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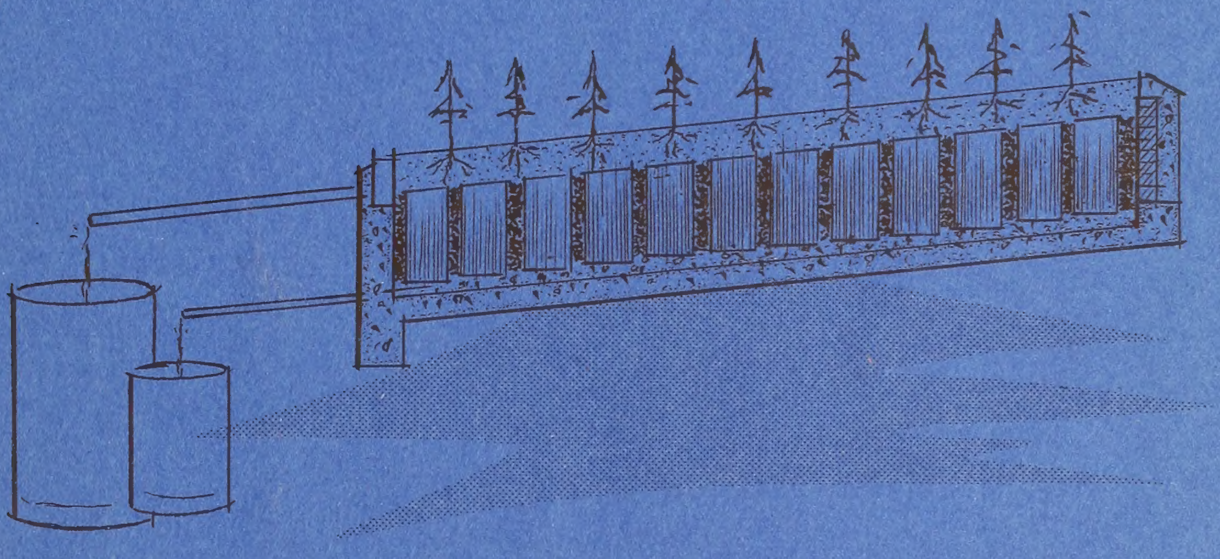
WATER YIELD and SOIL LOSS from SOIL-BLOCK LYSIMETERS

RICHARD S. SARTZ



LAKE STATES FOREST EXPERIMENT STATION
M. B. Dickerman, Director
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

ACKNOWLEDGEMENTS

The study reported here was made between 1934 and 1942 by personnel of the Lake States Forest Experiment Station. Director of the Station at that time was Raphael Zon. The study was planned and supervised by Carlos G. Bates, a pioneer Forest Service researcher. Harold F. Scholz was in charge of on-the-ground operations. He was assisted in construction of the lysimeters by J. H. Stoeckeler. Day-to-day measurements and records-keeping for most of the study were handled by Robert G. Neu.

Mr. Scholz is currently Research Forester (Forest Management) at the Lake States Station's field unit in Wausau, Wis.; Dr. Stoeckeler is Soil Scientist with the Station at St. Paul; and Mr. Neu is Administrative Assistant with the Agricultural Research Service at Madison, Wis.

The work was done at the Upper Mississippi Valley Soil Conservation Experiment Station, near La Crosse, a cooperative research station conducted by the United States Department of Agriculture and the Wisconsin College of Agriculture.

Mr. Bates was engaged in writing up the study when he died in July 1949. After the Lake States Station began its current program of watershed management research in southwestern Wisconsin, the author undertook preparation of the final report on the lysimeter study.

Messrs. Scholz and Neu provided much of the information presented here through the annual reports they had prepared and by correspondence and discussion with the author on details and procedures not shown in the records. Bates' unfinished, first-draft manuscript, an unpublished manuscript by Scholz and Bates, and various file memoranda have also been the source of much useful information.

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Water Yield and Soil Loss From Soil-Block Lysimeters Planted to Small Trees and Other Crops

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SUMMARY

From 1934 to 1942 the Lake States Forest Experiment Station operated 10 large lysimeters at the Upper Mississippi Valley Soil Conservation Experiment Station, La Crosse, Wis. For several reasons, the results have not previously been written up. This is the first and final published report on the experiments.

The lysimeters were 20 feet long, 10 feet wide, and 4 feet deep. They were filled with undisturbed blocks of Fayette silt loam, a loess, plus an 8-inch layer of topsoil.

After a test period of about a year, treatments were established, and surface runoff, percolation, and soil loss were measured for 6 years. The treatments in six lysimeters were: hardwood seedlings with leaf mulch (two lysimeters), hardwood seedlings without leaf mulch, Scotch pine seedlings with needle mulch, grass, and annual grain. Results from the four other lysimeters are not given because of faulty percolation records.

Analysis of the data showed a strong interaction between treatment and season. Growing-season runoff from the mulched trees and grass was low compared with dormant-season runoff, whereas the reverse was true for the annual grain. The unmulched hardwoods were in between.

During the growing season, 6-year runoff averages for the mulched trees and grass ranged between 0.46 and 0.65 inch. In contrast, the unmulched hardwoods and the grain averaged 3.68 and 6.49 inches. Most of the runoff came from a few high-intensity storms. During the dormant season, the effect of treatment on runoff was much less pronounced, probably because of uneven accumulation of snow and frozen ground on the lysimeters.

Most of the percolation occurred during the dormant season. Only the two mulched hardwoods yielded significant amounts (an average of 2.1 inches) during the growing season. Annual variation was high in both seasons. Treatment effects on dormant-season percolation were not clear-cut, for the same reasons as given for runoff.

Soil loss was very low from all the lysimeters that had a protective cover, and high from those with unmulched hardwoods and the grain. Most of this came from growing season rainstorms.

During the experiment the trees grew from rows of small seedlings to dense stands of saplings. Although the trend is not too clear-cut, growing season runoff appears to have decreased with time on all but the annual grain lysimeter.

Percolation from the mulched trees during the growing season showed a general decrease with time, but whether this is a real time trend or merely the result of climatic variations may be debatable.

The effect of time on soil loss from the unmulched hardwoods lysimeter was more pronounced. It dropped from 17.1 to 0.2 tons per acre in 5 years. The other lysimeters showed no change with time.

A separate analysis of individual periods of percolation showed that almost all the percolation occurred in the spring months, the result of melting snow and spring rains on wet soil. Percolate flowed for as long as 20 days without rainfall.

Analysis of the water budget showed that evapotranspiration accounted for about three-fourths of the precipitation. The figures agree well with other lysimeter studies made at the same location, and with estimates made for Madison, Wis. Total water yield from the lysimeters compared favorably with streamflow records from a nearby watershed.

INTRODUCTION

For 8 years, beginning in June 1934, the Lake States Forest Experiment Station operated 10 large lysimeters at the Upper Mississippi Valley Soil Conservation Experiment Station near La Crosse, Wis. Three lysimeters were seeded to native hardwood species and one was planted to Scotch pine seedlings. The other six were planted to grass or field crops or were given special, nonvegetative treatments. The first 2 years were used to test the uniformity of percolation, and to establish treatments. Treatment comparisons began with the third year and were continued for 6 years.

Sometime during the experiment, the percolation pipes from six of the lysimeters broke, invalidating, for the most part, the percolation records from those lysimeters. Since the percolation pipes were buried under about 5 feet of soil, the breaks were neither perceived nor investigated until after the experiment had ended and when, in Bates' words, "analysis of the data showed some impossible relations."

Fortunately, the tree-covered lysimeters, all four of which were on the west end of the installation, functioned properly, and the runoff and soil loss records for the other six were not affected by the malfunctioning of the percolation systems. One of the broken pipes, from a lysimeter with annual crops, had just a slight leak; Bates stated, "Do not believe (leak) caused either loss or gain." Although its percolation record may be slightly suspect, it has been used along with the "good" records.

This paper is the first and final report on the study. Because of the broken pipes and the premature ending of the experiment with the outbreak of World War II, the study yielded less information than was originally expected. Even so, the results are still pertinent — perhaps more so today than they would have been 10 or 20 years ago. The question of how much water is used and how much is made available for water supply by different kinds of crops is still a long way from being completely answered. The knowledge gained from this study should be a useful contribution toward this end.

THE AREA AND STUDY OBJECTIVES

The study site has been well described by Hays et al. (1949).[1] It is in the Driftless Area, an unglaciated region of some 10 million acres, mostly in Wisconsin, but also extending across the Mississippi River into the southeastern corner of Minnesota and into northeastern Iowa and down into Illinois. By some mysterious quirk of nature, the continental glaciers bypassed this area, leaving it a dissected plain, now weathered into an intricate drainage pattern. Flat or gently rounded ridges are a peculiarity of the landscape. Forests, predominantly oak-hickory, occupy only the very steep hillsides between the cultivated uplands and lowlands.

The lysimeters were located near the top of a windswept ridge. The ridgetop soils are loessal silt loams mapped either as Fayette or Dubuque. Colloidal content is low, but they are productive agricultural soils, and this has led to extensive overuse. Cultivation of slopes steeper than 30 percent is not uncommon.

Annual precipitation is about 32 inches. Two-thirds of this falls from May through September, much of it as high-intensity, convection storms. The ground normally freezes every winter, sometimes to a depth of 4 feet or more on openland, and this often contributes to spring floods. These things, combined with the land-use pattern and the erosive loess soils, have made the Driftless Area a land of flash floods and spectacular erosion.

From previous studies, Bates (1930) and Bates and Zeasman (1936) had found that there was practically no surface runoff on well-forested slopes. The lysimeter experiments were planned to find out how much of the infiltrated water was likely to become available as ground water, springflow, or streamflow, and how the water budget and soil loss differed for forest and nonforest crops.

[1] *Names and dates in parentheses refer to Literature Cited, pages 21 to 23.*

LITERATURE REVIEW

At the time the experiment was begun, lysimeters had not been used extensively in this country. One notable exception was a series of 12 lysimeters operated at Cornell University (Lyon et al. 1918 and 1930). However, most of the literature was from European experience and was applicable only in a very general way. An extensive review of these earlier experiments has been given by Kohnke et al. (1940).

Three other installations of large lysimeters, also constructed during the 1930's, have since become well-known. The monolith weighing lysimeters at Coshocton, Ohio, have been the subject of many papers. A recent progress report by Harrold and Dreibelbis (1958) gives the 10-year records from 1944-55. This report also contains a thorough review of lysimeter literature from 1939 to 1955. Colman and Hamilton (1947), in a two-part publication, described construction of the San Dimas, Calif., lysimeters and the relative performance of four different sizes. More recently, Sinclair and Patric (1959) reported on the operation of these lysimeters and gave results of some of the treatments. Compared to bare soil, all vegetation markedly decreased surface runoff and correspondingly increased infiltration. Evapotranspiration from vegetated soils was two or three times greater than from bare soil. Grass-covered soils yielded the most percolate.

Patric reported further on the large San Dimas lysimeters (1961a) and in another publication (1961b) assessed their value as a tool in forestry research. He concluded that lysimeters are a poor place for raising trees because the root systems are confined, and that, therefore, lysimeter results are at best only relative.

Zinke (1959), who also worked with the San Dimas large lysimeters, studied comparative moisture depletions under *Pinus coulteri* and under barren conditions. He reported that loss rates were nearly the same at various soil depths in the pine lysimeter, but that they diminished with depth in the bare lysimeter.

Construction and performance of the "Base Rock" lysimeters at the Sierra Ancha Experimental Forest were given by Martin and Rich (1948). Later, Rich also reported on further results (1959). He said that surface runoff and erosion increased as grass densities decreased, and that winter yield of percolate appeared to be independent of vegetation densities.

Other classic works on lysimetry are presented in the Symposium of Hannoversch-Munden (International Association of Scientific Hydrology 1959).

Good discussions of the various types of lysimeters and the limitations of each are given in the papers cited above by Harrold and Dreibelbis, and by Colman and Hamilton. The latter also discussed the presence of a "perched water table" in confined lysimeters and suggested design features to eliminate this unnatural condition. The recommendations were based on earlier studies by Neal et al. (1937) and by Richards et al. (1939), and on a later laboratory study by Colman (1946).

Other works that relate to this paper are cited at appropriate places in the text.

THE LYSIMETERS

Construction

Construction of the lysimeters and the installation itself have been fully described by Scholz and Stoeckeler (1940). However, the more important points are repeated here for convenience.

The completed installation consisted of 10 lysimeters, each 10 by 20 feet, or about 1/200 of an acre. They were 4 feet deep and were on a 10-percent slope that faced N. 79° E. Walls and floors were of reinforced concrete. They were built in pairs, each pair having a common wall. This was 6 inches thick and had a trough-shaped top to dispose of rain that fell on it. The pairs were separated from each other by a 3-foot strip which was later seeded to grass. Construction details are shown in figure 1.

The lysimeters were filled with natural profile blocks of the loessal Fayette silt loam. This is a well-drained, gray-brown podzolic soil commonly found on the ridges and upper slopes of the area.

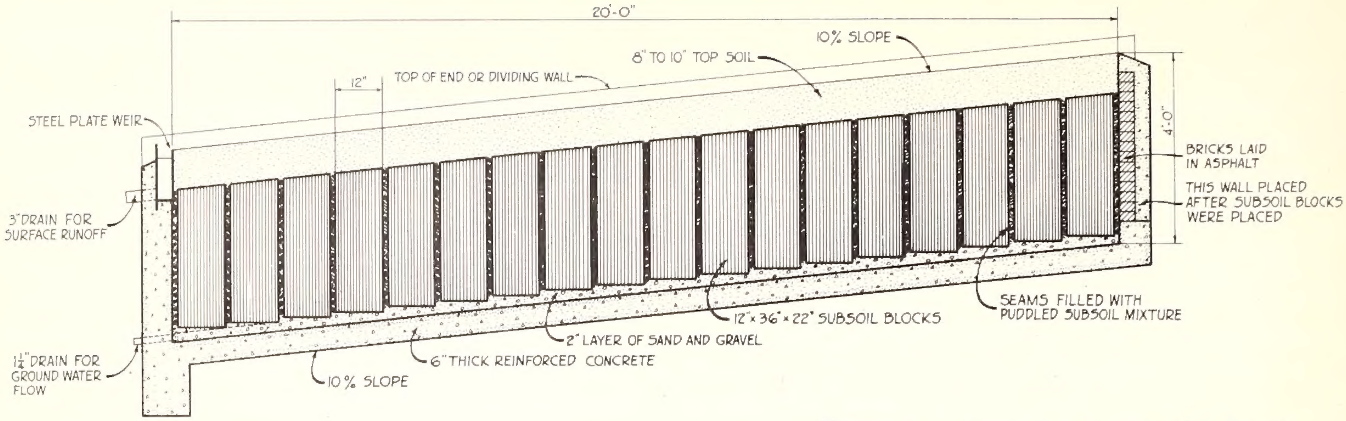

FIGURE 1. — Lysimeter construction details.

The undisturbed soil blocks or monoliths, which were 36 inches high, 22 inches wide, and 12 inches thick, were cut from a nearby borrow pit (fig. 2). They were cut out by means of special tools and were fitted into a steel casing for moving to the lysimeters. Since the uphill walls of the lysimeters had not yet been constructed, the blocks could be wheeled right into place. A block weighed about 500 pounds.

They were placed in the lysimeters in rows — 18 rows of 5 blocks each, or 90 per lysimeter. The blocks were spaced as uniformly as possible with about a 2-inch-wide space between them. These seams were filled with a viscous mixture of soil and water which was tamped in tightly. The blocks rested on a 2-inch layer of permeable sand and gravel so that percolated water would flow relatively unimpeded along the floor of the lysimeter to its outlet pipe.

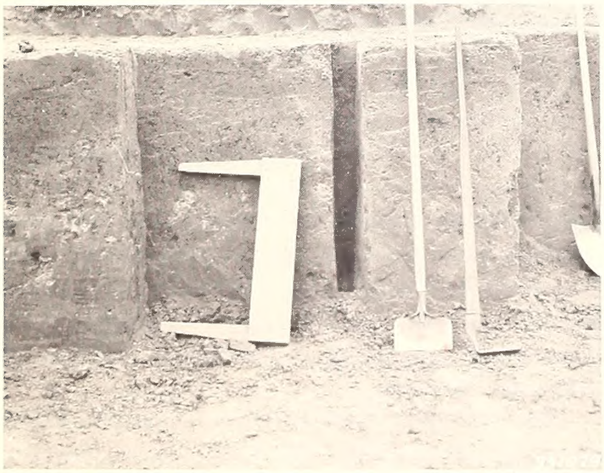

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FIGURE 2. — How soil blocks of loess were cut from a natural profile.

After all the soil blocks were in place, the uphill walls were built. Later, an 8- to 10-inch layer of topsoil was distributed over the surface. Some time was allowed to elapse before putting on the topsoil. This was to permit "amalgamation" of the soil blocks with the material that had been tamped into the seams. During this interval, 8.4 inches of rain fell. Before applying the topsoil, the blocks were shaved off to a uniform level.

Operation

Surface runoff and percolation were measured by catching the amounts that came from each lysimeter in calibrated tanks that were located in a shed about 12 feet downslope. Small amounts were weighed. Three-inch pipes leading from a trough in the lower end of the lysimeter carried the surface water and soil, while smaller pipes that drained from the bottom of the lysimeter carried the percolate. The amount of soil in the runoff solution was determined by drying and weighing samples of the solution. At first, runoff volumes were corrected for soil content, but when the differences were found to be small this was discontinued.

In June 1936, a tipping bucket system was installed as an additional means of measuring both runoff and percolate. This system, which was hooked up to a 20-pen Bristol recorder, provided a continuous chart record automatically.

Precipitation was measured by a Ferguson recording gage placed near the installation. The gage was fitted with a Nipher-type shield to minimize errors in gage catch that result from wind movement.

Pretreatment Testing of Lysimeters

After the topsoil had been spread on the lysimeters, contour ridges were built, spaced at about 32-inch intervals (fig. 3). This was done to prevent runoff and erosion while treatments were being started and to test the uniformity of percolation.

The testing procedures were somewhat involved. The results were inconclusive, and the inferences drawn from them were somewhat conflicting, depending upon the period of time that was considered. Unequal distribution of snow apparently caused most of the difficulty.

According to Bates' unfinished report:

> The plan for the first year was to give percolation capacities a severe test, surface runoff being precluded by the ridges or terraces that had been formed in the soil . . . measurements were begun by drawing off the percolate into cubic foot buckets . . . the time required to fill a bucket was recorded.
>
> The data clearly show that there existed differences in the freedom with which water could be delivered. The same general characteristics were exhibited by the several lysimeters throughout the whole period of measurements.

Bates then went on to say that these differences in the discharge rates did not necessarily imply differences in amounts.

Scholz and Stoeckeler (1940) state:

> A preliminary check of the performance of the 10 lysimeters as judged by the amount of percolation water obtained over a period of 9 months revealed that the average percolate from the lysimeters was 148.8 cubic feet, with the maximum variation from the average amounting to only 3.7 percent. This very close check would indicate that the grout-filled seams offer no serious obstacle to obtaining results which are strictly comparable.

An unpublished manuscript by Scholz and Bates says:[2]

> . . . direct percolate from rain (June, 1934, to February, 1935) shows a very satisfactory degree of uniformity in the behavior of the lysimeters. . . . The considerable variability in total percolation is plainly related to the spring or snow-melting period of 1935, and this in turn to observed variations in the depth of the snow mantle. . . .

Percolation for various periods during the first year is shown in table 1. Data are given only for the lysimeters to be reported on here. Although there was some variation between lysimeters for individual periods, the totals for non-snowmelt periods agreed very closely. Total rainfall for the three periods was 35 inches. Values for the snow-

[2] *Scholz, Harold F., and Bates, Carlos G. The use of water by trees, grass, and crops in southwestern Wisconsin, and resultant residues for groundwater replenishment. Unpublished report on file at the La Crosse field office of the Lake States Forest Expt. Sta. 1940.*

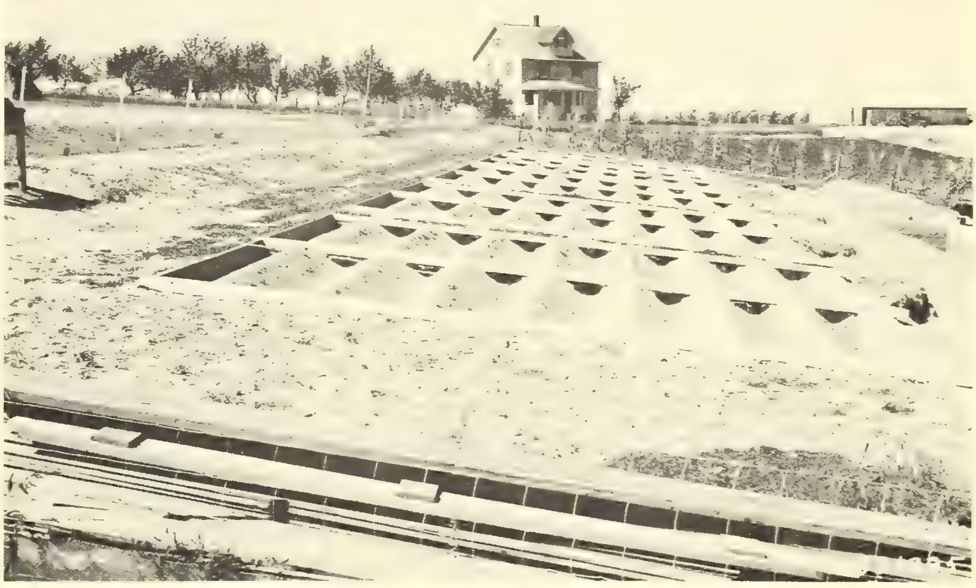

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FIGURE 3. — Completed lysimeters before treatment. The terraces were built to prevent runoff and soil loss during the first year of seedling growth, and to test the uniformity of percolation. The lysimeters have a 10-percent slope to the right.

TABLE 1. — *Percolation during pretreatment period*
(Inches of water)

Condition and period	Lysimeter number and subsequent treatment				
	1. Mulched hardwoods	2. Unmulched hardwoods	3. Mulched pine	4. Mulched hardwoods	9. Annual grain
PERCOLATION FROM RAIN					
Before topsoil added:					
June-August 1934	1.86	1.70	1.72	1.68	1.58
Topsoil terraced:					
Sept.-December 1934	7.31	7.25	7.67	7.62	7.26
April-May 1935	1.74	1.40	1.38	1.47	1.72
Total	10.91	10.35	10.77	10.77	10.56
PERCOLATION FROM SNOWMELT					
Topsoil terraced:					
January-March 1935	.69	1.61	5.18	4.28	1.33

melt period differed widely because of uneven snow cover, so they are shown separately.

It would appear from the data that if snowpack differences are accounted for, the lysimeters can be considered alike with respect to percolation amounts. Pretreatment tests on surface runoff were not made. Apparently it was felt that if percolation were uniform, surface runoff would also be uniform. This is a logical assumption, since if the soil masses responded uniformly, surface runoff would be affected only by surface condition, and except for treatment effects, this was the same on all lysimeters.

The Treatments

In July 1934, when the lysimeters were still terraced, seeds of red and white oak (*Quercus rubra* and *Quercus alba*) and black walnut (*Juglans nigra*) were planted in lysimeters 1, 2, and 4. The following May, the terraces were leveled and 1-0 Scotch pine (*Pinus sylvestris*) seedlings were planted in lysimeter No. 3. Both seeds and seedlings were planted just a few inches apart in rows spaced at only 16 inches. This spacing permitted 15 rows of trees per lysimeter. The hardwood species were planted in blocks of 5 rows for each species. The upper 5 rows were white oak; the middle 5, red oak; and the lower 5, black walnut. The close spacing was used so that the trees would fully occupy the site in as short a time as possible. Throughout the experiment the trees were thinned when they began to crowd each other. The thinnings were chopped up and scattered over the respective plots.

The lysimeters not planted to trees were seeded to rye to prevent excessive erosion, since the plan was to allow the trees to grow for a year before treating the other lysimeters.

The experimental period actually began in the spring of 1936. At that time two of the hardwood plots[3] (1 and 4) and the pine plot were covered with a 2- to 3-inch layer of leaf litter. Hardwood leaves were used on the hardwood plots and Scotch pine needles on the pine plot to simulate natural conditions. The third hardwood plot was left unmulched. The litter was replaced as needed to keep the cover uniform throughout the study.

The reason for the mulched plots was this: The people who planned the experiments knew that forests influence the disposition of rainfall in many different ways; that one of these was by protecting the soil against raindrop impact and by insulating it against radiation; and that this was due largely to the layer of leaf litter or mulch that blankets the floor of a forest. So by having both mulched and unmulched plots, they hoped to be able to isolate the effect of this factor from the separate effects of the trees themselves. They

3 *"Plot" as used here is synonymous with lysimeter.*

apparently felt that the effect of hardwood vs. softwood litter would not differ enough to justify separate experiments with each. So the mulched versus unmulched comparison was limited to the hardwoods. However, the interception effect of the two kinds of litter was investigated in a supplementary study.

Of the other two lysimeters whose records are used in this report, one was devoted to annual grain crops (barley 4 years, corn 2 years) and the other to grass. The grain was planted and harvested in the usual way. The grass was a heavy stand of Kentucky bluegrass (*Poa pratensis*), established by sodding. It was allowed to grow uninterrupted for the first 4 years, but starting with May 1939, it was clipped to simulate grazing use. The percolation records for this plot were faulty, so only its surface runoff and soil loss will be given. These records are included to give a comparative picture of how trees, grass, and cultivated crops may affect runoff and erosion in the study area.

LIMITATIONS OF THE STUDY

The results of any lysimeter study should be appraised in the light of the inherent weaknesses of lysimeters in duplicating truly natural conditions. Many of these, such as soil variability, border effects, and unnatural confinement of root systems, have been documented by various authors in the Symposium of Hannoversch-Munden (International Association of Scientific Hydrology 1959). Elsewhere Harrold and Dreibelbis (1958) reported that variation in percolation among lysimeters on the same soil type was due largely to soil heterogeneity and, in a small degree, to differences in the agricultural crop cover. They also discussed the probability of errors in measuring precipitation by standard methods and the effect that this has on computing the water balance from lysimeter data. Patric (1961b) discussed the inhibiting effect of root confinement on the growth of trees.

Certain limitations peculiar to the lysimeters of this study should be noted. Snow did not build up uniformly on the separate lysimeters. The tree-planted lysimeters tended to accumulate more snow by drifting than actually fell. Attempts to overcome this uneven distribution of snow by using snow fences and planting hedges were largely unsuccessful; drifting occurred through the years of the experiment. Snow depth was systematically measured, however, and these measurements are presented to help explain the erratic dormant-season results.

The paired construction and the short distance between pairs did not allow for isolation areas around individual treatments. This would have affected the later records more than the earlier ones because a marked difference in the height of the trees on the different lysimeters began to show up about the fourth year. By the end of the experiment (sixth year), the pines on lysimeter No. 3 were twice as tall as the unmulched hardwoods on adjacent lysimeter No. 2. This probably changed the effective area of these lysimeters (King et al. 1956). This may also have affected net rainfall on individual lysimeters.

No runoff records were lost by accident over the 6-year post-treatment period. However, it was suggested by Bates that inclined rains tended to fall on and drip from the lysimeter walls (which protruded about 6 inches above the soil surface) and thus form flow channels within the lysimeter during heavy rains. This could have produced slightly more runoff than would have occurred in a natural setting.

A perched water table in lysimeters and its restricting effect on percolation was suggested by Aderkas (1930) and was the subject of later research by Neal et al. (1937), Colman (1946), and Colman and Hamilton (1947). To see if this condition existed on the La Crosse lysimeters, soil moisture was sampled once during the study. The results showed that soil water apparently moved through the lysimeter soil mass much as it would move through a natural soil profile, except perhaps for some small effect at the seams between soil blocks.

Only one treatment — mulched hardwoods — was replicated. Apparently the original researchers felt that the pretreatment testing showed the lysimeters to be enough alike before treatment that replication was unnecessary. However, to strengthen treatment comparisons, the values for both replications of mulched hardwoods are given throughout the report.

ANALYSIS OF RECORDS

The results are summarized by hydrologic seasons rather than by years. Seasonal comparisons are more meaningful because rainfall effects are separated from snowmelt and frozen ground effects. This helps to reduce experimental error caused by climatic variations from year to year.

For purposes of analysis, May 1 was selected as the beginning of the water year. This approximates the ending of the dormant season, when soil moisture is usually at or near field capacity. The assumed growing season was May through October; and the assumed dormant season, November through April. Another reason for selecting May-April as the water year was that this made 6 full years of record available for analysis, the last records being taken in April 1942.

Effect of Treatment and Time

Treatment on only two (grass and annual grain) of the six lysimeters remained relatively fixed in time. The cover on the grain lysimeter, of course, varied with the annual planting, growth, and harvest cycle; and this probably accounted for some of the year-to-year differences in the water relations on this lysimeter. The occurrence of runoff-producing storms with respect to stage of crop development would have been particularly important.

The tree-covered lysimeters underwent a gradual change with time as the trees developed from rows of small seedlings to dense stands of saplings (fig. 4). With growth of the stems, the tree roots undoubtedly occupied more of the soil mass each year. An additional change probably took place on the unmulched hardwoods plot. Although there is

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FIGURE 4. — Tree growth on the lysimeters. Mulched hardwoods on the left, Scotch pine on the right. Upper picture, 1936; lower 1939.

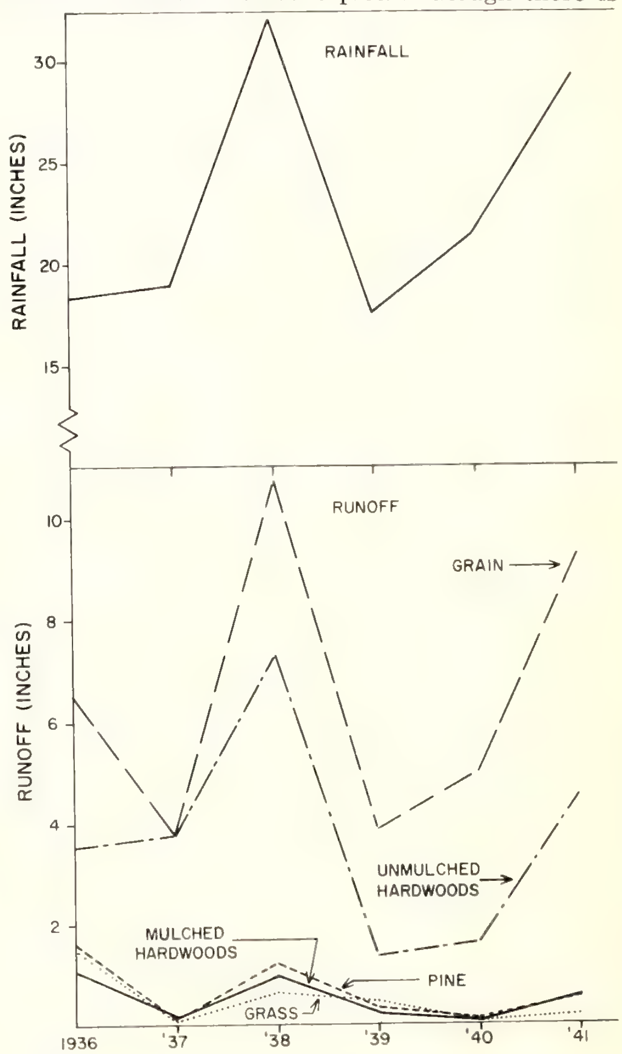

FIGURE 5. — Annual growing-season rainfall and runoff.

no record of it, natural leaf fall probably covered more of the soil each year. Cut-up thinnings were also scattered over the plot twice during the study.

Because of the changes on the lysimeters with time, the effect of treatment on soil and water relations also changed with time. Thus it is difficult to separate one from the other in an overall analysis. Showing monthly, seasonal, and annual values in the tables helps to do this to some extent. Six-year averages are also given. One should remember, however, that the average values by treatment reflect differences that are caused by both treatment and time. Where significant changes occurred with time, these are discussed separately.

On Runoff

Growing season. — During the growing season, the mulched hardwoods, the pine, and the grass yielded little runoff (fig. 5). Six-year averages were 0.46 inch for grass; 0.49 and 0.50 inch for the mulched hardwoods; and 0.65 inch for the mulched Scotch pine. In contrast, the unmulched hardwoods and the grain, both of which offered less protection to the soil, averaged 3.68 and 6.49 inches respectively. The effectiveness of forest litter in reducing runoff has been shown by a number of investigators.[4]

[4] *Bates and Zeasman 1930; Lowdermilk 1930; Rowe and Colman 1951; Rowe 1955.*

TABLE 2. — *Runoff from major rainstorms, 1936-1941*

Storm date	Precipitation			Runoff					
	Amount	Intensity		Mulched hardwoods		Unmulched hardwoods	Pine	Grass	Annual Grain
		5 min.	30 min.	Lys. No. 1	Lys. No. 4				
	Inches	In./hr.	In./hr.	Inches	Inches	Inches	Inches	Inches	Inches
1936									
May 22	1.78	4.80	0	0.32	0.51	0.75	0.38	0.41	0.95
Aug. 27	1.73	2.36	1.40	.05	.05	.12	.03	.18	1.34
Sept. 15	2.37	1.80	1.30	.19	.16	.37	.13	.12	.75
Oct. 3	1.31	3.36	1.78	.17	.18	.62	.11	.02	.80
Total	7.19			.73	.90	1.86	.65	.73	3.84
1937									
June 19	2.27	5.10	3.52	.16	.12	1.60	.14	.06	1.54
Aug. 3	1.35	3.60	2.12	0	0	.64	0	0	.81
Aug. 18	1.34	3.22	1.54	.01	.01	.50	0	0	.66
Nov. 7	1.52	2.28	.95	.03	.04	.59	.02	0	.60
Total	6.48			.20	.17	3.33	.16	.06	3.61
1938									
July 2	1.02	2.39	1.64	0	.02	.42	.01	0	.65
July 5	1.55	3.31	2.00	.06	.07	.76	.09	.04	1.26
July 21	1.75	6.08	2.86	.03	.04	.82	.12	0	.75
Aug. 16	3.45	1.27	1.06	.47	.35	1.46	.59	.28	2.53
Sept. 5	2.10	1.84	.97	.04	.06	.65	.06	.02	.91
Sept. 9	1.99	3.24	1.82	.38	.33	1.00	.30	.27	.95
Total	11.86			.98	.87	5.11	1.17	.61	7.05
1939									
Aug. 20	6.05	2.48	1.34	.21	.18	1.35	.30	.42	3.09
1940									
June 7	2.37	4.04	2.52	0	.02	.58	.08	.01	1.47
Aug. 1	1.27	3.25	1.95	0	0	.11	0	0	.62
Aug. 16	1.53	5.85	3.08	0	0	.67	0	0	1.16
Aug. 24	1.49	2.02	1.40	0	0	.17	.01	0	.39
Total	6.66			0	.02	1.53	.09	.01	3.64
1941									
May 15	1.61	5.20	1.78	.04	.01	.57	.03	.01	1.08
June 29	1.03	4.50	1.90	0	0	.25	0	0	.52
July 17	1.51	3.27	2.12	.04	0	.46	.06	0	.79
Sept. 7	3.20	1.68	1.02	0	0	.59	.05	0	1.17
Sept. 15	2.63	4.32	2.24	.31	.39	1.36	.18	.08	1.87
Oct. 6	1.78	3.24	1.38	.10	.11	.63	.04	.02	.91
Total	11.76			.49	.51	3.86	.36	.11	6.34

TABLE 3. — *Total runoff from major storms as percent of total storm precipitation*

Year	Mulched hardwoods		Unmulched	Pine	Grass	Annual
	Lys. No. 1	Lys. No. 4	hardwoods			grain
1936	10.1	12.5	25.9	9.0	11.4	53.4
1937	3.1	2.6	51.4	2.5	.9	55.7
1938	8.3	7.3	43.1	9.9	5.1	59.4
1939	3.5	3.0	22.3	5.0	6.9	51.1
1940	0	.3	23.0	1.4	.1	54.6
1941	4.2	4.3	32.8	3.1	.9	53.9
All years	5.2	5.3	34.1	5.5	4.1	55.1

Most of the yearly growing-season runoff came from just a few high-intensity storms (table 2). An average of four storms per year produced 71 percent of the runoff, using the annual grain plot as a base. This compares favorably with the findings of Hays et al. (1949). These storms made up only 36 percent of the total growing-season precipitation. To cite an extreme year, the 6.05-inch storm of August 1939 produced 81 percent of the runoff for that season from the annual grain lysimeter. The high runoff of 1938 and 1941 (fig. 5) is clearly related to the comparatively large number of major runoff-producing storms of those years (table 2).

Comparative runoff from the different vegetative covers expressed as a percent of storm rainfall may be of interest (table 3). The 6-year average was low for all mulched tree plots and for the grass (from 4.1 percent for the grass to 5.5 percent for the pine). On the other hand, the unmulched hardwoods gave up 34.1 percent and the grain 55.1 percent.

TABLE 4. — *Annual runoff as percent of runoff from annual grain lysimeter*

Year	Mulched hardwoods		Unmulched	Pine	Grass
	Lys. No. 1	Lys. No. 4	hardwoods		
		GROWING SEASON			
1936	15.2	18.2	54.5	24.7	23.5
1937	4.5	3.4	100.0	3.7	1.6
1938	9.6	8.8	68.3	11.2	5.7
1939	5.6	4.8	35.9	8.0	11.0
1940	0	.4	32.4	2.0	.3
1941	5.7	5.9	48.7	6.0	1.3
		DORMANT SEASON			
1936-37	61.0	74.0	299.7	31.0	171.3
1937-38	90.6	67.1	183.7	80.1	65.4
1938-39	112.4	164.0	303.6	53.2	57.1
1939-40	237.5	171.6	432.8	26.5	61.5
1940-41	14.4	51.6	17.9	30.8	44.2
1941-42	1.7	17.1	9.7	19.7	53.7

Although the trend of growing-season runoff with time is not too clear-cut, it appears to have decreased over the years on all but the annual grain lysimeter (tables 4 and 5, fig. 6). This can best be seen by comparing the record with that of the annual grain lysimeter on which the vegetation influence did not change progressively with time (table 4, fig. 6).

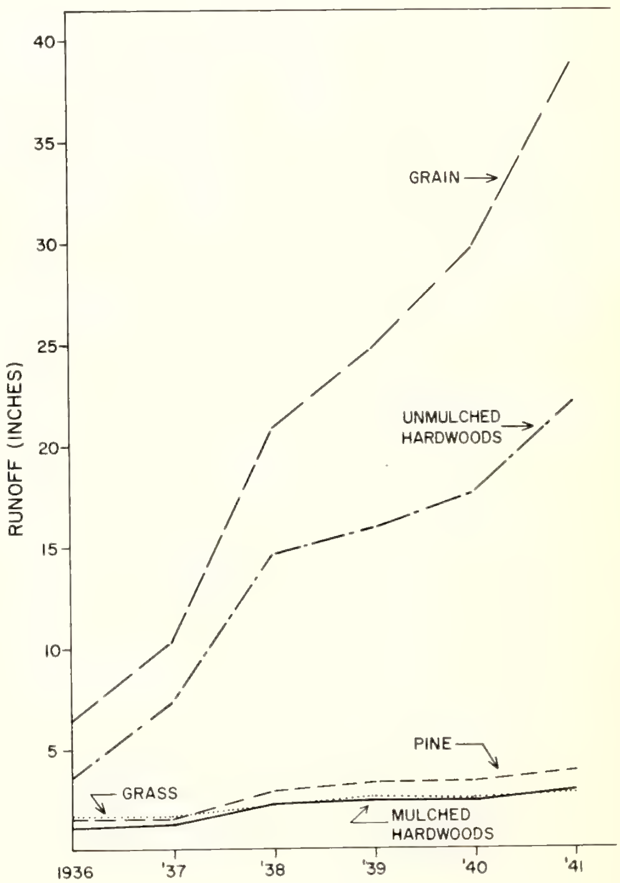

FIGURE 6. — Accumulated growing-season runoff.

TABLE 5. — *Seasonal precipitation, runoff, and percolation by years (Precipitation in inches; Runoff and percolation in percent of precipitation)*

Year	Precipitation	Mulched hardwoods Lys. No. 1 Runoff	Mulched hardwoods Lys. No. 1 Percol.	Mulched hardwoods Lys. No. 4 Runoff	Mulched hardwoods Lys. No. 4 Percol.	Unmulched hardwoods Runoff	Unmulched hardwoods Percol.	Pine Runoff	Pine Percol.	Grass[1/] Runoff	Annual grain Runoff	Annual grain Percol.
GROWING SEASON												
1936	18.43	5.3	7.6	6.4	6.4	19.1	0	8.7	1.6	8.3	35.1	0
1937	18.93	.9	20.6	.7	17.5	19.9	0	.7	4.5	.3	19.9	0
1938	32.05	3.2	19.1	2.9	18.7	22.7	1.8	3.7	.9	1.9	33.3	0
1939	17.51	1.2	.3	1.0	.1	7.8	0	1.7	0	2.4	21.8	0
1940	21.42	0	.2	.1	0	7.5	.5	.5	0	.1	23.1	0
1941	29.19	1.8	7.1	1.9	5.8	15.4	6.7	1.9	0	.4	31.7	1.4
Av.	22.92	2.1	9.2	2.2	8.1	16.0	1.5	2.9	1.2	2.2	27.5	0.2
DORMANT SEASON												
1936-37	8.03	9.6	51.2	11.6	52.3	47.0	0	4.9	51.0	26.9	15.7	0
1937-38	11.06	30.0	5.0	22.2	7.7	60.9	0	26.6	0	21.7	33.1	0
1938-39	9.62	22.1	31.6	32.3	33.6	59.7	25.1	10.5	37.4	11.2	19.7	0
1939-40	7.27	41.0	0	29.6	0	74.7	0	4.6	0	10.6	17.2	0
1940-41	10.39	7.6	34.8	27.1	1.9	9.4	59.5	16.1	0	23.2	52.4	.6
1941-42	8.34	.7	97.6	7.4	54.6	4.2	89.3	8.5	1.4	23.3	43.4	24.6
Av.	9.12	18.5	36.7	21.7	25.0	42.6	29.0	11.9	15.0	19.5	30.2	4.2

1/ Percolation record was faulty.

Dormant season. — The effect of treatment on dormant-season runoff, which was largely from melting snow, was less pronounced (table 6), probably because frozen ground is the major cause of dormant-season runoff (Hays et al. 1949). Most of the runoff normally occurs over a few days' time late in winter or in early spring when the accumulated snowpack melts. Rains at this time of the year can also contribute to it (Garstka 1944). Although forest cover is known to inhibit soil freezing in the study area (Scholz 1938), it is unlikely that the small trees and litter on the lysimeters would have begun to exert the same influence as do natural forest stands. These were essentially garden plots on soil that had been farmed for many years. The effect of living and dead plant materials on the ground, which exerted the primary influence on growing-season infiltration, was probably almost completely nullified when the ground froze. Although frost was not measured on the lysimeters, present-day knowledge of ground freezing (Pierce et al. 1958; Trimble et al. 1958; Sartz 1957) and the climate of the area both suggest that some freezing did occur on the lysimeters regardless of treatment.

TABLE 6. — *Dormant-season runoff by years (Inches)*

Year	Mulched hardwoods Lys. No. 1	Mulched hardwoods Lys. No. 4	Unmulched hardwoods	Pine	Grass	Annual grain
1936-37	0.769	0.932	3.776	0.391	2.158	1.260
1937-38	3.322	2.460	6.736	2.937	2.397	3.666
1938-39	2.126	3.103	5.744	1.006	1.081	1.892
1939-40	2.978	2.152	5.429	.332	.771	1.254
1940-41	.787	2.814	.974	1.676	2.410	5.450
1941-42	.062	.620	.350	.713	1.942	3.616
Total	10.044	12.081	23.009	7.055	10.759	17.138
Average	1.67	2.01	3.83	1.18	1.79	2.86

Table 7. — *Snow depths on day of peak snowpack*
(Inches)

Date	Mulched hardwoods: Lys. No. 1	Mulched hardwoods: Lys. No. 4	Unmulched hardwoods	Pine	Grass	Annual grain
1-31-37	12.7	11.8	14.3	13.6	11.9	10.6
1-31-38	7.3	9.1	12.4	12.4	8.8	2.6
3- 7-39	4.6	9.7	12.6	19.4	3.4	2.6
3-14-40	14.2	8.4	22.7	13.9	3.7	5.0
3-12-41	15.4	7.6	24.6	10.3	6.4	8.5
1-17-42	14.2	5.6	18.4	4.3	3.1	10.0
Average	11.5	8.7	17.5	12.3	6.2	6.6

Another factor that influenced dormant-season runoff was the uneven distribution of snow. Table 7 shows average snow depth (water equivalent was not measured) on each lysimeter at the peak date each year. This should be a reasonable estimate of the relative amount of snow water available for runoff and percolation, even though snow depth at the peak date was not necessarily an indication of snow water at the time of melt.

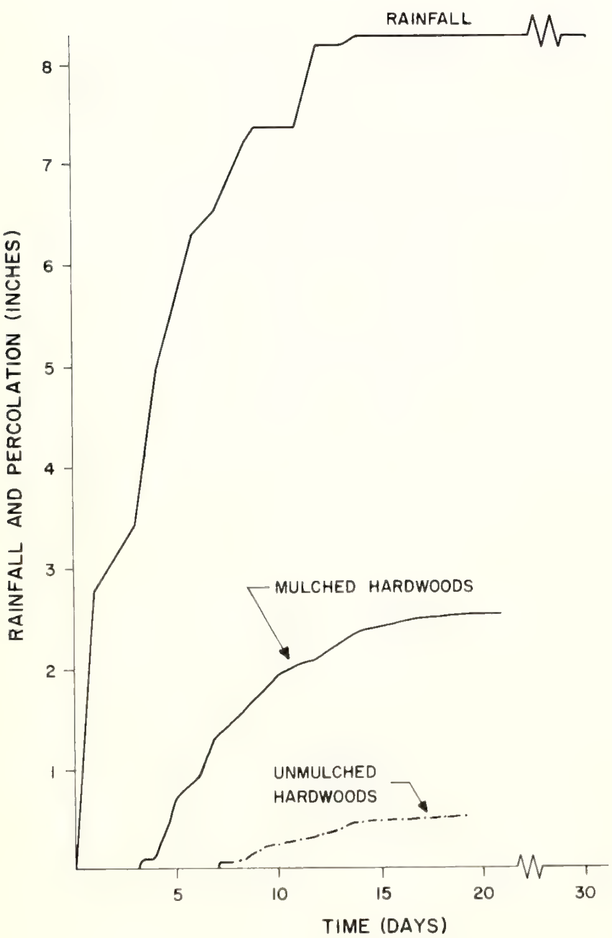

Figure 7. — Accumulated rainfall and percolation from prolonged summer rains, September 1938. Pine and grain plots showed no percolation during the month.

The impact of soil freezing and snowpack differences make it difficult to draw definite conclusions from the dormant-season data. While a deeper snowpack may have made more water available for runoff, it also may have had a greater inhibiting effect on soil freezing. Depth of snow is known to have a significant effect on soil freezing (Atkinson and Bay 1940; Bay et al. 1952). Thus less runoff could have come from the deeper snow because a shallower or less continuous frost allowed more water to infiltrate the soil.

The effect of a litter cover (the mulched trees and grass) as compared with bare ground (unmulched hardwoods and grain) may be reflected in the 6-year averages shown in table 6. However, the interrelationship between snow cover, vegetation and litter cover, soil freezing, and runoff is complicated. So the results of this phase of the experiment cannot be considered conclusive.

Annual distribution. — Seasonal runoff as a percent of annual runoff for the 6-year period is shown below:

	Percent of annual runoff during— Growing season	*Dormant season*
Mulched hardwoods:		
Lysimeter No. 1	22.7	77.3
Lysimeter No. 4	19.9	80.1
Unmulched hardwoods	49.0	51.0
Pine	35.5	64.5
Grass	20.4	79.6
Annual grain	69.4	30.6

Growing-season runoff from the mulched trees and grass was low compared with dormant-season runoff, whereas the reverse was true for the grain. This probably reflects the influence of a ground cover in maintaining a high capacity for infiltration from rainstorms (Packer 1951), and also its lesser influence under winter conditions (Rich 1959). Runoff from the unmulched hardwoods was about evenly divided between the growing and dormant seasons.

On Percolation

Growing season. — Monthly and annual percolate during the growing season is given in table 8. Data for the grass-covered plot are not shown because the records were faulty. Only the two mulched hardwood plots yielded significant amounts, averaging 2.26 and 2.03 inches annually. There was marked variation by year. The pine lysimeter, for example, yielded percolate only during the first 3 years; the grain, only in the last year.

Percolation from the mulched trees during the growing season generally decreased with time (table 5). Whether this is a real time trend or merely the result of climatic variations may be debatable. Seasonal variation in rainfall, snow accumulation, and soil moisture can easily obscure differences in percolation that may be caused by differences in land use (Dreibelbis 1954). However, according to both theory (Penman 1956; Tanner 1957) and experimental evidence (Moyle and Zahner 1954; Metz and Douglass 1959; Hill 1961), as a plant cover becomes denser and as its root system more fully occupies the soil, it will invariably use more water. This may well explain the apparent trends that the lysimeter records show.

Rate of percolate flow varied widely by treatment during an extended period of rain in September 1938 (fig. 7). Even after more than 8 inches of rain, the unmulched hardwoods lysimeter yielded but little percolate, the pine and grain, none.

The difference in percolation between the mulched hardwoods and the mulched pine is interesting. According to the pre-treatment test period, summer percolation from the three lysimeters was very much alike (table 1). Surface runoff in September 1938 was also similar, differing by less than one-tenth of an inch. Still the hardwoods yielded about 2.5 inches of percolate for this month as compared with none from the pine. The difference was probably caused by one or more of the following: higher transpiration loss by the pine; higher evaporation loss through the pine litter than through the hardwood litter; higher interception loss from the pine.

The low percolate yield from the unmulched hardwoods and grain is probably best explained by the higher amounts of surface runoff, hence a drier soil mass and greater opportunity for moisture storage in these lysimeters. The unmulched hardwoods and grain plots yielded 7.3 and 10.7 inches of surface runoff during the 1938 growing season, while the three mulched plots yielded only about 1 inch.

Dormant season. — Treatment effects on dormant-season percolation are not clear-cut. Annual variation was great (table 9) and does not appear to be related to snow depths (table 7). Dormant-season percolation can be affected by many different factors: soil moisture deficit at the end of the growing season; dormant-season runoff; snow drifting; net insolation, and snow interception; the pattern of soil freezing; and spring rains. The effects of treatment are therefore highly speculative. There does appear to be a gross relationship between snow depth and total water yield, however. Average percolation plus runoff from snowmelt (table 10) correlated well with peak snow depth for the three hardwood and the grain lysimeters (fig. 8) but not for the pine plot.

Percolation from the unmulched hardwoods increased substantially in the last 2 years (table 9). Part of this was no doubt the result of more favorable conditions for percolation in those years. This is indicated by the record from the grain lysimeter. However, it could also result from a combination of decreased surface runoff (table 5) and lower transpiration loss (as compared with the mulched hardwoods and pine) as well as from its deeper snowpack (table 7). In contrast to the unmulched hardwoods, the pine lysimeter yielded no percolate at all in 1940-41, and only 0.12 inch during the high percolation year of 1941-42. This was a decided drop from the first 3 years, when it yielded about the same amounts as the mulched hardwoods. The change probably resulted from increased soil moisture withdrawal by the faster-growing denser pines.

On Soil Loss

Soil loss was very low from all lysimeters that had a protective mulch cover but high from the

Table 8. — *Growing-season rainfall and percolation by months and years* (*Inches*)

Year and month	Rainfall	Mulched hardwoods: Lys. No. 1	Mulched hardwoods: Lys. No. 4	Unmulched hardwoods	Pine	Annual grain
1936						
May	3.17	0.682	0.537	0	0.051	0
June	2.24	.711	.637	0	.239	0
July	0.91	0	0	0	0	0
August	3.65	0	0	0	0	0
September	5.24	0	0	0	0	0
October	3.22	0	0	0	0	0
Total	18.43	1.393	1.174	0	.290	0
1937						
May	3.46	2.983	2.809	0	.836	0
June	4.42	.920	.507	0	.018	0
July	0.76	0	0	0	0	0
August	4.33	0	0	0	0	0
September	2.22	0	0	0	0	0
October	3.74	0	0	0	0	0
Total	18.93	3.903	3.316	0	.854	0
1938						
May	4.95	3.251	3.299	.058	.300	0
June	4.52	.116	.123	.022	0	0
July	7.52	.303	.076	0	0	0
August	5.51	.027	0	0	0	0
September	8.21	2.431	2.494	.493	0	0
October	1.34	0	0	0	0	0
Total	32.05	6.128	5.992	.573	.300	0
1939						
May	2.13	0.060	0.021	0	0	0
June	2.32	0	0	0	0	0
July	1.71	0	0	0	0	0
August	8.54	0	0	0	0	0
September	0.89	0	0	0	0	0
October	1.92	0	0	0	0	0
Total	17.51	.060	.021	0	0	0
1940						
May	3.41	0	0	0	0	0
June	5.45	.036	0	.116	0	0
July	2.06	0	0	0	0	0
August	7.29	0	0	0	0	0
September	0.38	0	0	0	0	0
October	2.83	0	0	0	0	0
Total	21.42	.036	0	.116	0	0
1941						
May	6.10	.979	.548	.408	0	0
June	5.29	1.044	.841	1.167	0	.395
July	2.17	0	0	0	0	0
August	1.01	0	0	0	0	0
September	9.28	0	0	0	0	0
October	5.34	.045	.310	.370	0	0
Total	29.19	2.068	1.699	1.945	0	.395
Total	137.53	13.588	12.202	2.634	1.444	.395
6-year av.	22.92	2.26	2.03	.44	.24	.07

Table 9. — *Dormant-season percolation by years*
(*Inches*)

Year	Mulched hardwoods: Lys. No. 1	Mulched hardwoods: Lys. No. 4	Unmulched hardwoods	Pine	Annual grain
1936-37	4.111	4.203	0	4.099	0
1937-38	.550	.852	0	0	0
1938-39	3.043	3.233	2.413	3.595	0
1939-40	0	0	0	0	0
1940-41	3.611	0.195	6.184	0	.058
1941-42	8.143	4.552	7.450	.118	2.053
Total	19.458	13.035	16.047	7.812	2.111
Average	3.24	2.17	2.67	1.30	.35

Table 10. — *Percolation plus runoff during snowmelt period*
(*Inches*)

Year	Mulched hardwoods: Lys. No. 1	Mulched hardwoods: Lys. No. 4	Unmulched hardwoods	Pine	Annual grain
1936-37	3.82	4.29	3.36	4.19	1.17
1937-38	3.30	3.22	5.41	2.92	1.92
1938-39	3.85	4.82	6.28	4.60	1.89
1939-40	2.98	2.15	5.43	0.33	1.25
1940-41	4.40	3.01	6.83	1.64	4.99
1941-42	5.59	3.45	6.15	0.83	5.02
Average	4.07	3.49	5.58	2.42	2.71

Table 11. — *Annual*[1] *soil loss*
(*Tons per acre*)

Year	Mulched hardwoods: Lys. No. 1	Mulched hardwoods: Lys. No. 4	Unmulched hardwoods	Pine	Grass	Annual grain
1936-37	0.15	0.19	17.09	0.12	1.08	11.15
1937-38	.03	.06	2.45	.01	.01	15.71
1938-39	.03	.10	0.39	.02	.03	55.80
1939-40	.04	.01	.13	.01	.01	5.46
1940-41	0	0	.21	.01	.02	12.20
Average	.05	.07	4.05	.03	.23	20.06

1/ From May 1 to April 30. Soil loss was not measured after September 30, 1941.

unmulched hardwoods, particularly the first year, and the grain (table 11). That forest litter and dense ground cover minimize soil loss, even though surface runoff may occur, has been shown by many others (Bates and Zeasman 1930; U.S. Forest Serv. and U.S. Soil Conserv. Serv. 1940; Marston 1952).

The 5-year averages of 0.03 to 0.07 tons per acre for the mulched trees versus 0.23 tons per acre for the grass is not a meaningful comparison. The higher average for the grass results from the 1.08 tons per acre for 1936-37; 97 percent of this came from one storm in May, just a few weeks after the sod had been laid. The higher-than-average values for the mulched trees in 1936 also resulted from this storm. The litter had been spread on the plots about the time that the sod had been laid, and the loosely lying leaves and needles were undoubtedly less effective in reducing erosion than they were later.

Although the effect of time on runoff and percolation was somewhat uncertain, its effect on soil loss from the unmulched hardwoods was clear-cut. Soil loss dropped from 17.09 tons per acre the first year to 0.21 tons per acre the fifth year. The decrease was progressive, despite the fact that the erosion potential, as judged from the performance of the annual grain lysimeter, varied greatly from year to year. The other plots showed no change with time. Since the soil was almost fully protected from the start (except for a settling period

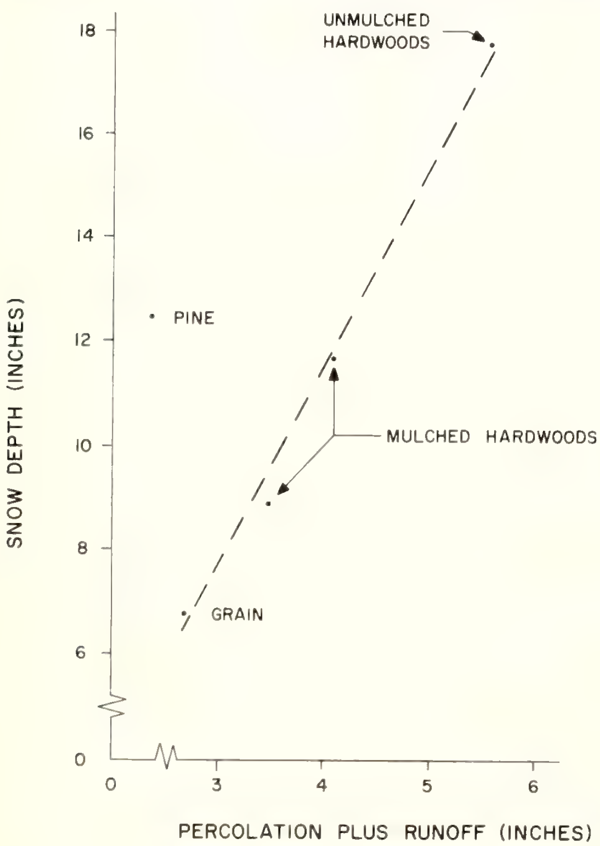

FIGURE 8. — Relationship of average percolation plus runoff during snowmelt period to peak snow depth.

the first month), soil loss was minimal throughout the study.

Seasonal distribution of soil loss did not follow that of runoff. Whereas most of the runoff occurred in the dormant season, most of the soil loss occurred in the growing season. This was expected, since dormant-season runoff was largely from frozen soil, and rate of soil detachment is normally low under this condition.

Distribution and Duration of Percolation

In the average year, percolate flowed on relatively few days, even from the higher producing lysimeters (table 12). This was especially true during the growing season. Most of the percolation that did occur then came in May and June. In most years there was a continuous flow from April into May, and some years it continued into June. This reflected the high level of soil moisture that is normal here in early spring months. Only in 1938 did any percolate flow in summer months, and this was an especially wet summer (table 13). Low percolate yield and ground-water flow during the months of high evapotranspiration loss are typical of the climatic belt, as has been shown by other lysimeter investigations (Lyon and Bizzell 1918; Harrold and Dreibelbis 1958), by streamflow records, and by recent studies of springflow on the Coulee Experimental Forest.[5]

Most of the dormant-season percolation occurred in March and April, the result of melting snow and spring rains on wet soil. The curves for each year except 1939-40 (none occurred on any of the lysimeters during the dormant season that year) are given in figure 9. Normally, fall rains went into soil moisture storage, replenishing moisture that had been depleted during the summer months. There were a few exceptions to this, however, one of which is worth noting. Percolate had flowed from the three hardwood lysimeters in September 1938, following an 8-inch rain. A 3-inch rain in November, falling on the already wet soil, also produced flow from these lysimeters (fig. 10).

There was only limited opportunity during the years of the experiment to study soil water depletion from percolation during extended rainless periods. Percolation occurred a few times, however, when precipitation either was lacking, was very low, or fell only as snow. Daily percolate

[5] *Data on file at La Crosse, Wis., field office of the Lake States Forest Experiment Station.*

TABLE 12. — *Number of days in which percolate flowed*

Year	Mulched hardwoods: Lys. No. 1	Mulched hardwoods: Lys. No. 4	Unmulched hardwoods	Pine	Annual grain
	GROWING SEASON				
1936	48	44	0	26	0
1937	47	42	0	36	0
1938	68	59	31	13	0
1939	9	4	0	0	0
1940	4	0	4	0	0
1941	38	32	41	0	8
Average	36	30	13	12	1
	DORMANT SEASON				
1936-37	108	79	0	109	0
1937-38	17	14	0	1	0
1938-39	108	107	83	39	0
1939-40	0	0	0	0	0
1940-41	37	13	54	0	7
1941-42	87	81	83	19	44
Average	60	49	37	28	8

yields during these periods are plotted in figure 10 to show the rate of drainage of soil water from the lysimeters when evapotranspiration losses were low. Percolate flowed continuously for as long as 20 days without rainfall. That water can be discharged from unsaturated soils over extended periods of time has been verified recently by Nixon and Lawless (1960), and by Hewlett (1961), who gave this as one explanation for the base flow of streams.

TABLE 13. — *Precipitation by months and seasons (Inches)*

Month and season	1936	1937	1938	1939	1940	1941
GROWING SEASON						
May	3.17	3.46	4.95	2.13	3.41	6.10
June	2.24	4.42	4.52	2.32	5.45	5.29
July	0.91	0.76	7.52	1.71	2.06	2.17
August	3.65	4.33	5.51	8.54	7.29	1.01
September	5.24	2.22	8.21	0.89	0.38	9.28
October	3.22	3.74	1.34	1.92	2.83	5.34
Total	18.43	18.93	32.05	17.51	21.42	29.19
DORMANT SEASON						
November	0.66	2.27	3.25	0.26	2.97	1.70
December	1.10	0.45	0.84	0.76	1.35	1.63
January	1.69	0.81	1.28	0.57	1.26	0.23
February	1.01	0.92	1.65	0.71	0.58	0.70
March	0.34	2.79	0.55	1.25	1.70	2.69
April	3.23	3.82	2.05	3.72	2.53	1.39
Total	8.03	11.06	9.62	7.27	10.39	8.34
Water year	26.46	29.99	41.67	24.78	31.81	37.53

The Annual Water Budget

The complete water budget is shown in table 14. The budget is given for two 3-year periods because of tree growth and its apparent effect on evapotranspiration. The grass plot is not shown because of its faulty percolation record, but a rough estimate is given a little farther on.

Evapotranspiration rates were high for all crops, ranging from 65 percent of precipitation (unmulched hardwoods in the first 3-year period) to 96 percent (pine in the second 3-year period). Similar high rates of evapotranspiration were reported from lysimeter studies in Ohio by Harrold and Dreibelbis (1958) and from another lysimeter study at the La Crosse Station by Kilmer et al. (1944). From heat-budget measurements and lysimeter data, Tanner[6] estimated average annual net radiation at Madison to be 29 inches and evapotranspiration (average for all cover conditions) to be 24 inches. These are estimates of the long-term

[6] *Tanner, C. B., unpublished data, College of Agriculture, University of Wisconsin.*

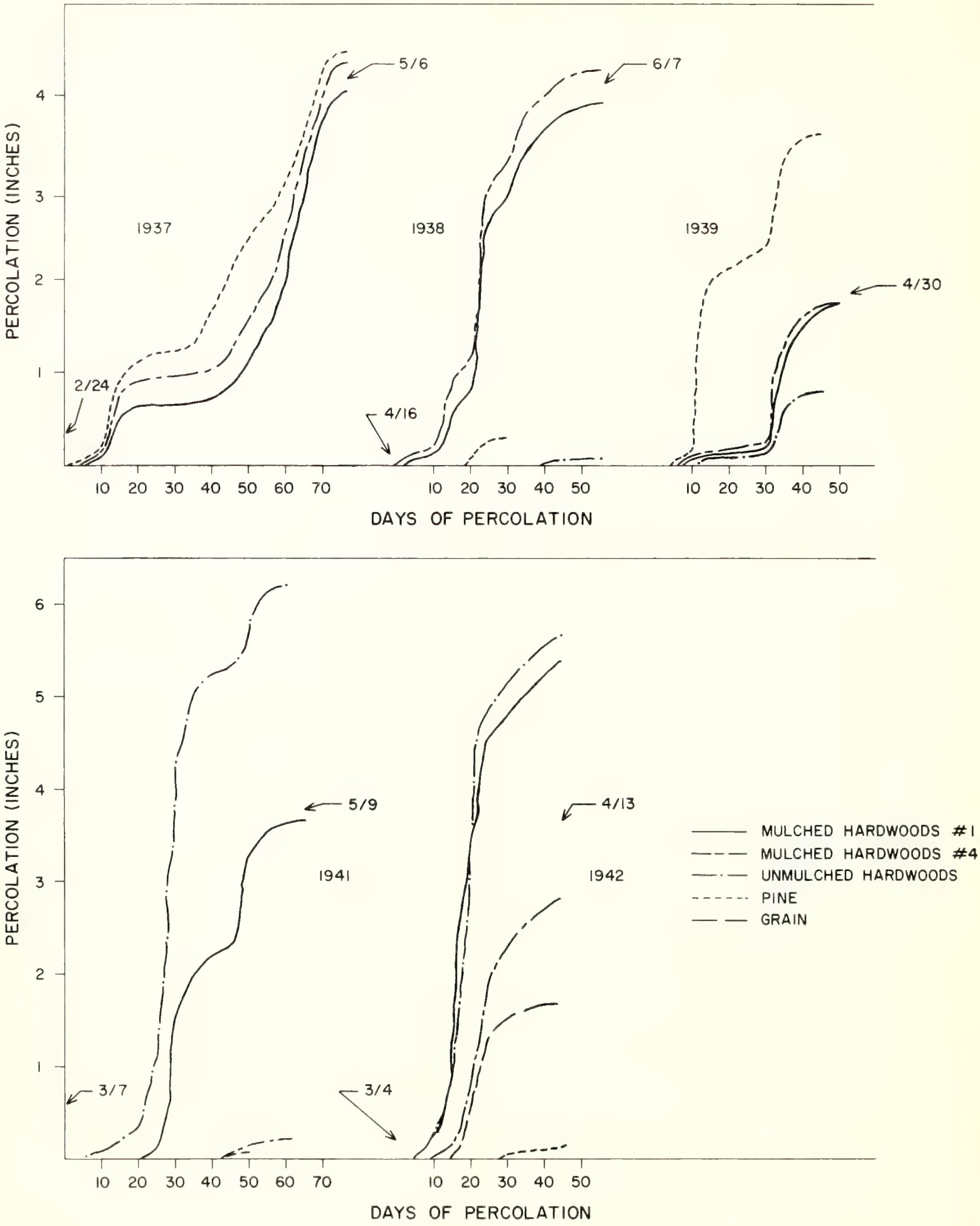

FIGURE 9. — Accumulated percolation from snowmelt and spring rains, 1937-39, 1941, and 1942. No percolation occurred during this period in 1940.

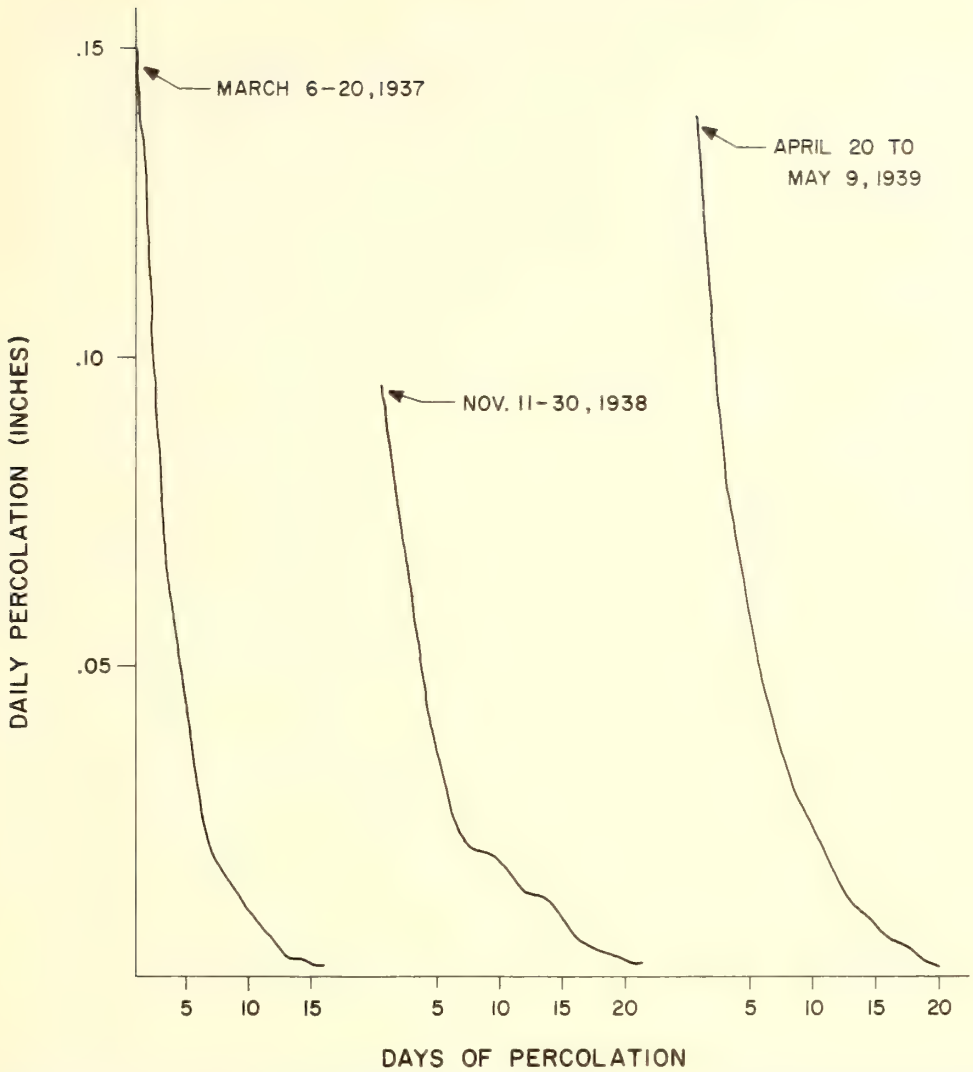

FIGURE 10. — Rate of soil moisture drainage during rainless periods, lysimeter No. 1 (mulched hardwoods).

averages. Since the actual values would vary somewhat from year to year as precipitation does, the figures are not directly comparable to the data cited here.

In terms of total water yield, the unmulched hardwoods and the grain produced the most — about 10 inches. This resulted from their high rates of surface runoff, hence less opportunity for loss by evapotranspiration.

At the time the Forest Service lysimeters used in this study were built, the Soil Conservation service installed a battery of six soil-monolith lysimeters. These were only 36 inches in diameter, but soil type and depth were the same as those of the Forest Service lysimeters. The surface of the lysimeters was level. They were located on the same slope and were less than 50 feet away.

The study by Kilmer et al. (1944), which was made on the Soil Conservation Service lysimeters, provides an interesting comparison for the water budget from the annual grain lysimeter, since both were operated from 1936 to 1938. Three lysimeters of Kilmer's study were in corn annually. The water budget for the two follows (in inches):

	Annual grain Forest Serv.	Corn SCS
Runoff	9.2	12.8
Infiltration	23.5	21.8
Percolation	0	.2
Evapotranspiration	23.5	21.6

Estimates for a low, closely growing cover obtained by Bay and Hull (1952) may serve as a substitute for data lost from the grass lysimeter.

TABLE 14. — *Average annual water budget for two 3-year periods*[1]
(*Inches*)

Treatment	Precipitation	Runoff	Infiltration[2]	Percolation	Evapo-transpiration	Total yield
			1936-1938			
Mulched hardwoods						
Lysimeter No. 1	32.71	2.80	29.91	6.38	23.53	9.18
Lysimeter No. 4	32.71	2.91	29.80	6.26	23.54	9.17
Unmulched hardwoods	32.71	10.28	22.43	1.00	21.43	11.28
Pine	32.71	2.42	30.29	3.05	27.24	5.47
Annual grain	32.71	9.24	23.47	0	23.47	9.24
			1939-1941			
Mulched hardwoods						
Lysimeter No. 1	31.37	1.52	29.85	4.64	25.21	6.16
Lysimeter No. 4	31.37	2.11	29.26	2.16	27.10	4.27
Unmulched hardwoods	31.37	4.74	26.63	5.23	21.40	9.97
Pine	31.37	1.23	30.14	.04	30.10	1.27
Annual grain	31.37	9.45	21.92	.84	21.08	10.29

1/ Water year: May 1 to April 30.
2/ Precipitation less runoff. Interception ignored.

They studied water losses from clover-timothy hay on the Soil Conservation Service lysimeters at La Crosse for 2 years — 1943 and 1945. Average annual losses and the 2-year averages, all in inches, were:

	1943	1945	Average
Precipitation	24.41	38.73	31.57
Runoff	2.82	4.72	3.77
Infiltration	21.59	34.01	27.80
Percolation	.48	4.24	2.36
Evapotranspiration	21.11	29.77	25.44

Although the range between the 2 years is large, average precipitation is about the same as for the period 1939 to 1941. So the corresponding evapotranspiration of 25.44 inches should be a rough approximation of what evapotranspiration losses from the grass lysimeter would have been for this period.

It is interesting to compare lysimeter records with local streamflow records (Harrold 1947). Coon Creek, a 77-square-mile watershed south of La Crosse, provides such a comparison. About 35 percent of the watershed is forested; most of the rest is in agricultural crops or pasture. Soils on about three-fourths of the watershed are loessal silt loams — the soil used in the lysimeters. For the 1936 to 1938 period used in this report, the flow of Coon Creek was 7.05 inches. This was 25 percent of the average precipitation measured on the watershed. Total yield from the lysimeters for this period ranged from 17 to 34 percent of precipitation.

EVALUATION OF THE STUDY

The results of this lysimeter study, though limited in time and statistical design, should still be of interest to land-use hydrologists and others concerned with the conservation of soil and water. Because analysis and publication were unavoidably delayed, the writeup is perhaps of more value in confirming the results of more recent research than it is in presenting new findings.

As originally planned, the study was to continue for a much longer period of time so that the "forest" plantings would have had greater opportunity to alter the soil. Comparing the small trees with agricultural crops, both on an agricultural soil, does not provide a true measure of the effects of trees in a forest. In many ways the study dealt more with a variety of agricultural crops. Under these conditions then, it would be presumptuous to draw inferences on the relative effects of forests versus agricultural crops on elements of the water cycle.

Uneven accumulation of snow and the lack of snow-water measurements on the lysimeters reduced the accuracy of the water budget figures. When accurate water budget figures are desired from lysimeter measurements in climates where snow is a significant component of the annual precipitation, provision should be made to prevent drifting or to properly account for it on the lysimeters.

Despite its shortcomings, the study provided some new information on the disposition of precipitation by different types of cover on loessal soils in a cold, midcontinental climate. And it further confirmed that the distribution, amount, and quality of water are strongly affected by the nature of the watershed cover and by the condition of the land.

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