

Four inches of water applied to each plot in spring when the alfalfa was 5 inches tall resulted in 5.9 per cent runoff in prairie and 40.8 per cent in alfalfa. No erosion occurred in the grassland but .72 ton per acre in the field.

Runoff resulting from the application of 3 inches of water in 1.5 hours on May 10 on a 7° slope on Lancaster sandy loam was nil from burned prairie, but 20 per cent from broken prairie cropped to corn for a period of six years. Topsoil lost by erosion was 12.2 tons per acre.

A soil covered with its natural mantle of climax vegetation represents conditions most favorable to maximum absorption of rainfall and maximum erosion control.

Soils that have been depleted of their organic matter and are poor in structure are less absorptive and are easily eroded.

Methods of increasing the use of grass and other thickly growing crops that furnish a cover similar to the prairie should be intensively studied. Thus more of the rain may be retained where it falls and the soil on the slopes held in place.

Work at the Federal Erosion Experiment Stations shows that under many conditions erosion can be enormously reduced or almost completely controlled with adaptable measures involving a cover of vegetation. One of the chief essentials of erosion control is the increased use of grasses.

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