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METZ, L. J. DOUGLASS, J. E. 1 OF 1

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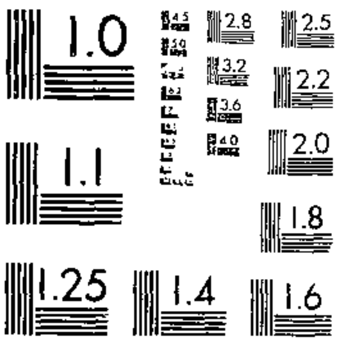

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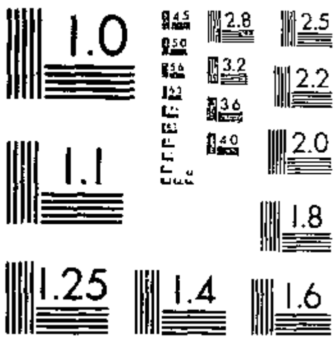

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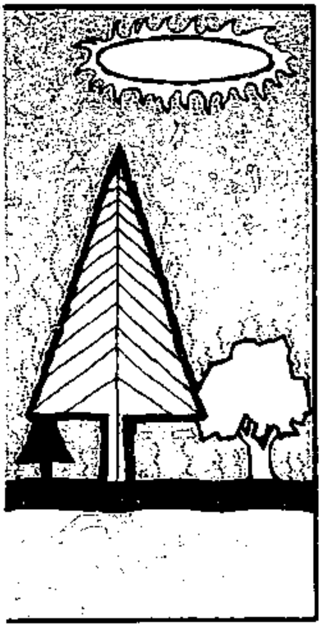

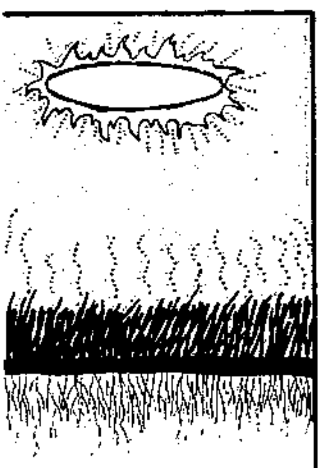

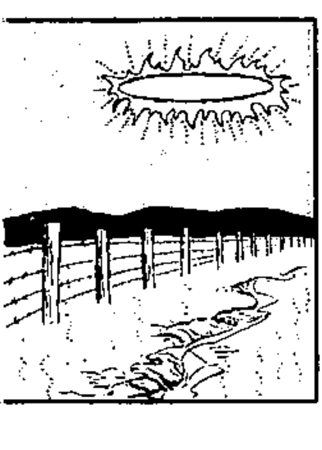

Soil Moisture Depletion Under Several Piedmont Cover Types

by

LOUIS J. METZ and

JAMES E. DOUGLASS

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The research reported here was planned and started by Marvin Hoover, former leader of the Union, S.C., research center of the Southeastern Forest Experiment Station.

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INTRODUCTION

Knowledge of soil moisture depletion during various seasons is basic in evaluating the moisture stresses of vegetation and in studies concerned with water intake and storage under various cover types. This knowledge is needed for management of lands and realistic classification according to soil, vegetation, and water resources. The silviculturist needs to know how moisture competition between plant species affects his crop. The hydrologist wishes to predict the water storage capacity of the soil at any given time. Very few studies have been made in the Piedmont of soil moisture under different vegetative cover types or at various seasons of the year. This report presents findings from a 5-year investigation of soil moisture fluctuations under forest cover, broomsedge field, and bare soil, on old-field sites at the Calhoun Experimental Forest near Union, S.C.

Although there have been many studies of soil moisture depletion under agricultural crops, only in recent years have such observations been made for forest vegetation.

In northern Wisconsin, Thames, Stoeckeler, and Tobiaski (*10*)[1] compared the moisture regime of forested and nonforested sites throughout a growing season. They found less available soil moisture in the surface 1 to 2 feet of the forested site because of heavy depletion of moisture by the tree stand, as compared with a nearby site in timothy hay.

Fraser (*2*) studied soil moisture on a variety of soils in Ontario and found that on all the dry sites (those with no water table within several feet of the surface) the upper layers of the soil dried out first. Gaiser (*3*) found that the rate of moisture extraction from three forest soils was such that all horizons of the profile simultaneously approached the wilting point. He also found that the oak forests of southeastern Ohio are capable of using all readily available soil moisture present at the beginning of the growing season as well as subsequent increments from rainfall.

Moyle and Zahner (*8*), working on the Crossett Experimental Forest in Arkansas, found that about the same amount of water was removed over the same period of time from an all-aged pine stand, an all-aged hardwood stand, and a young even-aged hardwood stand.

[1] Italic numbers in parentheses refer to Literature Cited, p. 23.

Hoover *et al.* (*5*), working in the South Carolina Piedmont, observed in a young loblolly pine plantation that water was withdrawn from the zone in which it was most readily available, regardless of depth.

The upward movement of soil water by transpiration and evaporation removes great quantities of moisture from the soil. Zahner (*11*) reports a water loss averaging 0.19 inch per day for a 6-week period during June and July from the upper 48 inches of soil under a pine and a hardwood stand.

Lyon and Buckman (*7*) report that for cropped lands of the humid regions approximately one-half of the annual rainfall is lost through transpiration and evaporation, and that the loss is divided about equally between them.

Evaporation of water from soil is controlled by the evaporating power of the air. The rate decreases as a layer of dry soil is produced at the surface. Russell (*9*) states that a 3-month drought in Rothamsted, England, caused a loss of 1.3 inches of water by evaporation, of which 0.5 inch was lost the first 5 days. He further states it is unlikely that more than 0.25 inch of water moved up from below 9 inches into the 0 to 9-inch layer.

Assuming evaporation will reduce soil moisture from field capacity to wilting point, the amount of loss will depend on the texture of the soil. Kittredge (*6*) cites an example where evaporation losses over a 10-day period vary from 0.41 inch for a sand to 2.8 inches for a clay soil.

It is very difficult to separate evaporation and transpiration in field measurements. Therefore, in the work reported herein, these two processes are considered as one—i.e., evapotranspiration—for all study areas except the barren plot. The clay soil on this site has no vegetation, and thus all atmospheric losses of water are due to evaporation.

METHODS

Study Areas

In order to measure changes of soil moisture *in situ*, and to relate these changes to plant cover differences, Colman fiberglas soil moisture units were installed in the soil to a depth of 66 inches under representative Piedmont cover types. The plots are located on nearly level ridges and upper slope positions, and are in deep, red soils of the Cataula and Lloyd series. These soils are derived from weathered granites, gneisses, and schists; they have good surface drainage but slow internal drainage because of their heavy red clay B horizons of 3 to 6 feet in thickness.

At the time the units were installed, a study was made of the physical properties of the soil at each meter plot. At nearby pits, undisturbed volume samples were collected from each unit depth for each plot. From these samples, determinations were made of bulk density, retention and detention pore space, infiltration rates, and wilting point.

As far as possible, all environmental factors on the plots are the same, with the exception of plant cover and past land use. The study areas are examples of three major cover types of the region: forest cover, herbaceous cover, and barren or no cover. Past land-use practices are reflected in the degrees of erosion which have taken place.

The seven sites selected for this study were a second-growth, 40- to 50-year-old shortleaf pine-hardwood stand; a 30- to 40-year-old shortleaf pine stand; a loblolly pine plantation planted in 1941 on cotton land abandoned in 1940 (2 plots); a broomsedge field; and two barren areas, one severely gullied. In the broomsedge field, where pines were seeding in rather heavily, the young trees were cut in order to halt the successional trend from broomsedge to old-field pine. Figure 1 shows the appearance of four of the study plots and table 1 gives the characteristics of the vegetation for all plots.

Soil Moisture Units

The soil moisture units were installed in each plot in a single auger hole. The soil removed from the holes was replaced to the depth it originally occupied and tamped to fill the original volume. The cables on the units were spiraled up the holes, laid horizontally for several feet on the soil surface, and then attached to a switch. Units near the surface were placed horizontally in undisturbed soil at the edge of the auger hole, whereas lower units were placed vertically in disturbed soil. To facilitate reading the electrical resistances of the decks of units, the cables were wired to a three-gang selector switch housed in a weather-protected shelter mounted on a short post. The units were read with the soil moisture ohmeter, as described by Colman (*7*); these readings were taken once a day for the first 3 years, and at least three times a week after that.

TABLE 1.—*Characteristics of vegetative cover* [1] *of seven soil moisture plots, Calhoun Experimental Forest, S.C.*

Plot number and cover type	Species	Stems per acre	Basal area per acre	Average d.b.h.	Average height of dominants
		Number	*Square feet*	*Inches*	*Feet*
Plots 1 and 5, loblolly pine plantation.	Loblolly pine	760	103	5. 3	31
Plot 6, shortleaf pine	Shortleaf pine	500	110	6. 0	55
Plot 7, shortleaf pine-hardwood.	Shortleaf pine, redcedar, elm, dogwood, oak, blackgum.	520	140	6. 8	50
Plot 3, broomsedge old field.	Broomsedge, aster, goldenrod, horseweed.				
Plots 2 and 4, barren areas.	None	0	0	0	0

[1] Trees 4 inches d.b.h. and larger.


A
B

C, A barren eroded area void of cover (plot 1); *D*, a shortleaf pine-hardwood stand (plot 7).

TABLE 2.—*Partial profile description and characteristics of the soil at moisture plot 1* [1]

Profile description and depth (inches)	Horizon	Depth sampled	Profile characteristics				
			Bulk density	Saturated pore space, by volume	Retention storage at 60 cm., by volume	Detention storage at 60 cm., by volume	Percolation rate
		Inches	*Grams/cc.*	*Percent*	*Percent*	*Percent*	*Inches/hour*
Loamy sand; slightly indurated; powdery; yellowish (0-2).	A_p	0-2	1. 31	45. 9	16. 3	29. 6	23. 17
Brown sandy clay loam; strongly indurated; hard and brittle (2-6).	A_p	2-4	1. 43	42. 3	22. 9	19. 4	9. 58
		4-6	1. 56	36. 5	27. 8	8. 7	1. 88
Yellowish-red sandy clay; tough; blocky (6-10)	B_2	6-8	1. 55	42. 3	31. 2	11. 1	1. 34
		8-10	1. 40	47. 8	39. 4	8. 5	. 61
Red clay; tough; massive structure (10-17)	B_2	12-14	1. 38	48. 3	42. 7	5. 6	. 39
		14-16	1. 38	49. 4	43. 8	5. 6	. 04
Transition zone; mica and feldspar present (17-27)	B_2	16-18	1. 37	49. 7	43. 0	6. 6	. 11
		22-24	1. 39	47. 7	42. 4	5. 3	. 08
Red clay; much feldspar and mica; platy structure; compact (27-48).	B_3	28-30	1. 35	50. 4	41. 8	8. 6	. 09
Yellowish-brown color; decomposed schistose material; very micaceous (48-66).	B_3	52-54	1. 42	47. 6	39. 0	8. 6	. 05

[1] Soil moisture plot 1 was established in a loblolly pine plantation on the Cataula Soil Series.

Calibration of the resistance units was based on field sampling. Gravimetric tube samples were collected over the entire range of soil moisture found in the field, and the moisture percentage on an oven-dry weight basis was plotted over corrected resistance of the unit at the time of sampling. Natural soil variation around each installation caused considerable variation in the relationship of unit resistance to sample values of soil moisture for some of the Colman units. This was an unavoidable error. The best curves of soil moisture over unit resistance have been drawn in each case, and data reported are from these.

Since these data are subject to the inherent variability of soil, the soil moisture figures, though expressed in quantitative terms, must be evaluated in a relative way only. Indications of the depth and season of moisture withdrawal, and the comparative water use between the cover types, are quite valid. The data express only relative amounts of moisture in the soil as measured beneath these classes of cover.

Table 2 gives a partial description of the soil at one of the plots in the loblolly pine plantation. In table 3, the percolation rate for the surface 6 inches of soil is given for the five vegetative covers studied. Procedures used for these determinations are described by Hoover, Metz, and Olson (*4*).

TABLE 3.—*Percolation rates of the surface 6 inches of representative moisture plots*

Cover type (and plot number)	0–2 inches	2–4 inches	4–6 inches
	Inches/hour	*Inches/hour*	*Inches/hour*
Loblolly pine plantation (1)	23.17	9.58	1.88
Barren (2)	.06	.06	.06
Broomsedge field (3)	44.79	19.86	12.26
Shortleaf pine (6)	4.98	4.61	1.43
Shortleaf pine-hardwood (7)	90.00	13.24	11.34

Climate

Precipitation was measured in the vicinity of each plot. Rainfall in the experimental area is distributed farily evenly throughout the year; however, droughts have occurred in all seasons. Table 4 shows the 50-year average rainfall record at nearby Santuck, S.C., and rainfall at the Calhoun Experimental Forest, 1951–55.

The winter precipitation differs from the summer precipitation in character and origin. Most rains in the late autumn, winter, and early spring are gentle, widespread, and of long duration. They are the warm-front type caused by the steady advance aloft of warm, moist air from the south over a wedge of colder and denser air of polar origin. In the late spring, summer, and early autumn, most of the precipitation originates in convectional storms which produce rains of high intensity, generally of short duration and small areal

TABLE 4.—*Record of rainfall at Santuck, S.C., and Weather Station Number 1, Calhoun Experimental Forest*

Month	Santuck, S.C., 50-year average	Calhoun Experimental Forest				
		1951	1952	1953	1954	1955
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January	3. 80	1. 86	2. 20	4. 96	6. 03	4. 31
February	4. 44	2. 23	4. 05	6. 28	3. 27	4. 10
March	4. 38	4. 32	9. 36	5. 41	5. 42	1. 97
April	3. 47	2. 35	3. 93	. 95	2. 40	4. 31
May	3. 36	. 77	2. 37	5. 06	3. 32	3. 69
June	3. 81	4. 84	2. 05	4. 36	. 62	1. 20
July	5. 18	3. 65	2. 53	4. 45	3. 97	5. 25
August	5. 79	. 89	7. 03	2. 35	2. 18	3. 25
September	3. 44	4. 67	1. 31	5. 38	. 01	3. 25
October	3. 04	. 94	. 80	. 81	. 62	1. 03
November	2. 65	3. 09	1. 08	. 54	2. 95	2. 49
December	4. 25	6. 30	3. 83	7. 92	3. 24	. 32
Total	47. 61	35. 91	40. 54	48. 47	34. 03	34. 93

extent. Whereas much of the summer rainfall is lost as storm runoff, the winter rains soak into the soil and recharge the soil moisture.

Temperatures vary from below 10° F. in the winter months to the high 90's in the summer. Temperatures over 100° occur nearly every summer.

RESULTS

Five years of soil moisture records for the seven study areas are too voluminous to be presented in full; therefore, only excerpts are given for certain plots. These illustrate the soil moisture patterns beneath forest cover, old-field grass vegetation, and barren, eroded areas with little or no vegetation. Four of the field plots are in forest cover (plots 1, 5, 6, and 7), two are on barren soil (plots 2 and 4), and one is in an old field (plot 3). In general, the data show that the four forested areas behave similarly, as do the two barren areas. The single, old-field plot is used for comparison with one of the barren plots and the forested areas.

Soil Moisture Comparisons by Depth Zones Under Three Cover Types

To visualize more readily what is happening to the moisture in the surface 66 inches of soil, we divided this depth into different zones. The zones selected are arbitrary, and the moisture in any one zone is measured with one to three units. Thus, there are usually units at three different depths contributing data in the surface 15-inch zone, and only one unit in the 54- to 66-inch zone.

Total soil moisture by depth for three cover types is plotted in figure 2. The period March through October 1953 was selected to show the depletion of soil moisture during the growing season and early fall.

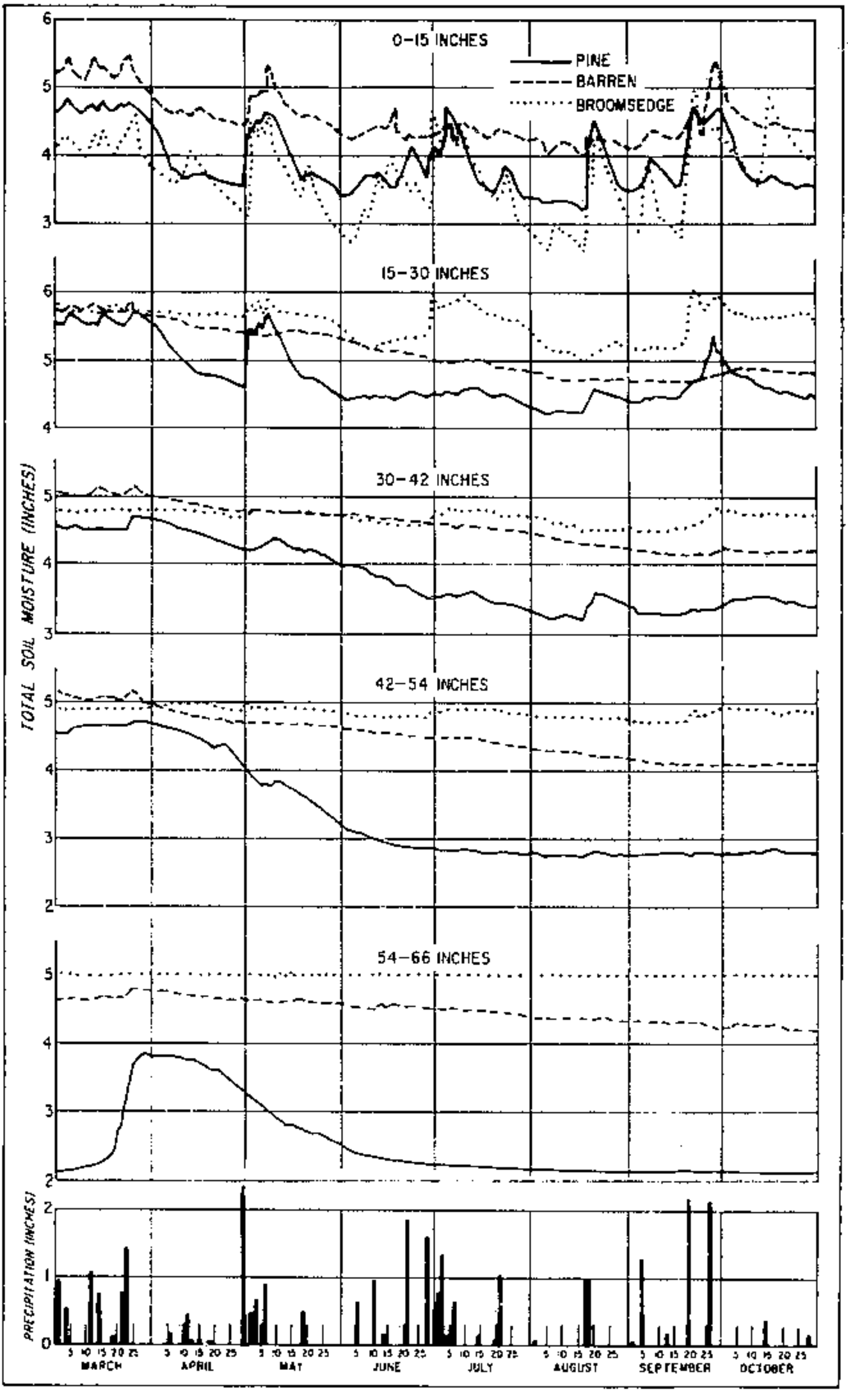

FIGURE 2.—Soil moisture fluctuations by depths under a pine plantation, broomsedge field, and a barren area (1953).

The loss of water from the vegetated plots is due to the combined effect of evaporation from the soil and transpiration by plants. On the nonvegetated plots all upward moisture loss is due to evaporation.

Soil moisture fluctuations in the surface 15 inches are similar for the pine plantation and broomsedge field. The greatest difference between these plots is in the amount of total water held in this zone. Evapotranspiration during the summer months reduces the moisture of both cover types from field capacity to near wilting in approximately one month.

When the soil beneath the pine and broomsedge types is at or near field capacity, one week of evapotranspiration can reduce the moisture of the surface 15 inches of each type approximately 0.8 inch and 0.7 inch respectively. If the soils could be recharged to field capacity once each week, evapotranspiration theoretically could remove 15 to 18 inches of water from the surface 15 inches of soil between April and September. The potential loss from this zone is significant, since average precipitation during this period is only 21.61 inches.

Water losses from the surface 15 inches of a barren soil are less than from either pine or broomsedge. The extremely low infiltration capacity of the surface of the barren soil limits recharge of moisture. Water intake in barren soil is much less than in the more permeable soils of the broomsedge and pine areas (table 3).

In the 15- to 30-inch depth, depletion and recharge characteristics for the pine plantation and broomsedge field are different. The contrast in depletion is a reflection of variations in the depth and number of roots. Under the pine stand, roots extend throughout the zone in sufficient numbers to deplete available water quite rapidly. Fewer roots are present in the 15- to 30-inch zone of the broomsedge field, and depletion occurs at a slower rate. Recharge resulting from precipitation is greater under the broomsedge than under pine cover because of more rapid infiltration.

As seen from the graph, soil moisture recharge from precipitation was slight in the compact, nearly impervious clay of the 0- to 15-inch zone of the barren area. Of the water added to this zone, only an infinitesimal amount moved lower in the profile. In the 15- to 30-inch depth, water loss from evaporation, vapor movement, and downward drainage was slow but continuous from April until September.

Evapotranspiration from the plantation steadily depletes soil moisture of the 30- to 42-inch zone to the wilting point. Only very heavy rains interrupt this depletion trend. A large enough deficit exists in the surface 30 inches to contain the precipitation increments from small storms.

Trends of soil moisture loss from the 30- to 42-inch zone of the barren and broomsedge plots are similar. Loss from these plots is slight and almost constant throughout the period shown. At this depth, recharge of soil moisture by precipitation is slight under the broomsedge cover and almost nonexistent under the barren plots.

No moisture is added to the 42- to 54-inch zone of the barren soil by rainfall during the growing season, and only slight increments are added in the pine and broomsedge cover types. Apparently at this depth, soil moisture loss practically ceases under the broomsedge cover because evapotranspiration, vapor movement, and downward drainage are at a minimum. Although there is a slight water loss in the barren soil, only the plantation shows appreciable loss. Evapotranspiration losses continue beneath the pine, but at a slower and steadier rate than in zones of greater root concentration.

In the 54- to 66-inch zone, recharge of soil moisture in the pine plantation did not occur until the period of heavy rains during the last weeks of March. After recharge, depletion began in April and continued throughout the summer with no interruptions. Depletion of soil moisture continued to occur at a very slow rate at this depth in the barren plot, but moisture under the broomsedge cover remained constant from March through October.

Depletion of soil moisture under the pine plantation was considerable and easily discernible throughout the depth studied. It is apparent that the roots, by their withdrawal of moisture, have a pronounced effect on water content of the surface 66 inches of soil.

Some investigators have reported that under forest vegetation all zones approach the wilting point at approximately the same time (*3*). An examination of soil moisture by depths under the pine plantation indicates that this may not be true in Piedmont soils. Rate of loss of soil moisture is dependent on the depth of the soil. Root concentration, being greatest near the surface, causes depletion of the surface layers at a much faster rate than at the lower layers. The rate of depletion decreases with depth; thus, if no precipitation occurred, the wilting point would be reached first at the surface and last at the lowest depth measured. Conversely, after a heavy summer storm, it is possible for the 54- to 66-inch zone to be at the wilting point while there is still considerable moisture in the surface 30 inches. For example, under the pine stand at the end of September the 42- to 54-inch zone and the 54- to 66-inch zone were approximately at the wilting point. Rains of the 19th and 26th had replenished the soil moisture of the surface 30 inches; the 30- to 42-inch zone was a transition between the two extremes. Thus, the time at which each zone nears the wilting point is a function of precipitation and evapotranspiration (which is a function of root concentration through a depth of soil), and if all zones reach the wilting point at the same time, it is only so by chance.

For all practical purposes, soil moisture depletion under the broomsedge cover was limited to the upper 30 inches, with greatest water loss occurring in the 0 to 15-inch depth.

Soil moisture losses occurred throughout the depth studied under the barren plot. Soil moisture depletion was greatest at the surface and decreased with depth. Since evaporation has its greatest influence at the surface, it is probable that only a small loss from evaporation occurred below the 15-inch depth, and that most of the loss could be attributed to vapor movement and slow, downward movement of water. However, bare clay soil often cracks to considerable depths because of shrinkage associated with drying. Because of these cracks, evaporation at depths greater than 15 inches plays a more important role in clays than in soils of other textures.

Complete Profile

Figure 3 shows the 1952 moisture conditions of the 0 to 66-inch zone of the pine plantation, the broomsedge field, and the barren area.

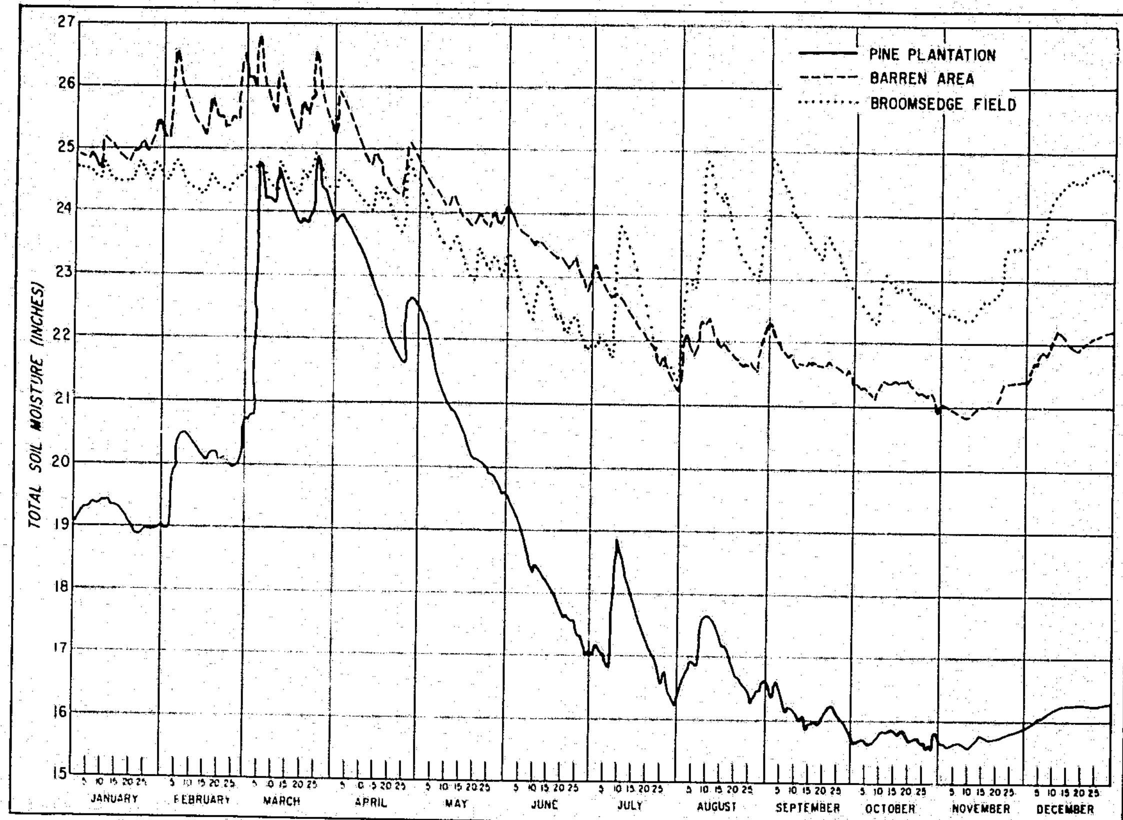

FIGURE 3.—Soil moisture regime in a pine plantation, a barren area, and a broomsedge field for the 0 to 66-inch depth of soil (1952).

The barren and broomsedge areas were recharged at the beginning of the year, whereas the soil beneath the pine was not recharged until March. The greatest net soil moisture loss occurs under the pine cover type, which loses 9.47 inches of water, as compared with a loss of 6.05 inches for the barren soil, and 3.70 inches for the broomsedge field. Soil characteristics of the broomsedge plot enable it to take in more of the precipitation occurring in July, August, and September than the barren plot. Tests show that the surface 2 inches of the broomsedge plot has a percolation rate many times that of the barren soil. Also, water can percolate more rapidly through the upper 8 inches of the old-field soil because of its greater large-pore space.

The rate of water loss is greater from the broomsedge than from the barren plot, and the soil in the broomsedge plot is recharged more from given increments of rainfall than the bare soil. Thus, moisture is maintained at a high level during August, September, and October, a period when the soil moisture is lowest for the pine plantation and barren soil.

Forest Cover Comparisons

Figure 4 compares the soil moisture beneath a young pine plantation and a pine-hardwood stand. This comparison clearly illustrates that the two stands affect soil moisture approximately the same. Moyle and Zahner report corresponding results with their studies in Arkansas (*8, 11*). Both plots have similar depletion and recharge characteristics; and for comparable rainfall, both plots take in about the same amount of water. However, there is a question whether this would be true if the comparison were between pine and old-growth hardwoods on comparable sites. As shown, the difference between the moisture content of the two stands is primarily in the amount of water that can be stored in the soil. Throughout most of the year the soil beneath the pine-hardwood stand contains about a half inch more water in the surface 66 inches.

Cyclic Effect

The soil moisture cycle—seasonal depletion and recharge—was similar throughout the 5 years of study. Figure 5 compares the yearly soil moisture trends for a pine-hardwood stand and broomsedge field over a 3-year period. The maximum and minimum points reached in recharge, depletion of soil moisture, and the differences in magnitude of the peaks and troughs are attributable to variations in precipitation. Assuming the rainfall pattern remains the same, this cyclic moisture regime should continue with only minor differences until the vegetative or soil characteristics change.

Soil Moisture Depletion

In deriving curves of soil moisture loss for a given period, a technique much like that used to determine ground water or streamflow depletion was devised. By this method, all growing-season drying periods of 6 days or more were tabulated, and the individual drying

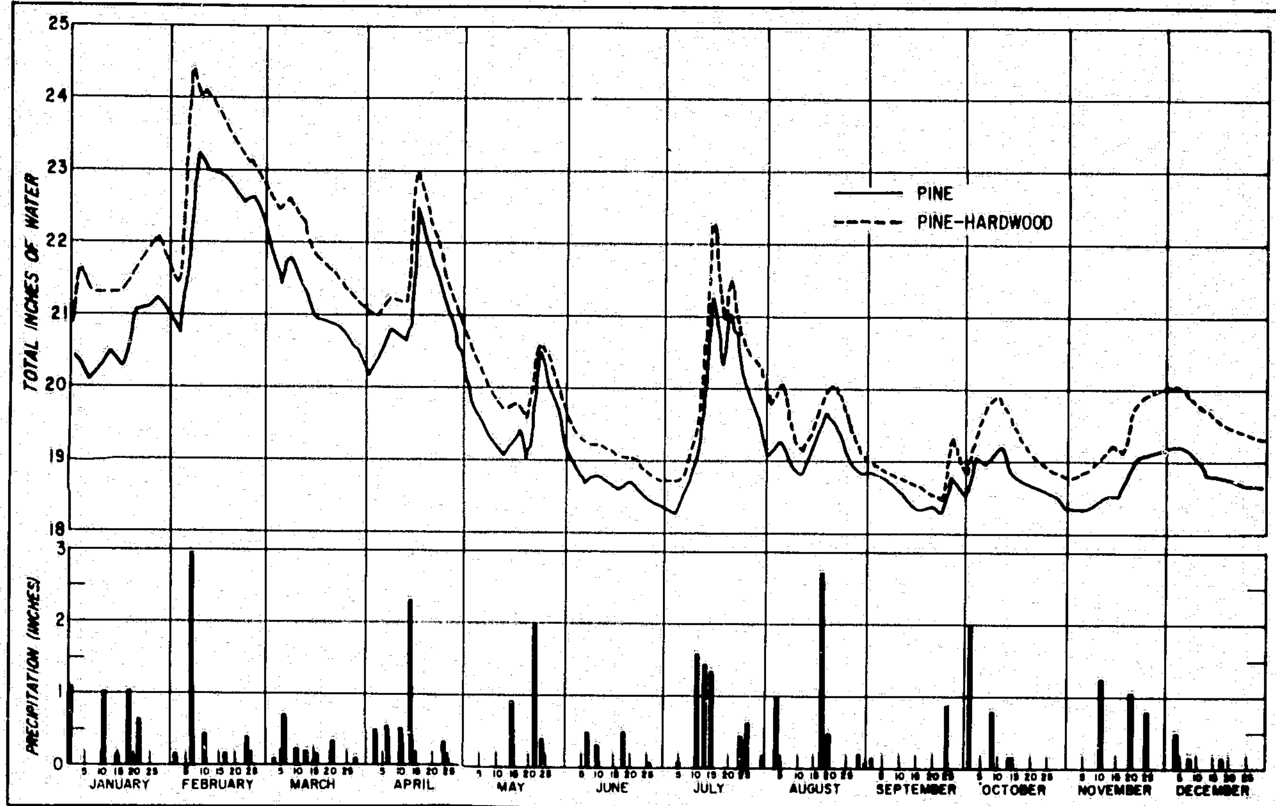

FIGURE 4.—A comparison of moisture in the surface 66 inches of soil under a young pine plantation and a pine-hardwood stand (1955).

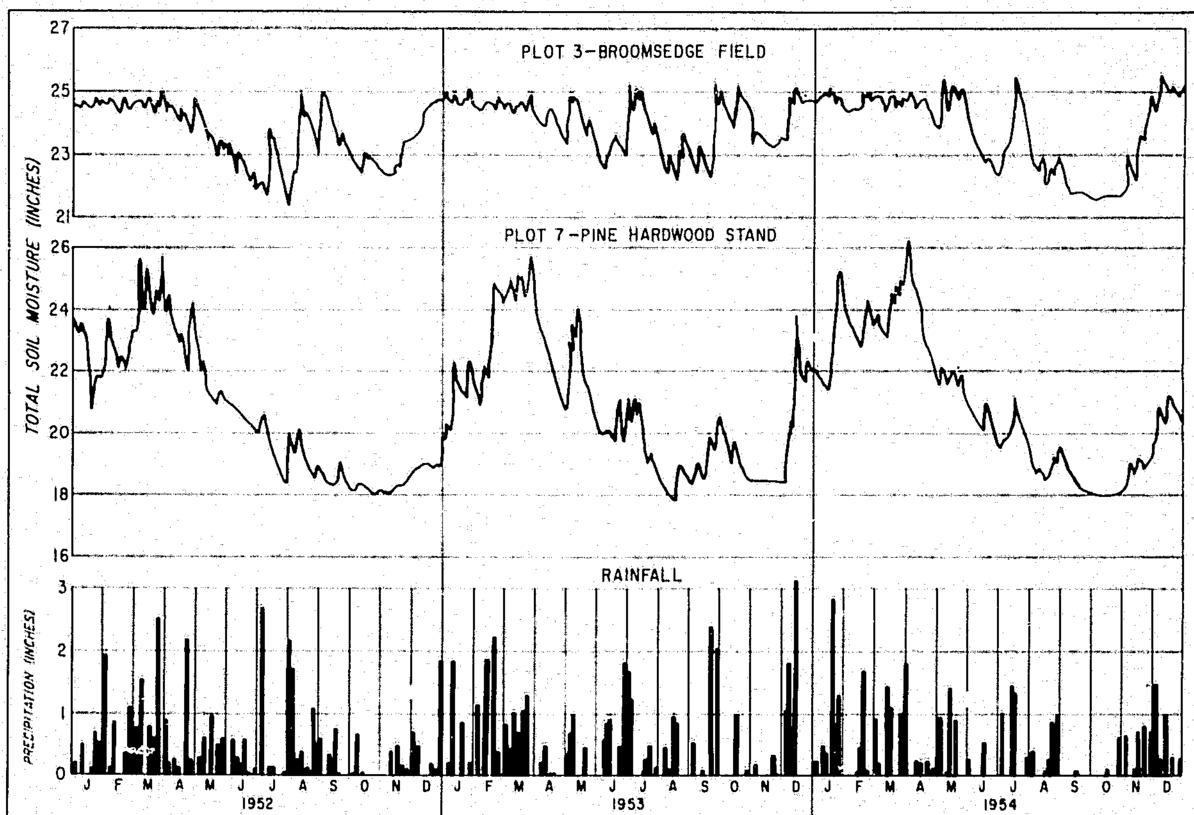

FIGURE 5.—Soil moisture fluctuations in a broomsedge field and a pine-hardwood stand over a 3-year period (0 to 66-inch soil zone; 1952–54).

curves were plotted on tracing paper (templates) as total soil moisture over days of drying. On graph paper as a base, all individual drying curves were fitted together into a mosaic representing the total drying curve. Initial soil moisture on the templates was carefully superimposed over the corresponding soil moisture on the base sheet. The average curve was constructed by sliding the templates to the right or left.

By summing and averaging all individual soil moisture readings for each day of drying, average soil moisture was derived and plotted. The plotted points determined the shape of the depletion curve and formed the basis for fitting either a freehand or a mathematical curve to the data.

The highest initial soil moisture is the reading taken one day following a rain. For this reason, all depletion curves start at one day and not at zero days of drying. The rate of moisture depletion varies with the forces withdrawing the moisture and with the amount of moisture in the soil (fig. 2). Evaporation from the barren plots and evapotranspiration from the vegetated plots are the major agencies withdrawing moisture from the soil. Vapor exchange and drainage are minor factors affecting the soil moisture of both vegetated and barren soils. To illustrate the moisture trends at different depths, soil moisture depletion curves are presented for the entire 0 to 66-inch depth and six subdivisions of that depth.

0 to 5-inch zone (*fig. 6*).—In this zone all soils showed similar depletion curves. The barren area contained more total water in the surface 5 inches than the pine plantation or broomsedge field. At the end of the 40-day drying period, the moisture losses were 0.95 inch for the broomsedge, 0.77 inch for the barren area, and 0.54 inch for the pine plantation.

The rate at which moisture was lost from the broomsedge and pine plots was practically identical for the first 4 days of drying. Thereafter, moisture losses slowed considerably under the pine cover, and on the 10th day the soil neared its wilting point. Moisture loss

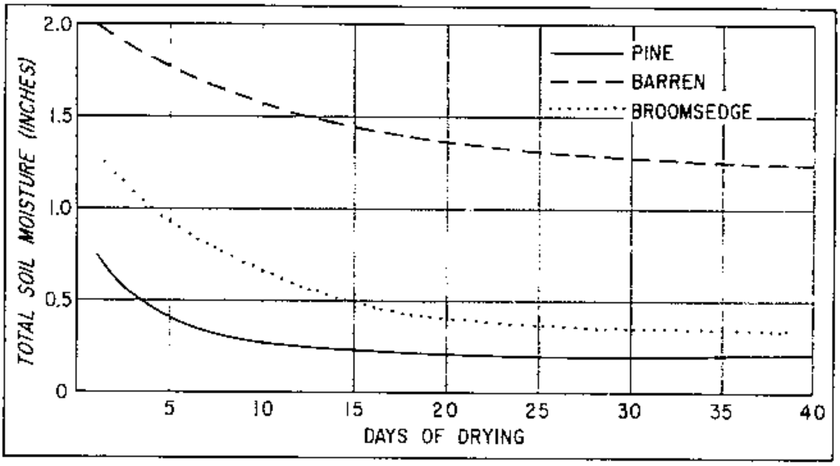

FIGURE 6.—Soil moisture depletion of the 0 to 5-inch zone under three cover types.

under the broomsedge cover proceeded rapidly for about 15 days. As the soil approached wilting, the rate at which moisture was lost slowed appreciably, and about the 24th day the soil reached wilting point.

Initially, the rate of loss from evaporation (barren plot) was considerably less than from evapotranspiration (pine and broomsedge plots). The wilting point in the barren soil was approached about the 28th day of drying.

5- to 10-inch depth (*fig. 7*).—The interesting feature of the depletion from this depth is found in the broomsedge plot. The moisture depletion starts out slowly and increases quite rapidly about the 10th day, when the 0 to 5-inch zone has lost over two-thirds of its available water. This rapid loss is maintained until the moisture in the 5- to 10-inch zone approaches the wilting point about the 30th day.

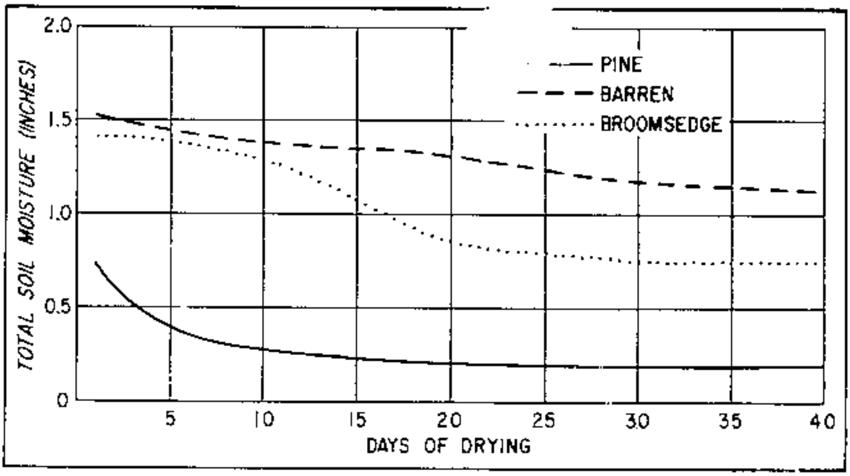

FIGURE 7.—Soil moisture depletion of the 5- to 10-inch zone of a pine plantation, a broomsedge field, and a barren plot.

It is suggested that this phenomenon is a result of the difference in root concentration and moisture in the two zones. The surface 5 inches of soil contains the greatest root concentration, which rapidly depletes this zone of moisture. As this upper zone approaches wilting, the water needed by the plants must be obtained from some other depth. For the broomsedge plot, this was from the 5- to 10-inch depth, which then contained the most readily available water.

Even though this zone contains fewer roots, these roots will withdraw the plentiful water at a more rapid rate than from the upper, drier soil where water is held more firmly. Plants can develop many atmospheres of pull on soil moisture, and since more water exists in the moist 5- to 10-inch depth than in the drier 0 to 5-inch depth, it is logical to expect the 5- to 10-inch depth to supply water at a more rapid rate. As the 0 to 5-inch zone continues to dry, the rate of moisture loss from the lower depth will increase until moisture in that depth becomes limiting.

Since the soil moisture depletion curves of the pine plantation for the 0 to 5- and 5- to 10-inch zones are consistent in shape, it is assumed that the quantity of roots in the 5- to 10-inch depth is sufficient to obscure the effect observed for the broomsedge plot.

The barren area reacts in a manner similar to that of the broomsedge plot. However, since the losses from evaporation are considerably smaller than from evapotranspiration, the results are not so readily perceptible.

10- to 15-inch zone (*fig. 8*).—Losses are initially high for the pine plantation and broomsedge plot. Moisture losses from the pine progressively decrease. Under the broomsedge the loss begins at a fairly rapid rate, decreases, and then increases again when the moisture in the 5- to 10-inch zone becomes limiting (around the 20th day). This same relationship holds for the 15- to 30-inch depth. However, to show the phenomenon for depths below 15 inches, the depletion curves for the broomsedge plot must be extended from 40 to 60 days. This occurrence substantiates findings of Hoover *et al.* (*5*) that "Water is withdrawn from the zone in which it is most readily available, regardless of depth."

Losses from the 10- to 15-inch depth of the barren plot progressively decrease with time, indicating that the action of evaporation is diminishing.

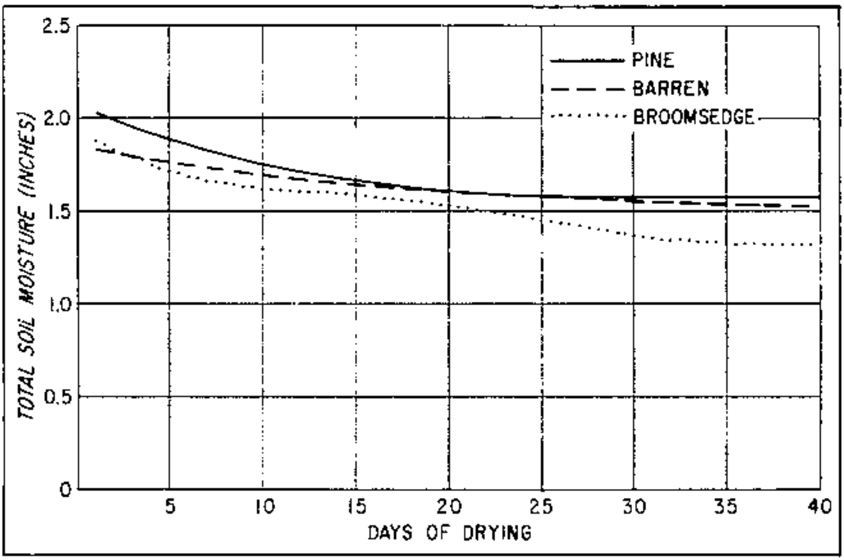

FIGURE 8.—Soil moisture depletion of the 10- to 15-inch zone of a pine plantation, a broomsedge field, and a barren plot.

0 to 15-inch zone (*fig. 9*).—Total soil moisture was greatest in the barren plot. The broomsedge plot and pine plantation contained approximately equal volumes of water. At the end of the 40-day drying period, the broomsedge plot had lost the greatest amount of water (2.20 inches); losses from the plantation and barren plot were 1.63 and 1.42 inches respectively. Also, at the end of 40 days the pine and broomsedge plots were at wilting point.

Initially, soil moisture depletion was most rapid from the plantation. This soil reached the wilting point on approximately the 25th

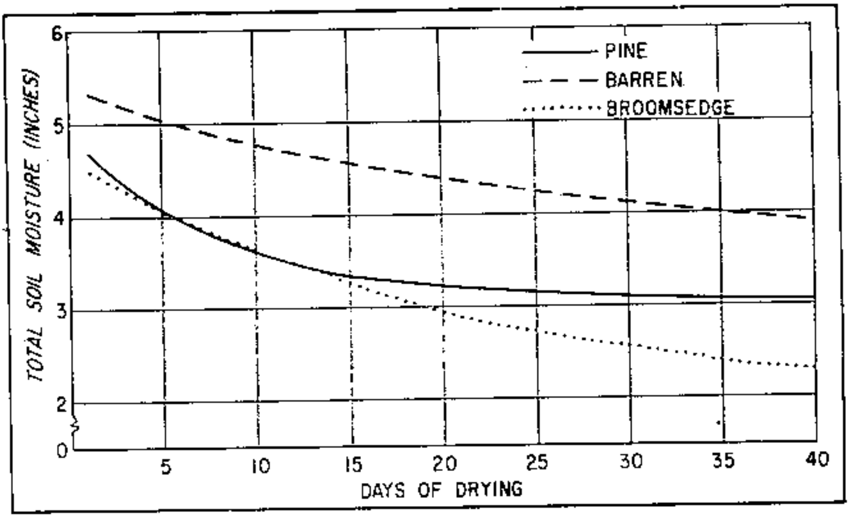

FIGURE 9.—Soil moisture depletion of the 0 to 15-inch zone of a pine plantation, a broomsedge field, and a barren plot.

day. Early in the drying period, moisture was used somewhat more rapidly by the pine stand than by the broomsedge. Since the broomsedge plot contained the greatest amount of available water, depletion continued after the plantation soil had reached the wilting point. Moisture was exhausted under the broomsedge toward the end of the 40-day drying period.

Soil moisture loss in the barren plot decreased as drying continued. The moisture was used more rapidly by the plantation and broomsedge plot than by the barren plot. During the entire drying period, this soil did not approach the wilting point.

Note that the increase in the rate of depletion in the lower depth, when water is nearly exhausted in the zone above, as observed in the broomsedge and barren plots, is not visible when these zones are taken collectively. By pooling the zones, the effect is obscured.

15- to 30-inch zone (*fig. 10*).—The pine plantation lost the greatest volume of water from this zone. Total moisture loss was 1.44 inches from the pine plantation, 1.04 inches from the broomsedge field, and 0.55 inch from the barren area. When depletion of moisture from this zone is compared with that of the surface 15 inches, it is obvious that the rate of depletion from all plots is less in the lower depths. Loss from this zone over a period of 40 days was less than that from the surface 15 inches. The loss was 68, 53, and 12 percent less for the barren, broomsedge, and pine plots respectively. The reduction in the amount of water lost during the drying period is most striking for the barren plot. The slight reduction in loss from the 15- to 30-inch depth of the pine stand indicates that roots in this depth are sufficient to deplete the moisture almost as rapidly as it is depleted from the surface 15 inches.

In order of magnitude, the rate of loss from the 15- to 30-inch depth was greatest for the pine and broomsedge plots, followed by the barren plot. The average loss per day for the barren plot was one-fourth that of the pine plantation and one-third that of the broomsedge plot.

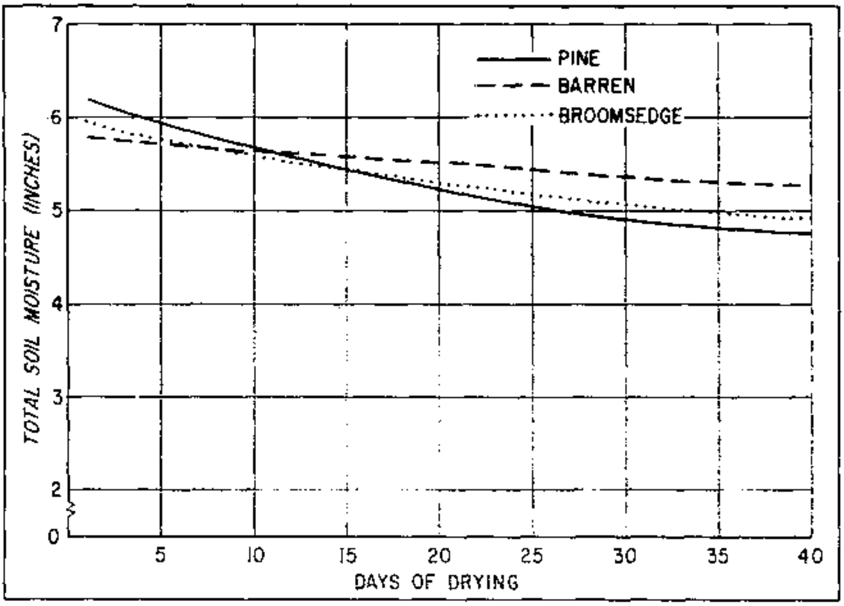

FIGURE 10.—Soil moisture depletion of the 15- to 30-inch zone of a pine plantation, a broomsedge field, and a barren plot.

30- to 66-inch zone (fig. 11).—Data for this zone indicate clearly the difference in root concentration in the zone. Although it had less available moisture, more water is lost from the pine plantation than is lost from the broomsedge plot. The rate of moisture loss from the plantation is constant throughout the 40-day drying period. If this curve were extended to 60 days, it would level out as the soil approached the wilting point.

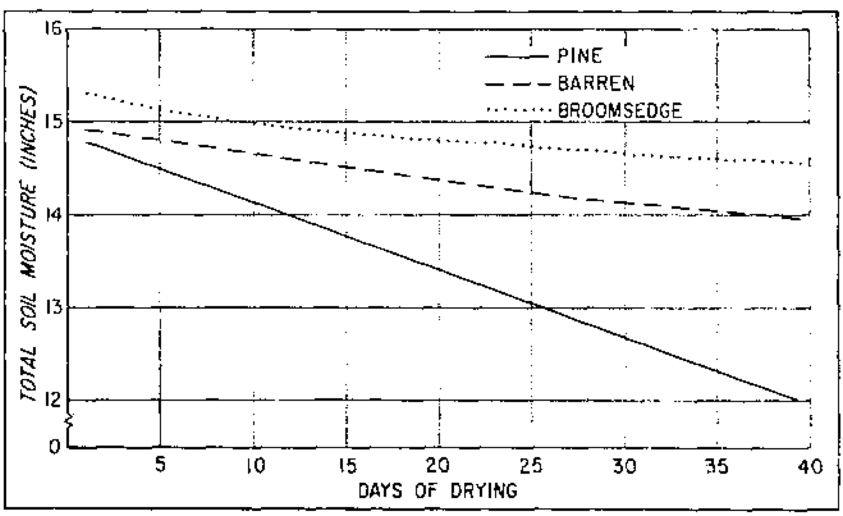

FIGURE 11.—Soil moisture depletion of the 30- to 66-inch zone of a pine plantation, a broomsedge field, and a barren plot.

The depletion curve for the broomsedge plot tends to level out after the first 2 weeks of drying, even though the soil still has approximately 4 inches of available water. This would seem to indicate, and field observations confirm, that roots of the broomsedge field fail to penetrate the entire zone. It appears that the roots deplete the moisture in their immediate vicinity, and moisture at greater depths remains relatively the same.

The barren area has the greatest amount of available water of the three plots, and soil moisture loss continues at this great depth; however, not all of this loss is from evaporation. At the beginning of the drying period, this zone was over field capacity. A portion of the moisture was lost from downward drainage, and it is conceivable that some moisture moved by capillary action and vapor movement from zones of high water content to zones of low water content.

0 to 66-inch zone (fig. 12).—Soil moisture losses from the barren plot, broomsedge plot, and pine plantation for the drying period of 40 days were 2.89, 3.99, and 5.85 inches respectively. Soil moisture depletion from the plantation was one and one-half times greater than the depletion from the broomsedge plot and twice the depletion by evaporation.

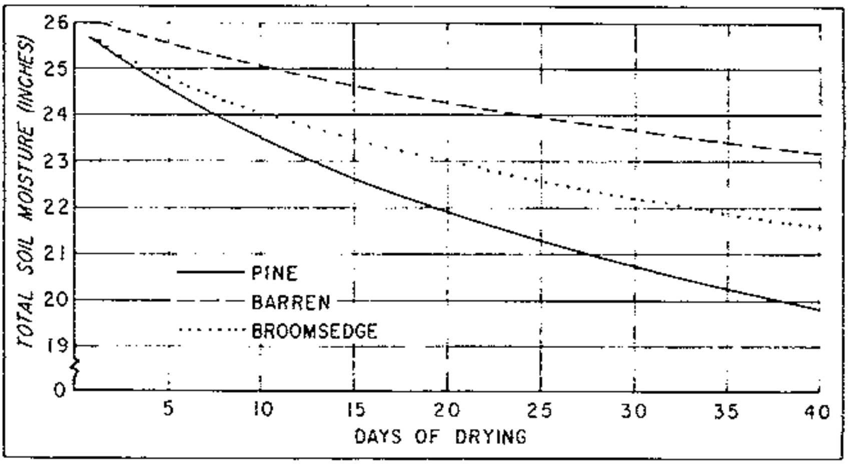

FIGURE 12.—Soil moisture depletion of the 0 to 66-inch zone of a pine plantation, a broomsedge field, and a barren plot.

Moisture loss was greater from the plantation than from the broomsedge plot because of the greater depth and volume of roots of the former. Deep roots of the pine stand made available much water below the roots of the broomsedge. Even though there was considerable water in the lower depths, it was unavailable to the broomsedge because the roots did not reach it.

DISCUSSION

The quantity of moisture in the soil depends on many factors; some of the more important ones are precipitation, season of year, plant cover, and soil material. The quality of the plant cover and the soil condition depend to a great extent on past land use. All the plots studied were located on abandoned fields. Soil in the plots varies, especially near the surface, according to the differences in severity of treatment when in agricultural crops, the length of time it took vegetation to become established after the land was abandoned, and the number of years the present vegetation has been growing. Thus, plant cover is confounded with previous land use; however, even though there are important site differences, soil moisture behavior at least suggests that cover type is the main variable.

From the hydrologic viewpoint, the primary aims of watershed management determine the type of cover needed. In any event, bare soil is undesirable, and any manipulation of vegetative cover must be accomplished in ways that minimize erosion and siltation hazards.

This study supports the widely held assumption that deep-rooted species such as trees can transpire more water than shallow-rooted species, and thereby create maximum storage space for winter precipitation. Hence, it also supports the thesis that forest vegetation is desirable where flood prevention is the principal aim. During summer months, water is disposed of by evapotranspiration, lateral flow, and downward drainage. In the dormant season, the latter two processes account for most of the withdrawal of water from the root zone.

Shallow-rooted grasses did not withdraw as much water as the deep-rooted trees; thus, the soil which supported grasses had less storage space available for winter rains than the soils with deep-rooted vegetation. This suggests that if maximum total yield of water is the management aim, a grass cover may be desirable. In these study plots, grass cover afforded good protection from erosion, maintained a structure favorable for rapid infiltration of water, and removed less water from the soil than did the forest stands.

Aside from evaporation, the rate of moisture depletion is determined principally by the concentration of roots. Soil moisture depletion is greatest where root concentration is greatest. Root concentration is inversely related to depth in the soil, as is the rate of soil moisture loss. If no rain occurred for an entire summer, the surface soil would reach the wilting point quickly, and each succeeding depth would require a greater period of time to reach the wilting point. Fortunately, rainfall is generally distributed so that under normal conditions the entire profile is rarely reduced to the wilting point for more than a week or so at a time.

Under forest cover, the recharge by precipitation during the growing season replenished the moisture lost in the surface 30 inches. This water was used rapidly by vegetation, and only very heavy rains added to the moisture supply of the 30- to 42-inch zone. Below 42 inches, depletion was generally unaffected by rainfall during the summer months. Hence, it is clear that little ground water recharge can take place during the growing season. Ground water recharge takes place during the late fall and winter seasons, when plants are withdrawing moisture slowly, and when the intensity of the precipitation is such that the water can soak in.

SUMMARY

Data are presented on soil moisture observed under forest cover, old-field vegetation, and bare soil.

1. The withdrawal and recharge of soil moisture is cyclic, repeat-

ing itself each year. Recharge begins in the late fall or winter, and depletion begins with the start of the growing season, continuing until late fall. During dry years, the soil may not be recharged to field capacity.

2. Recharge from summer precipitation adds moisture to the soil surface layers beneath vegetation: however, even for very heavy rains, the water is quickly used by evapotranspiration, so that for all practical purposes it does not move below 30 inches. Low infiltration rates limit the recharge of soil moisture of barren eroded soils.

3. Depletion of soil moisture lends itself to curvilinear analysis by depths or profile and cover types. Forest types appear to deplete soils of moisture to depths of at least 66 inches at relatively the same rate regardless of species. Under old-field herbaceous vegetation and bare soil, moisture is lost primarily from the surface 30 inches, although slight losses occur at greater depths.

4. Moisture loss from barren and vegetated soils is related to depth. With increasing depth of soils, the rate of moisture loss decreases. Under vegetation this is a reflection of root concentration, while from bare soils it is a reflection of the characteristics of evaporation from soil.

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