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THE RELATION OF THE SMALLER FOREST AREAS IN NON-FORESTED REGIONS TO EVAPORATION AND MOVEMENT OF SOIL WATER

IRWIN T. BODE

The importance of the climatic and edaphic relations of forests has been the basis for wide discussion and study. The scope of this field is shown in a condensed way in a report of the Sub-Committee on Forest Investigations to the Fifth National Conservation Congress,[1] which discusses studies undertaken up to the time of the report (1913) and presents in general results obtained. Recently, Zon,[2] in a paper, "Forests and Water in the Light of Scientific Investigation," has presented a much more comprehensive view of the subject and the literature. He has attempted to bring together "all the well established scientific facts in regard to the relation of forests to the water supply." The work includes an extensive bibliography.

It is not necessary in the present discussion, therefore, to attempt to review the whole field or all of the literature with reference to these edaphic and climatic relations. Such citations are made as are pertinent to the particular phases of the present studies.

In connection with the management of the timber-lands in the Southwest, Pearson [3] has presented considerable data as the result of studies to determine the influence of forest cover upon local climate. The effects upon air temperature, soil temperature, precipitation, atmospheric humidity, and wind are included. Only meager information, however, is presented as to the relation of forests to soil moisture and evaporation. With regard to evaporation, Pearson states that the influence of the forest in decreasing the same is 30 per cent greater in Europe than it was found to be in his studies for New Mexico and Arizona.

1 The relation of forests to water, Rept. Sub-committee on Forest Investigations to Fifth National Conservation Congress. November, 1913.

2 Zon, Raphael, Forests and water in the light of scientific investigation, Final Rept., National Waterways Commission, Appendix V.

3 Pearson, G. A., A meteorological study of parks and timbered areas in the western yellow-pine forests of Arizona and New Mexico. Reprinted from Monthly Weather Rev. 41: 1615-1629. 1913.

Hall and Maxwell,[4] Toumey,[5] Bray,[6] and Schwartz [7] have confined their studies more particularly to the influence of forests upon stream flow, although Bray includes studies concerning the general influence upon climate and the relations of various plant associations to soil moisture. Hall and Maxwell present very interesting information regarding the flood problem along the courses of various streams in the United States. They show that, with certain exceptions, the tendency is toward increased floods and that this has a relation to the forest cover especially on the slopes of the drainage area, which slopes are considered by them as making up the vital part of a water-shed. Zon arrives at a similar conclusion.

None of these writers, however, has dealt to any great extent with direct measurements of soil moisture in forested areas, to determine specifically the extent to which forests control the movement of soil water after the surplus has passed on as run-off, and the effect that this influence may have as regards the water table throughout a region in general. It is true that Zon does present extensive information to show that there is a direct relation between forests and stream flow, seepage into the soil, flow of springs, etc., and he establishes further that there is an important relation existing between forests and the water table.

The importance of this latter problem has been more fully presented by McGee.[8] He shows that the level of the water table throughout the United States has lowered appreciably within the past fifty years, having dropped 12.5 feet in Iowa. He shows also the importance of forested areas in connection with this lowering.

It was with these considerations in mind that the studies here discussed were undertaken. It is recognized that the work done is of more or less preliminary nature, and that the results of various phases at least are to be interpreted as indications of certain deductions rather than as permitting final conclusions.

The work consisted of two lines of investigation: first, the determination of the rate of evaporation for forested and open

4 Hall, Wm. L., and Hu Maxwell, Surface conditions and stream flow: U. S. Dept. Agric., Forest Service, Circular 176, January, 1910.

5 Toumey, James W., The relation of forests to stream flow: Reprinted from U. S. Dept. of Agric., Yearbook for 1903.

6 Bray, Wm. L., The timber of the Edwards Plateau of Texas; its relation to climate, water supply, and soil: U. S. Dept. Agric., Bur. Forestry, Bull. 49, 1904.

7 Schwartz, G. Frederick, The diminished flow of the Rock River in Wisconsin and Illinois, and its relation to the surrounding forests: U. S. Dept. Agric., Bur. Forestry, Bull. 44, 1903.

8 McGee, W J, Wells and subsoil water: U. S. Dept. Agric., Bur. Soils, Bull. 92, 1913.

sites and for sites representing a stage between these two; second, soil moisture determinations for forested and open sites.

THE AREA

The area chosen for these tests was in the "Backbone" State Park in northwestern Delaware county, Iowa. It is in a section of the state which was covered by the older continental glaciers, where there is still a large portion of native timber growth and where conditions do not approximate so nearly the prairie conditions of other parts of the state. The park area itself is rough in topography and typical of much of that country, which is not valuable for agriculture other than for grazing.

Description of Sites.— Four main sites were selected upon which to locate the various stations as described in Table A. All of these were at one time covered with heavy timber growth. This has been entirely cleared from sites 1 and 3. Site 1 has been continuously grazed since the removal of the timber, while site 3 has been grazed only occasionally and is now reproducing a timber stand. A good layer of litter and decaying vegetable matter covers the soil on sites 2 and 4, both of which still carry a heavy stand of timber growth.

EVAPORATION

Column 1 Table A shows the location of all the various stations.

Evaporation readings were made at stations as follows:

TABLE A. SITE AND DESCRIPTIONS AND STATION LOCATIONS

Site No.	Location of Stations and Exposure	Soil			Description	Chief Timber Species	Undergrowth Species	Ground Cover
		Surface	Subsurface	Subsoil				
1	X—Top	Silt loam	Light clay loam, some sand	Light clay loam, some sand	Open; heavy grass sod, wide scattered red cedar; formerly timbered; no brush growth; slope steep; pastured since cutting	Juniperus virginiana		Bluegrass; clover; scattered Achillea millefolium
	XI—Middle (south)	Very fine sandy loam	Silt loam, some sand	Silt loam, some sand				
	XII—Foot (south)	Very fine sandy loam	Very fine sandy loam	Fine sandy loam				
2	IX—Middle (east)				Timbered; no sod; trees forming full stand, complete canopy; slope steep, protected by ridges to north and south	Quercus ellipsoidalis, Quercus macrocarpa, Populus deltoides, Populus grandidentata, Ostrya virginiana, Ulmus americana, Tilia americana		Adiantum pedatum, Pteris aquilina, scattered grasses (very light)
3	V—Top IV—Middle (south) VI—Middle (north)				Not timbered; formerly timbered; dense stand of brush and timber reproduction; slope moderate; not continuously pastured	Populus tremuloides, Populus grandidentata, Populus deltoides, Quercus rubra, Quercus ellipsoidalis, Quercus alba, Juniperus virginiana	Rhus typhina, Rhus glabra, Corylus—(40 to 50 per cent of cover)	Heavy grass sod wherever openings occur
4	II—Top	Very fine sandy to silt loam	Very fine sandy loam	Very fine sandy loam, some clay	Timbered; dense stand with nearly complete canopy; moderate growth of underbrush and ground cover; slope steep	Quercus macrocarpa, Quercus rubra, Quercus ellipsoidalis, Acer saccharum, Ostrya virginiana, Ulmus americana, Carpinus caroliniana, Populus tremuloides, Populus grandidentata	Cornus alternifolia, Cornus asperifolia, Cornus circinata, Cornus paniculata, Physocarpus opulifolius, Viburnum acerifolium	Adiantum pedatum, Pteris aquilina, Pellæa atropurpurea, Asarum canadense, scattered grasses
	Ia—Foot (south)	Very fine sandy to silt loam	Sandy loam	Coarse sandy loam				
	Ib—Middle (south)	Very fine sandy loam	Sandy loam	Sandy loam				
	III—Middle (north)							

Timbered site: Station II (top of slope); station I b (middle of south slope); station III (middle of north slope); station IX (middle of east slope).

Brushy site: Station V (top of slope); station IV (middle of south slope); station VI (middle of north slope).

Open site: Station X (top of slope); station XI (middle of south slope).

The stations at the top of the slopes especially were located with respect to uniformity of exposure to the action of the wind from all directions, so that the only mitigating influence in this regard would be that offered by the vegetation.

Evaporation readings were taken morning and evening of alternate days, at 6 A.M. and 6 P.M. For these determinations the standardized cylindrical form of the Livingston atmometer was used.

RESULTS OF EVAPORATION STUDIES

These results have been brought together in tables B and C and in the form of a chart, figure 28.

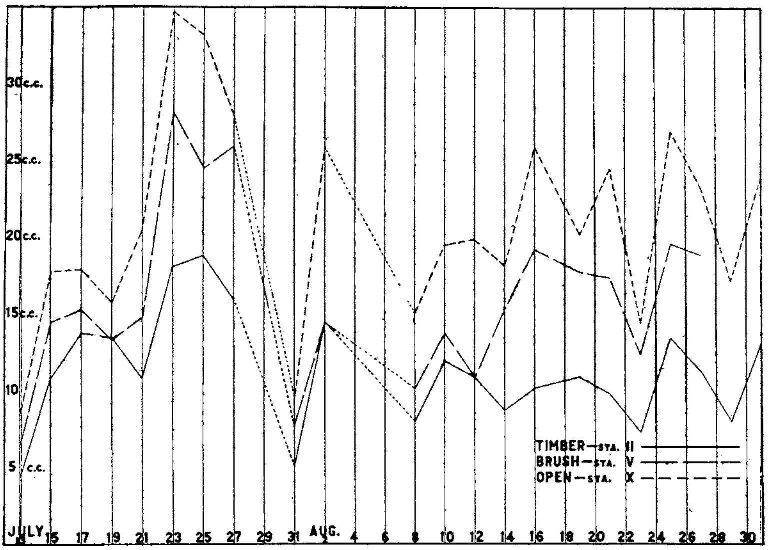

Fig. 28. Evaporation at top of timbered, brushy and open slopes. Readings for period 6 A.M. to 6 P.M. Fine dotted lines indicate points where readings were affected by precipitation.

In consulting table B it is found that the average daily rates of evaporation for the period of the tests for the stations at the top of the slopes are as follows: 11.24 c.c. in the timber; 15.83 c.c. on the brushy site; 20.25 c.c. in the open. Again, for the stations at the middle of the slope, the average daily rate is 7.12 c.c. for the timber, 12.87 c.c. for the brush and 18.69 c.c. for the open. Furthermore, the rate of evaporation for each individual day shows the same ascendency as the above averages. This comparison is shown diagramatically in figure 28.

TABLE B. EVAPORATION IN C. C. AT THE TOP AND MIDDLE OF SLOPE FOR TIMBERED, BRUSHY AND OPEN SITES

	Location—Top of Slope			Location—Middle of Slope		
Date	Timbered Slope (Sta. II)	Brushy Slope (Sta. V)	Open Slope (Sta. X)	Timbered Slope (Sta. 1a)	Brushy Slope (Sta. IV)	Open Slope (Sta. XI)
July 13	4.32	6.48	8.50	2.88	4.32	
15	10.80	14.40	17.64	5.76	8.64	
17	13.68	15.12	17.68	9.36	11.52	
19	13.32	13.24	15.64	6.94	13.68	
21	10.80	14.76	20.40	5.40	12.24	
23	18.00	28.08	34.68	14.40	19.44	
25	18.72	24.48	33.12	12.96	20.16	
27	15.84	25.92	27.88	12.24	21.60	30.24
31	5.04	5.76	9.52	2.16	5.04	7.20
Aug. 2	14.40	14.40	25.84	9.36	14.40	23.04
8	7.92	10.08	14.96	5.04	10.80	12.24
10	11.88	13.68	19.38	7.92	12.96	18.00
12	10.80	10.80	19.72	7.20	8.64	18.00
14	8.64	15.12	18.00	3.96	9.52	18.00
16	10.08	19.08	25.84	6.48	14.40	23.76
19	10.80	17.64	20.06	6.84	14.40	19.44
21	9.72	17.28	24.48	5.04	12.96	20.16
23	7.20	12.24	14.28	4.68	9.36	15.12
25	13.32	19.44	26.86	7.92	18.00	21.60
27	11.16	18.72	23.12	7.92	15.48	20.52
29	7.92		17.00	5.04		14.40
31	12.96		23.80	7.20		18.72
Total	247.32	316.12	425.38	157.70	257.56	280.44
Aver. for season	11.24	15.83	20.25	7.12	12.87	18.69

The results obtained here agree closely with data presented by Fuller [9] as the result of comprehensive studies carried on for three seasons in the sand dune region near Lake Michigan. He showed that in this region there exists a direct relation between the rate of evaporation and the succession from pioneer cottonwood to climax beech-maple associations. The average daily evaporation rates for the three seasons in this region were found by Fuller to be as follows: Cottonwood dune, 22.3 c.c.; edaphic prairie, 12.5 c.c.; Oak dune, 11.0 c.c.; Pine dune, 10.4 c.c.; Oak-hickory forest, 8.8 c.c.; beech maple forest, 7.0 c.c. Transeau [10] in connection with studies made near Cold Springs Harbor, Long Island, New York, has presented similar facts. Likewise, Weaver [11]

9 Fuller, G. D., Evaporation and soil moisture in relation to the succession of plant associations: Bot. Gaz. **58**, 193-234, 1914.

10 Transeau, E. N., The relation of plant societies to evaporation: Bot. Gaz. **54**, 424-426, 1912.

has found the same decrease of evaporation with succession of plant associations in Washington and Idaho. In Minnesota and Nebraska, Weaver and Thiel [12] found the same relation to exist.

Gleason and Gates [13] have studied the influence of the various types of vegetation in Central Illinois. They have presented facts to show that here, as in other regions, the differences in the amount of evaporation in various associations are due chiefly to the nature of the vegetation, and that the more primitive types have the higher rates of evaporation, while those most nearly like the climax types have the lowest rates.

In comparing the daily rate of evaporation at the top of the slope with that at the middle, the averages are found to be:

	Top	Middle
Timber	11.24 c. c.	7.12 c. c.
Brush	15.83 c. c.	12.87 c. c.
Open	20.25 c. c.	18.69 c. c.

Thus it will be observed that in each case the average daily rate is less at the middle than at the top of the slope, and reference to table B shows again that this is uniformly true for each day.

Again, comparing the rates for the north and south slopes as shown in table C the following averages are obtained:

	North	South
Timber	5.58 c. c.	6.79 c. c.
Brush	9.64 c. c.	12.26 c. c.

However, while the averages in this case are lowest for the north slopes it is not true that the readings for each individual day show the same relation. For example, on July 15, the evaporation was 1.44 c.c. higher on the north than on the south timbered slope. The same is true in several other instances. It is important to note in this connection that, in the cases where the evaporation of the north slope exceeded that of the south slope, the direction of the wind was northwest, northeast or westerly.

The lowest minimum evaporation for the season occurred on July 13 on the north timbered slope, being only 1.44 c.c. The lowest maximum (11.52 c.c.) occurred on the same slope on

11 Weaver, J. E., A study of the vegetation of Southeastern Washington and adjacent Idaho: Reprint from Univ. Studies, Univ. Neb., XVII, No. 1, January, 1917.

12 Weaver, J. E., and Albert F. Thiel, Ecological studies in the tension zone between prairie and woodland: Bot. Sur. Neb., New Series, No. 1, April, 1917.

13 Gleason, H. A., and F. C. Gates, A comparison of the rates of evaporation in certain associations in Central Illinois: Bot. Gaz., **53**, 478-491, 1912.

TABLE C. EVAPORATION IN C. C. FOR NORTH AND SOUTH SLOPES IN TIMBER AND BRUSHY SITES

Date		Site—Timbered Slope: Direction of Slope, North (Sta. III)	Site—Timbered Slope: Direction of Slope, South (Sta. 1a)	Site—Brushy Slope: Direction of Slope, North (Sta. VI)	Site—Brushy Slope: Direction of Slope, South (Sta. IV)
July	13	1.44	2.88	4.32	4.32
	15	7.20	5.76	10.80	8.64
	17	5.04	9.36	8.64	11.52
	19	4.68	6.94	5.40	13.68
	21	8.28	5.40	13.68	12.24
	23	7.20	14.40	15.48	19.44
	25	7.20	12.96	13.68	20.16
	27	8.64	12.24	15.12	21.60
	31	2.88	2.16	4.32	5.04
August	2	9.36	9.36	10.08	14.40
	8	5.04	5.04	9.36	10.80
	10	5.04	7.92	7.20	12.96
	12	3.60	7.20	5.76	8.64
	14	2.88	3.96	7.92	9.52
	16	7.20	6.48	12.96	14.40
	19	4.32	6.84		14.40
	21	3.60	5.04	12.24	12.96
	23	2.52	4.68	6.48	9.36
	25	11.52	7.92	15.84	18.00
	27	9.36	7.92	13.68	15.48
	29	5.76	5.04		
Total		122.76	149.50	192.96	257.56
Aver. for season		5.58	6.79	9.64	12.26

August 25th. The range from minimum to maximum for the various sites is shown in the following table, taken from the records of the stations at the tops of the respective slopes.

	Minimum	Maximum	Range
Timber	4.32 c. c.	18.72 c. c.	14.40 c. c.
Brush	5.76 c. c.	28.08 c. c.	22.32 c. c.
Open	8.50 c. c.	34.68 c. c.	26.18 c. c.

It is interesting to compare the data in this connection with observations made by Shimek [14] near Missouri Valley, Iowa, and by Weaver [15] in the mountains of northern Idaho. Shimek found, with cup evaporimeters, an average evaporation of 21.07 c.c. for the prairie as against 10.07 c.c. for the groves. Furthermore, in a series of curves he shows a direct increase in evaporation with increase of wind velocity and temperature; also, in his discussion, he presents facts bearing out the results obtained above relative to the evaporation on sites with north and south exposures, and relative to the effect of topography on evaporation. Weaver

14 Shimek, B., The prairies: Lab. Nat. Hist., Univ. of Iowa, **6**, 169-240, 1911-13.

15 Weaver, J. E., Natural reforestation in the mountains of Northern Idaho: Plant World, **18**, 31-47, 1915.

found the average daily evaporation to be 19.0 c.c. on north slopes as compared with 27.7 c.c. for south slopes.

Summary

The results obtained from the present studies in northern Iowa may be summarized briefly as follows:

Forest cover exerts a direct influence in checking evaporation.

There is a regular decrease in the rate of evaporation with the succession from open to brushy sites, and in turn to timbered sites.

The evaporation is uniformly greater at the top of the slopes than at the middle for all the sites.

The evaporation is greater on south than north slopes, except as influenced by the direction of the wind.

Topography and wind direction, therefore, both have a direct influence on the evaporation rate.

Forested areas have a distinct effect in equalizing the rate of evaporation as shown by the low minimum and maximum rates and the small margin or range of fluctuation throughout the season in the timbered area.

SOIL MOISTURE

Relation to Plants and Plant Associations

It has long been recognized that the amount of moisture in the soil is an important factor in all plant growth and distribution. Fuller,[16] Weaver,[17] Weaver and Thiel,[18] and other writers have shown that soil moisture content bears a direct relation to the type of vegetation found in various regions and to the succession of plant associations.

On the other hand, it is recognized that all the moisture present in the soil is not available for plant growth, and that plants wilt before the entire moisture content becomes exhausted. In work by Clements,[19] Livingston,[20] Briggs and McLane,[21] and Briggs and Shantz,[22] the point at which this wilting occurs is shown further to be by no means constant for the various soil types. Briggs and McLane compared the moisture retaining power of

16 Fuller, G. D., Bot. Gaz., **58**, 213-233.

17 Weaver, J. E., Univ. Studies, Univ. Nebraska, XVII, No. 1, 21-37.

18 Weaver, J. E., and A. F. Thiel, Bot. Sur. Nebraska, New Series, No. 1, 15-26.

19 Clements, F. E., Research methods in ecology, p. 334, 1905.

20 Livingston, B. E., The relation of desert plants to soil moisture and to evaporation: Carnegie Institution of Washington, Publ. No. 50, p. 78, 1906.

21 Briggs, L. J., and J. W. McLane, The moisture equivalent of soils: U. S. Dept. Agric., Bur. Soils, Bull. 45, 1907.

22 Briggs, L. J., and H. L. Shantz, The wilting coefficient for different plants and its indirect determination: U. S. Dept. Agric., Bur. Plant Ind., Bull. 230, 1912; Bot. Gaz., **51**, 210-219, 1911; and **53**, 20-37, 229-335, 1912.

different soils by subjecting them to centrifugal force, and have called the percentage of moisture retained the *moisture equivalent.* Briggs and Shantz have worked out the method which has come to be most generally used in comparing the available moisture supply of various types of soils. They have called the percentage of water remaining in soils when wilting occurs the *wilting coefficient.* Fuller has termed the amount of moisture contained in soils above the wilting coefficient *growth water.* Again, it has been shown that the wilting point of plants is not constant for the same plants and soil types. Brown,[23] has studied its relation to the evaporating power of the air and has found that the wilting point is reduced with reduction in evaporation. Briggs and Shantz [24] have found in another study that it varies also, although to a less degree, for the same soil with different types of plants. Therefore, a comparison of the total amounts of moisture contained by various soils is not a criterion of the ability of those soils to maintain plant growth.

It is necessary to recognize the above facts in view of the data presented here. The wilting coefficients have not been determined. The chief purpose is a study of the water holding capacity of the various soils and the relation of the movements of the soil water. It is evident that an increase in the total moisture content of an ordinary soil would make it more nearly capable of sustaining plant life without regard to the wilting coefficient.

Relation of Forests to Water Table

McGee [25] in his work explains how the general level of the water table of a region affects the total soil moisture content, and also the resultant effect that its recession has upon the amount of moisture available for the growth of plants in the upper soil layers. This, of course, in turn affects the ability of the vegetation to withstand periods of excessive drought and evaporation. He discusses further the causes for this recession, as does also Schwartz,[26] and it is not necessary to review the field here. A matter of especial note, however, is the general statement at which McGee arrives, namely, that it is clear that the lowering of the ground level of water is due mainly not to consumption of the accumulated stock, but to the cutting off of the natural source

23 Brown, Wm. H., The relation of evaporation to the water content of the soil at time of wilting: Plant World, **15**, 121-134, 1912.
24 Briggs, L. J., and H. L. Shantz, Bot. Gaz., **53**, 229-235, 1912.
25 McGee, W J, U. S. Dept. Agric., Bur. Soils, Bull. 92, pp. 7-11, 1913.
26 Schwartz, G. Frederick, U. S. Dept. Agric., Bur. Forestry, Bull. 44, pp. 13-15, 1903.

of supply — to the waste of storm waters through floods in lieu of compelling them to pass into the soil and enter the normal circulatory system through which alone the waters of the earth can be fully utilized. Thus, McGee concludes that so far as may be estimated, at least 80 or 90 per cent of the lowering recorded in 31 typical states is due not to excessive removal of water from the subsoil, but to failure to get a normal supply into the soil and on into the subsoil beneath.

Now, Zon [27] shows clearly that the effect of forest growth on soil water, in the immediate area of the forest at least, and in a level country with a minimum of run-off differs greatly from that in a mountainous or hilly country with maximum run-off. That is to say, in the former forests tend to act as drainers of the soil moisture and hence would apparently tend to lower the water table in their immediate vicinity. In the latter, because of the interception of run off, they have the opposite effect, namely, that of increasing the water content and of prolonging the period during which the water of the soil is depleted. He states further that observations carried on in forests over broken topography, where the geological strata are not horizontal, and the ground water therefore is in motion, and where there is a surface run-off, have failed to establish any lowering of the water table under the forest; also, that Hartman, hydraulic engineer for the State of Bavaria, found the water at Mindelheim (altitude 2000 feet) to be nearer the surface in the forest than outside.

Hall and Maxwell in their work relating to stream flow and floods bring out the same facts. Hence, upon first thought, the inference might be drawn that in an essentially level state like Iowa the general effect of forest areas with respect to the water table would be to operate to the detriment of general agriculture. However, in view of the many other influences which already have been established, the question arises as to what part forests really may have in governing the soil moisture content of a region in general and the direction or tendencies of water movement in the soils. In other words, how great a conservator of moisture is a forest in an essentially level region?

In this connection, the conclusions drawn by Shimek [28] are pertinent, namely, that the question of sufficient soil moisture in a region such as Iowa is one of conservation of the precipitation, that the claim that forests have no effect on precipitation has

27 Zon, Raphael, Rept. National Waterways Commission, Appendix V, pp. 238-245,
28 Shimek, B., Lab. Nat. Hist., Univ. Iowa, **6**, 207-208.

no significance in connection with the forest as a conservator of moisture, and that both moisture of the air and of the soil will be conserved by protection against evaporation, which may be accomplished by topography or by groves.

Area and Site Descriptions for Soil Moisture Studies

The area on which the present studies were made comprises the hillsides and banks bordering both sides of the Maquoketa river near its headwaters. Lying in a section of the state which has not been glaciated for a long time, it has drainage fairly well established. The stream in this section depends for its regular flow largely upon underground waters which come out as springs all along both banks of the river. Part of these emerge from the immediate borders of the stream, while others break forth at considerable distances from the banks. The soils of which the tests were made are for the most part sandy, especially in the surface and subsurface layers, and the movement of water in them is apt to be well defined.

In choosing the sites an attempt was made to have the soil layers as nearly similar as possible, and also, to have the slopes nearly alike in elevation, degree of slope and exposure, so that the run-off in all directions would be approximately uniform except as checked by absorption into the soil. A study of table A shows, however, that the soils on the open slope are apt to contain less sand than those for the timbered slope, especially in the subsoil layer.

Methods

Soil moisture determinations were made for stations on open and timbered slopes as follows:

Timbered site: Station II, top of slope; station Ib, middle of slope; station Ia, foot of slope.

Open site: Station X, top of slope; station XI, middle of slope; station XII, foot of slope.

Soil samples were taken at these stations at three day intervals for depths as follows: surface (0 to 7 inches), subsurface (7 to 20 inches), and subsoil (20 to 36 inches). These samples were immediately placed in screw-cap containers and taken to camp where the moisture content was determined. This was calculated in per cent of air-dry soil.

Care was taken to have the various soil borings at each station not closer than six feet. The top of each hole was filled with a grass plug and mulched over. Thus the borings already made affected to a minimum degree the drying out of the soil and the normal water content.

Results of Soil Moisture Studies

The most direct comparison of the soil moisture content can be made by reference to the accompanying tables and charts. It becomes at once apparent that, on the whole, the curves which represent the timber soils, plotted on the charts with solid lines, are higher throughout the season than those for the respective soils in the open. The exact difference between these curves is shown in the following comparison of the averages for the period of the tests.

Location on Slope	Soil	Average in Timber	Average in Open
Top of slope	Surface	15.25	5.96
	Subsurface	16.23	10.66
	Subsoil	14.65	21.80
Middle of slope	Surface	13.39	7.03
	Subsurface	15.13	8.13
	Subsoil	13.20	17.38
Foot of slope	Surface	15.88	8.10
	Subsurface	18.00	6.16
	Subsoil	17.12	18.86

It will be noted that an exception to the generally higher average of the timber soils occurs in the subsoil layers. Here the subsoil of the open slope is 7.15 per cent above that of the timber at the top, but only 4.18 and 1.74 per cent higher at the middle and foot respectively. The reason for this becomes clear in considering the physical composition of the soil as shown in table A. With similar composition in all soils there would be every reason to expect a uniformly high average for all the timber soils. It is interesting, however, to note in this connection, how very little higher are the averages for the subsoils of the open, especially at the middle and foot, in spite of their greater clay content.

As shown in table E the maximum moisture contents with the exception of the subsoils, range from 19.45 to 28.3 per cent for the timber as against 14.75 to 27.85 per cent for the open. The minima range from 6.4 to 11 per cent as against 1.55 to 5.05 per cent, respectively. Here again exceptions must be made of the subsoils for reasons already stated. An important consideration, however, with respect to the minima in these latter is that, notwithstanding the uniformly higher content of these soils, the

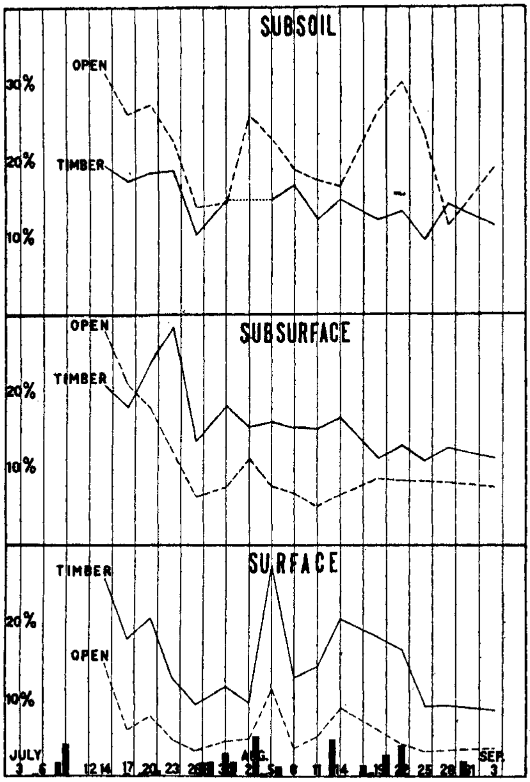

Fig. 29. Soil moisture content in per cent of air-dry soil for the top of timbered and open slopes — stations II and X, respectively. Rainfall, shown in solid columns at bottom, was approximately as follows:

For July: 5, .01 in.; 8, .43 in.; 9, 1.05 in.; 17, .01 in.; 19, .02 in.; 21, .16 in.; 27, .40 in.; 28, .42 in.; 30, .73 in.; 31, .43 in.

For August: 3, 1.30 in.; 4, .04 in.; 6, .30 in.; 13, 1.17 in.; 17, .30 in.; 18, .10 in.; 20, .75 in.; 22, 1.0 in.; 30, .40 in.

minima fall to points ranging only from .95 to 3.05 per cent above those for the timber soils.

Another interesting observation is the deficiency of moisture toward the latter part of the season in the subsurface layers of the open slope, especially at the middle and foot. These soils show the lowest constant average of any of the soils, after the general drop in July, while the corresponding timber soils show averages approximately the same as or higher than the normal for the others.

These considerations, in view of the character of the rainfall during this period, are undoubtedly significant, in that the precipitation was almost entirely in the form of heavy showers, tending to produce rapid run-off except as the precipitation was absorbed into the ground.

TABLE E. MAXIMUM AND MINIMUM SOIL MOISTURE CONTENT IN PER CENT OF DRY WEIGHT OF SOIL FOR OPEN AND TIMBERED SLOPES

Location of Station	Soil Depth		Timbered Slope		Open Slope	
			Moisture Content	Diff.	Moisture Content	Diff.
Top of Slope	Surface	Maximum Minimum	27.40 8.70	18.70	14.75 3.25	11.50
	Subsurface	Maximum Minimum	28.30 11.00	17.30	27.85 5.05	22.80
	Subsoil	Maximum Minimum	19.45 9.65	9.80	31.60 11.45	20.15
Middle of Slope	Surface	Maximum Minimum	26.05 6.40	19.65	19.85 1.55	18.30
	Subsurface	Maximum Minimum	25.00 8.00	17.00	16.50 3.35	13.15
	Subsoil	Maximum Minimum	20.10 7.60	12.50	31.55 8.55	23.00
Bottom of Slope	Surface	Maximum Minimum	24.80 9.95	14.85	25.15 1.70	23.45
	Subsurface	Maximum Minimum	29.00 9.45	19.55	21.90 1.85	20.05
	Subsoil	Maximum Minimum	23.50 8.25	15.25	28.25 11.30	16.95

RESPONSE OF MOISTURE CONTENT TO PRECIPITATION

Following the more or less clearly defined periods of precipitation it is possible to trace a rather definite response in the various soils.

After the showers of July 21, on the open slope there is no rise in the curves for the soils at the top. In all probability this is due to the high evaporation between the time of precipitation and the time of taking the soil samples on July 23, the effect of which would be the greatest at these stations. On the timber slope, however, there is apparent at the top a rise in the subsurface and subsoils. At the middle of the slopes no rise appears in either timber or open. At the foot the response is evident in the subsurface and subsoils of the timber slope but not of the open.

The rainfall of July 27 and 28 produced a general increase throughout the soils at the top of the slopes, this being the more marked in the timber. In the open at the middle and foot the increase is apparent in all the soils except the middle subsoil. In the timber, on the other hand, the curves remain approximately level or show a slight decrease. This might easily be the case in view of the character of the precipitation, which was in the form of showers of short duration, and further in view of the fact that just previous to this period the open soils showed a content equal to or very near the minimum reached for the season. Since these soils also show a finer texture they might be expected

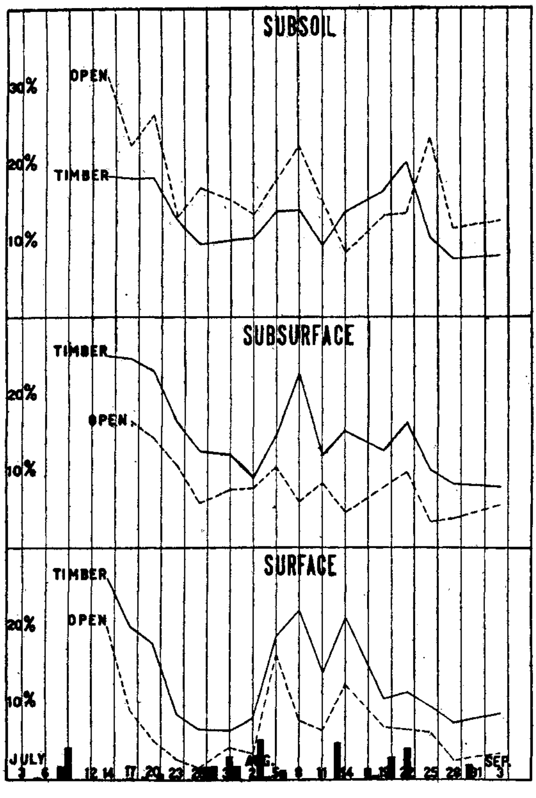

Fig. 30. Soil moisture content in per cent of air-dry soil for middle of timbered and open slopes — stations Ib and XI, respectively. For amount of rainfall see note, fig. 29.

to be more retentive of moisture, and any light precipitation would be apt to make itself more manifest here than in the timber soils, which latter may exhibit a more rapid permeability but showed more nearly a normal content before the showers occurred. It is important to observe here, however, that the content of the open soils does not reach that of the timber soils.

Following the rains which fell from July 30 to August 6, all the soils at the *top* of the timbered slope show a fluctuation with a decided rise in the surface soil. The rainfall was evidently sufficient here to maintain the moisture content in the lower layers and to add a considerable surplus to the surface. In the open, on the other hand, the rise is apparent in all the soils immediately and is greatest in the subsoil. It continues to August 5 in the surface but begins to drop in the subsurface and subsoil after August 2. Apparently then, there is in this case a more rapid gravitational movement and a greater influence of evaporation in the open than in the timber. This is particularly evident when the tendency of the curves following August 6 is considered.

At the *middle* of the slopes for the same period there appears a well marked continuous rise in all soils. This is greatest for the surface of both timber and open slopes and for the subsurface of the timber. Furthermore, the rise in the timber continues until August 8 in all soils, while in the open there occurs a drop after the 6th, except for the subsoil. The rains were heavy and the

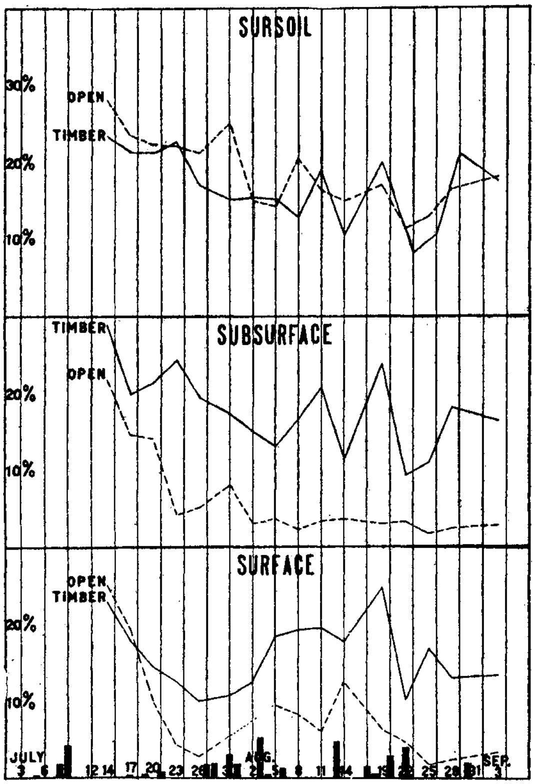

Fig. 31. Soil moisture content in per cent of air-dry soil for foot of timbered and open slopes — stations Ia and XII, respectively. For amount of rainfall see note, fig. 29.

run-off was rapid unless hindered. The subsurface of the timbered slope shows almost as great a gain as the surface, while in the open the corresponding gain is only a slight one. This would indicate again the greater power of obstructing run-off in the timbered slope, with the resultant benefit to the lower soil layers.

At the *foot* of the slopes the surface in both open and timber shows a distinct increase, but the subsurface and subsoils drop. This drop is the more rapid on the open slope. An important observation to be made at this point is that there is a marked increase lagging over into the dry period of August 6 to 11. This is decidedly more marked for the timber than for the open. The surface soils during this period show practically no increase in the timber and a decrease in the open. Then too, the subsoil of the open begins to show a drop following August 8, while in the timber there is a rise until August 11. Thus, there is further evidence of the gravitational movement toward the lower soil layers as well as toward the foot of the slopes, and also further evidence of the delaying or prolonging of the response to rainfall over a longer period in the timber soil, especially on the lower part of the slope.

The rain of August 13 was of a character which would produce moderate run-off. As a result, the response is manifested in general in all the timber soils except those at the foot of the slope. At the foot the effect of the rainfall is apparently delayed until after the 14th. In the open, however, there is evident very little or no rise in subsoils or in the subsurface soils at the middle and foot of the slope. Here, as before, the timber soils show clearly the greater amount of precipitation absorbed.

Moreover, consideration of the curves for the period subsequent to August 14, bears out other observations previously made. No precipitation is recorded until the 17th, but there is an increase in moisture content as follows:

For the Open Slope: Top of slope; in subsurface and subsoil. Middle of slope; in subsurface and subsoil. Foot of slope; in subsoil.

For the Timbered Slope: Top of slope; no increase. Middle of slope; in subsoil. Foot of slope; in surface, subsurface and subsoil.

With the exception of the foot of the timbered slope these increases for this period are accompanied by decreases in the respective surface soils. Furthermore, the increase in the timber soils is much greater than that in the open soils, this being particularly true for the lower parts of the slopes, and the increase at the foot of the timber slope extends into the subsurface and surface layers. There is in this case as in previous cases an evident gravitational movement, not alone from surface to subsoil, but also from the top to the foot of the slope. This is apparently in greater volume in the timber soils and becomes manifest at the foot of the slope much nearer the surface than in the open.

The showers during the period of August 17 to 20 were accompanied by intervening periods of comparatively high evaporation. They were neither heavy nor of long duration. As a result almost without exception the surface soils show a loss during this period except at the foot of the timbered slope. The subsurface and subsoils on the whole show a gain. This gain tends to become apparent earliest in the open soils, the timber soils again showing a tendency to lag behind. Also, with the exception of the clay subsoil at the top of the open slope, the timber soils show the highest gains. In the subsoils the moisture content remains approximately level at the top of the timbered slope but shows a decided rise at the middle and foot.

The rains of the 22d and 30th affected the soil moisture curves as did the previous periods of precipitation, and here again one of the outstanding facts is the delayed rise in the lower layers, especially at the middle and foot of the slopes, and the decidedly greater rises of the timber over the open soils.

SUMMARY

The comparative results of these studies are in many respects less clearly defined than those for the evaporation studies. A cursory consideration appears to indicate rather irregular results, with less clearly defined relationships of forest cover to soil moisture and especially to the movement of ground water than is the case with evaporation. It is true that the results obtained and the deductions made here should form the basis of further study, and they are presented as indications of existing relationships. However, certain rather direct influences are apparent.

On the whole, the timber soils used in this study show greater sand content and therefore would be expected to show, from the standpoint of physical composition alone, a more rapid rate of permeability and a lower moisture holding capacity than the finer textured soils of the open. This is of especial interest since it undoubtedly explains the relatively high moisture content of the subsoils of the open slope. Moreover, it emphasizes the importance of the influence of forest cover, in that actual comparison shows the coarser forest soils used in these studies to be capable of maintaining the higher moisture content in all instances but in the subsoil, and here there is found almost a clay soil in the open.

The average content of the timber soils as well as both maximum and minimum contents are above those for the open soils, with an exception made of the heavier subsoils of the open slope. This is most clearly emphasized toward the latter part of the season. The fact that, in the open, in spite of the greater retentive power of the heavier subsoils, the minimum drops to a point almost equal to or lower than that for the timber soils, is important, since, as has been shown by Fuller and by Briggs and Shantz and others, the wilting coefficients of such soils are higher than for the sandier soils. Furthermore the wilting coefficient of these soils would be expected to be above that of the timber soils, because as Brown and others have shown the wilting coefficient rises with increased evaporation of the air.

Throughout all of the above the greater absorptive power of the timber soils is apparent, as well as the influence this has upon the moisture content of the various soil layers. This is perhaps most strikingly manifested at the middle of the slopes where precipitation with rapid run-off has the least opportunity to penetrate into the subsurface and subsoils. It is found that on the open slope the subsurface soils at the middle and foot show the lowest constant averages of any of the soils, while the same relation does not exist in the timber.

The run-off is, therefore, without question the greatest on the open slopes. The result of this is especially marked in the subsurface and subsoil regions where we frequently find little or no response to rainfall in the open but a decided upward tendency of the curves for the timber areas. This difference seems more marked as the season progresses.

There is apparent a distinct gravitational movement of soil water from upper to lower soil layers and from the top toward the foot of the slopes. The lower soil areas rather uniformly show a continued increase in moisture content after the surface layers have begun to exhibit a drop. The difference in the rate at which gravitational movement takes place is not finally established, but every indication points to its being most rapid on the open slope following precipitation, and to its being in greater quantity, steadier, and distributed throughout a longer period in the timber soils. Furthermore, in these latter soils there is evidence of the increased volume of gravitational moisture and the delayed increase, during a period without precipitation, of the moisture content of the subsurface and even surface layers at the lower part of the slope.

Consequently, these general results all lead directly to a recognition of the close relationship between forest cover and soil moisture content in regions like the one under consideration here. They lead to the further recognition of the influence of forest areas of even small extent in maintaining greater quantities of moisture in the upper soil layers, and to their ability to prolong the period of gravitation of moisture, both from surface to lower soil strata and from upper to lower elevations on a slope. This, it is evident, would have a direct bearing upon the source of streams such as exist in the area discussed, where this source is largely in underground waters or springs.

Since in even a limited area, as was included in the present studies, the removal of the forest cover from one of the slopes has had the marked effect shown, indications point strongly to the final influence of forests in maintaining a higher water level throughout the region in general as being an exceedingly important one.

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