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Soil Moisture Depletion Patterns Around Scattered Trees

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ABSTRACT: Soil moisture was measured around an isolated mature sugar pine tree (*Pinus lambertiana* Dougl.) in the mixed conifer forest type of the north central Sierra Nevada, California, from November 1965 to October 1966. From a sequence of measurements, horizontal and vertical soil moisture profiles were developed. Estimated soil moisture depletion from the 61-foot radius plot for the 1966 summer depletion season was 22.57 inches.

RETRIEVAL TERMS: soi1 moisture depletion; vegetative water use; evapotranspiratlon; forest influences; watershed management; *Pinus lambertiana;* California.

OXFORD: 116.254:111.73:174.7 *Pinus 1ambertiana (794).*

Ever-growing demands for fresh water in the West have, for some time, resulted in an emphasis on new sources of supply. The major efforts to date have been devoted to importing water from areas of relative abundance to areas of deficit. Alternative means to augment local water supplies may be possible in many areas by treating the vegetative cover so as to reduce the amount of water used by plants.

Streamflow and soil moisture storage in forested watersheds are affected by the nature of logging and by the resultant spacing of the residual vegetation. If the land manager is to decide rationally what effect land treatment will have on water yield, he needs to know how vegetation is related to the soil moisture regime. He may wish to treat the vegetative cover so as to reduce the amount of water used by plants.

Effects of vegetation on soil moisture have been studied for some time. As early as 1889, Wyssotzky[1] reported the effect of logging on soil moisture depletion in Germany. Since then, the volume of literature has grown and some of the findings appear contradictory. The contradictions are related to soil, vegetative, and climatic variables, as well as to sampling technique. Since the introduction of the neutron method of soil moisture measurement in the 1950's, the researcher has a much more reliable tool with which to study soil moisture depletion. As a result, the sampling problem is closer to solution.

To get an idea of how much and at what rate isolated trees deplete soil moisture, I sampled soil moisture around a single mature sugar pine *(Pinus lambertiana).* One year of sampling provided a profile of soil moisture

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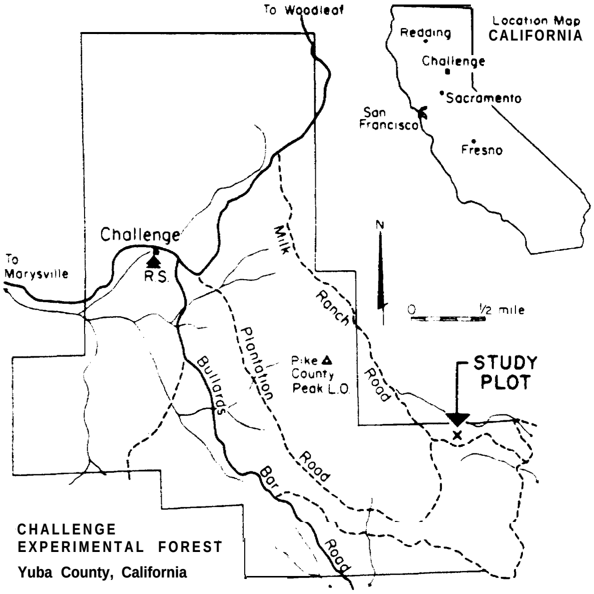
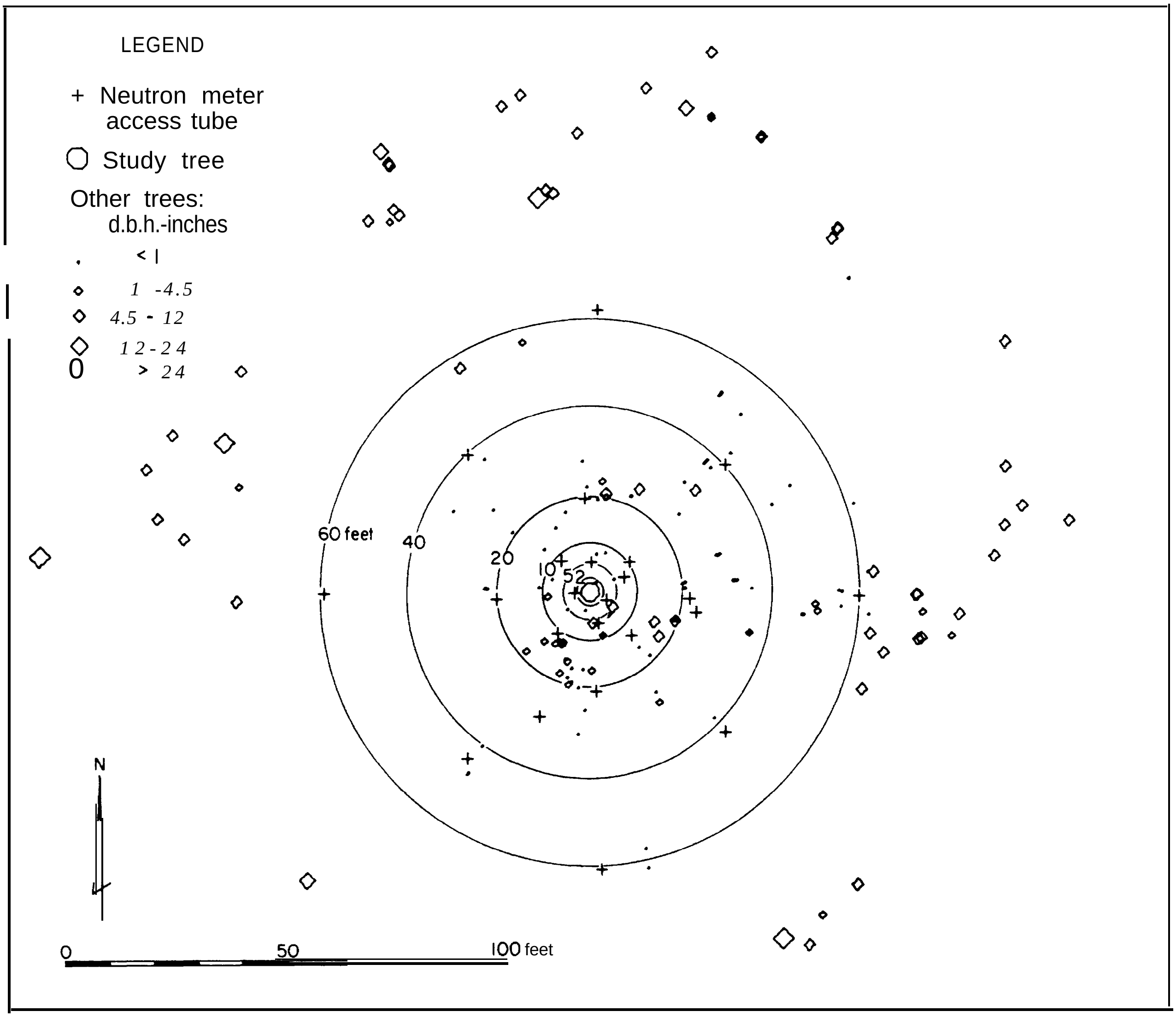


Figure 1. --*A study plot was set up on the Challenge Experimental Forest, California, to measure soil moisture around an isolated mature sugar pine tree.*

Figure 2. -- *Soil moisture was sampled with a neutron meter at six distances ranging from 2 feet to 60 feet away from the study tree.*



depletion. Nearby vegetation could be affecting the amount of soil moisture use. Therefore,, we plan to remeasure this moisture use after we cut the surrounding vegetation within 120 feet of the study tree.

CHALLENGE EXPERIMENTAL FOREST

The study was made on the Challenge Experimental Forest, in Yuba County, California (fig. 1). The Experimental Forest lies between the South fork of the Feather River and the North fork of the Yuba River. The Forest is representative of more than 1 million acres of highly productive timberland of the Sierra Nevada mixed-conifer forest type.

Precipitation averages 68 inches a year--most of it falling in the winter months and in the form of rain. Less than l/2-inch of precipitation per month falls during June to September--chiefly from high intensity convectional thunderstorms. The temperatures are mild, with a mean annual maximum of 69 degrees F. and a mean annual minimum of 42 degrees F.

The soils within the Experimental Forest are principally of the Aiken soil series. The soil is of a uniform clay loam texture. Bedrock is estimated to be at a depth of 50 to 100 feet.

THE STUDY SITE

A study plot was set up in a cutover area at 2,900 feet elevation. The area was originally logged in the early 1870's. In 1962, 88 percent of the trees larger than 3.5 inches d.b.h. was removed from the study site. The logging slash was left on the ground.

Before cutting, the stand had a basal area of 230 sq. ft./acre. The predominate species were, in order of frequency: ponderosa pine *(Pinus ponderosa* Laws.), sugar pine *(P. lambertiana* Dougl.), tanoak *(Lithocarpus densiflorus* Rehd.), madrone (Arbutus menziesii Pursh), Douglas-fir *(Pseudotsuga menziesii* Franco) incense-cedar *(Libocedrus decurrens* Torr.), and white fir *(Abies concolor* Lindl.) (table 1).

After logging, trees of only two species--ponderosa pine and sugar pine --were larger than 12 inches d.b.h. The basal area for all species was reduced from 230 sq.ft./acre to 27.5 sq. ft./acre.

STUDY METHODS

During the summer 1963, I inserted three aluminum access tubes in the soil to a depth of 21 feet. To determine soil moisture we took readings with a neutron meter at l-foot intervals in each access tube. In late summer 1964, a ground water observation well was drilled to a depth of 43 feet and lined with a 2-inch diameter perforated plastic pipe. At no time since the well was installed have we seen the water table within the 43-foot depth.

Climatological data was obtained from recording rain gages, hygrothermographs, and maximum and minimum thermometers.

Analysis of soil moisture data from 1963 and 1964 showed the plot to be well drained, with no evidence of surface ponding, and the soil to be deep and uniform in texture. In 1965, 20 additional access tubes were inserted to depths varying from 16 to 21 feet. The tubes were placed in specific quadrants on concentric circles at six distances from a 27.7-inch diameter sugar pine. The distances were 2, 5, 10, 20, 40, and 60 feet (fig. 2).

All vegetation within 120 feet of the study tree was measured (fig. 2). There were several large trees 80 to 90 feet from the study tree, and a group of smaller trees about 10 feet southeast of the study tree. Scattered throughout the plot were clumps of tanoak and madrone sprouts. All trees within 60 feet of the study tree were less than 12 inches d.b.h., with the great majority less than 4.5 inches d.b.h. I assumed that the residual vegetation had some effect on moisture depletion from the plot.

Table 1. --*Stand conditions in the study plot before and after logging, Challenge Experimental Forest, Yuba County, California*

Diameter class (inches)	Ponderosa pine	Sugar pine	White fir	Douglas fir	Incense cedar	Hardwood	Total
	BASAL AREA BEFORE LOGGING						
	Sq. ft./acre						
3 - 12	0.	0.	0.3	4.1	2.5	37.9	44.9
12 - 24	37.8	4.5	0.	20.7	2.4	403	69.7
24 +	48.7	66.5	0.	0.	0.	0	115.3
Total	86.5	71.0	.3	24.8	4.9	42.2	229 9
	BASAL AREA AFTER LOGGING						
3 - 12	0.	0.	0.	0.	1.9	8.3	10 3
12 24	0.	0.	0.	0.	0.	0.	0.
24 +	8.9	8.4	0.	0.	0.	0.	17.2
Total	8.9	8.4	0.	0.	1.9	8-3	27.5
	Percent of initial stocking						
3 - 12	--	--	0.	0.	75.9	22.0	22.9
12 - 24	0.	0.	--	0.	0.	0.	0.
24 +	18.2	12.6	--	--	--	--	14.9
Total	10.2	11.8	0.	0.	38.8	19.8	12.0

Table 2. --*Daily precipitation*[1] *Challenge Ranger Station, Challenge Experimental Forest,* *Yuba County, California, October 1965-September 1966*

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	Inches											
1	--	--	--	--	--	0.07	--	--	--	--	--	--
2	--	--	--	--	0.73	--	--	--	--	--	--	--
3	--	--	--	0.24	--	--	--	--	--	--	--	--
4	--	--	--	.94	.42	--	--	--	--	--	--	--
5	0.02	--	--	5.35	.63	.16	--	--	--	--	--	--
6		--	--	1.01	.58	.11	--	--	0.08	--	--	--
7	--	--	--	--	--	.31	--	--	.02	--	--	--
8	--	0.68	--	.07	--	(2/)	--	--	--	(2/)	--	--
9	--	--	--	.03	--	.03	--	0.01	--	--	--	--
10		--	--	--	--	.97	2.24	.43	--	--	--	--
11	--	--	--	--	--	.01	.51	.01	--	--	--	--
12	--	.19	0.85	--	--	--	.83	--	--	--	--	--
13	--	1.64	--	--	--	.65	.07	--	--	--	--	--
14	--	2.74	--	--	--	--	--	--	--	--	--	--
15	.44	.35	A-	--	--	--	--	--	--	--	--	--
16	--	.05	--	--	--	.25	--	--	--	--	--	--
17	--	1.35	--	--	--	--	--	--	--	--	--	--
18	--	2.87	--	--	--	--	03	--	--	--	--	(2/)
19	--	.93	--	--	.80	.54	--	--	--	--	--	--
20	--	.02	--	--	.42	—	--	--	--	--	--	--
21	--	--	--	--	--	--	--	--	--	--	--	--
22	--	--	--	.04	--	--	--	--	--	--	--	--
23	--	.45	--	.11	.37	--	--	--	--	--	--	--
24	--	1.75	.19	--	.32	--	--	--	--	--	--	-
25	--	.78	3.79	--	.27	--	--	--	--	--	--	--
26	--	.26	--	--	.64	--	--	--	--	--	--	--
27	--	.17	--	--	--	--	--	--	--	--	--	--
28	--	--	.01	--	--	--	--	--	--	--	--	--
29	--	--	2.67	--	--	--	--	--	--	--	--	--
30	--	--	.79	2.58	--	--	--	--	--	0.08	(2/)	
31	--	--	1.20	(2/)	—	--	--	--	--	.01	0.05	--
Monthly totals	0.46	13.23	9.50	10.37	5.18	3.10	3.68	0.45	0.10	0.09	0.05	0.00

[1]Total annual precipitation 46.21 inches (28 year normal precipitation 67.83 inches).
[2]Trace

Table 3. *--Monthly air temperature and precipitation, Challenge Ranger Station, Challenge Experimental Forest, Yuba County, California, October 1965 - September 1966*

Month	Air temperature							Precipitation	Departure from normal.[1]
	Averages			Extremes					
	Max. °F.	Min. °F.	Mean °F.	Highest. °F.	Date	Lowest °F.	Date		
								Inches	*Inches*
Oct	79	46	63	92	8	34	15	0 46	3 52
Nov	58	39	49	*82*	1	29	26, 28	13.23	+ 6.01
Dec	52	29	41	*70*	4	19	20	9.50	2.88
Jan	51	29	40	*63*	7	23	21	10 37	2 38
Feb	52	30	41	*63*	22	23	13	5.18	6.87
Mar	59	36	48	*79*	31	20	3	3.10	680
Apr	72	43	58	*86*	3	31	20	3.68	1.74
May	76	48	62	*88*	4, 19	39	31	45	2 32
June	81	51	66	*99*	15	30	2	.10	52
July	86	50	68	*96*	23	41	8, 10, 14 15	.09	+ 06
Aug	91	56	74	100	7	40	31	.05	05
Sept	84	51	68	101	30	38	14	(2/)	- 61
Total								46 21	-21 62
Average	70	42	57						

[1] Normal precipitation based upon 28 years of record.
[2] Trace

THE 1965-1966 RECHARGE SEASON

The Sierra Nevada characteristically has cool wet winters followed by hot dry summers. Precipitation is sporadic and soil moisture recharge insignificant during summer. For purposes of this report, the year was divided into two hydrologic periods: the recharge season and the depletion season.

The recharge season begins in late October or early November, after the first major storm with 2 to 3 inches of precipitation. Vegetative growth has slowed, and the trees are becoming dormant. The recharge season continues until the heavy spring rains have ended and the soil has drained to field capacity.

The depletion season extends from late spring to early winter when the soil water is depleted from field capacity to its driest state. During this time nearly all vegetative growth and a major portion of the transpiration occurs.

PRECIPITATION

The first significant precipitation that ended the 1965 summer depletion period fell on November 8, 1965 (tables 2, 3). Intermittent precipitation for about 20 days followed. The result was more than 13 inches of rainfall--about twice the 28-year normal precipitation for November. Winter rainfall was substantially below normal. By May 1, the total precipitation since October 1 amounted to only 45.52 inches--or 18.18 inches below normal for that period. But even with the low precipitation, the soil was probably fully recharged to at least a depth of 20 feet before the 1966 depletion season began, in May.

SOIL MOISTURE

Soil moisture was measured at 1-foot depth intervals in the plot's 23 neutron meter access tubes at various times through the recharge season. From the data, we developed a pattern of total soil moisture held in the surface 15 feet of soil (figs. 3-6). The

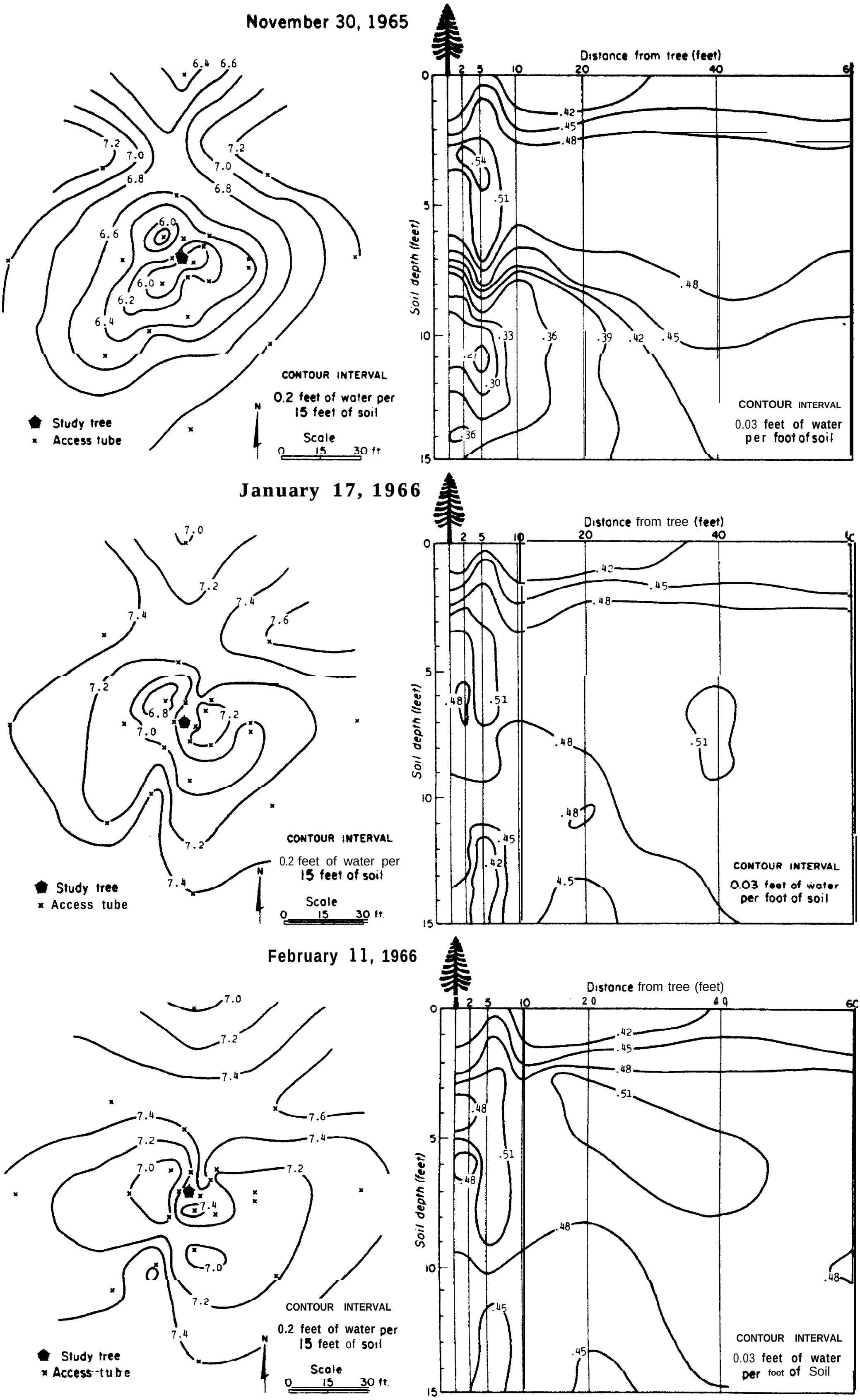


Figure 3.--*Patterns of total soil moisture in the surface 15 feet of soil, left; and of distribution of soil moisture as related to depth and distance from the study tree, right; on dates shown.*

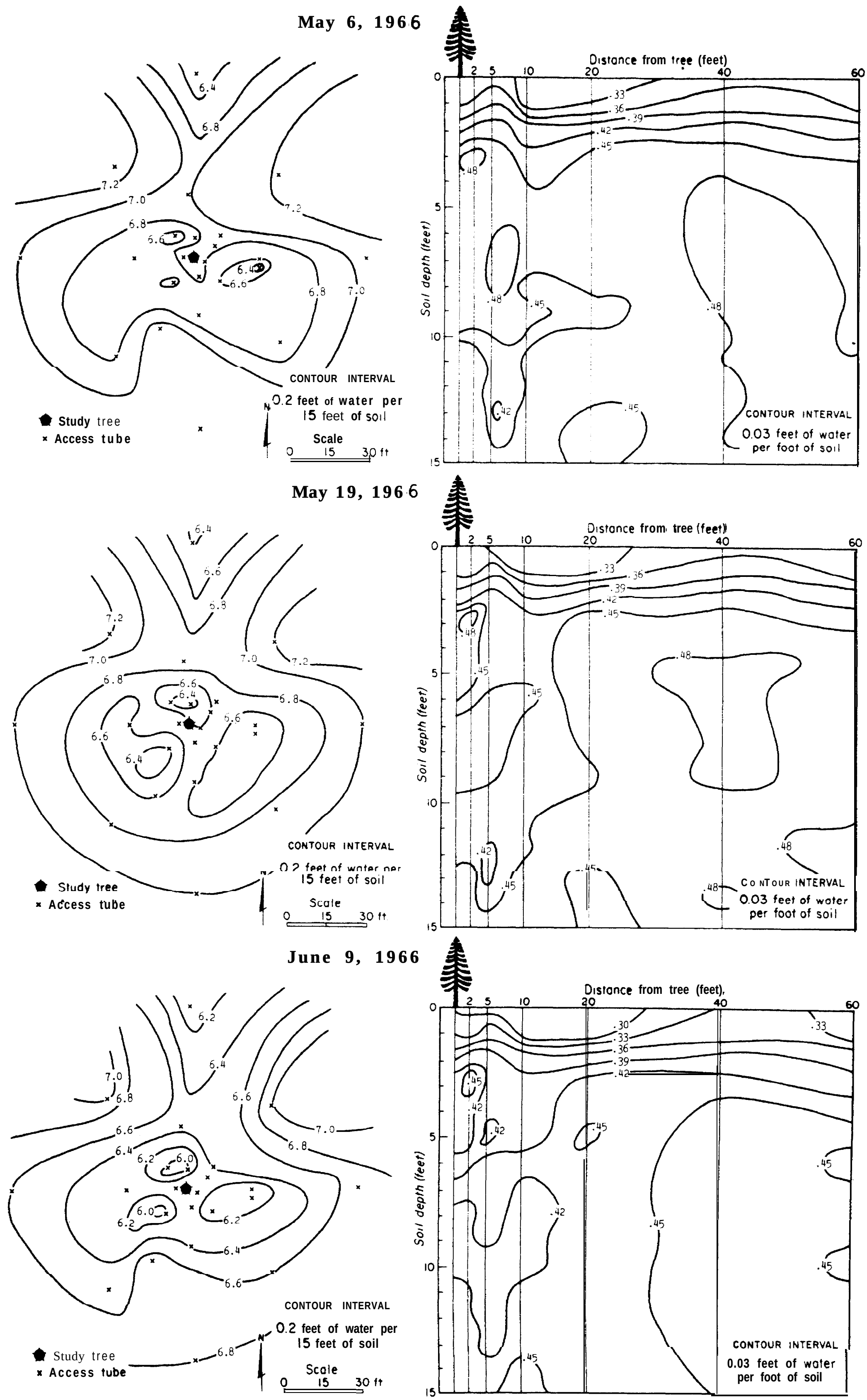


Figure 4--*Patterns of total soil. moisture in the surface 15 feet of soil left; and of distribution of soil moisture as related to depth and distance from the study tree, right; on dates shown.*

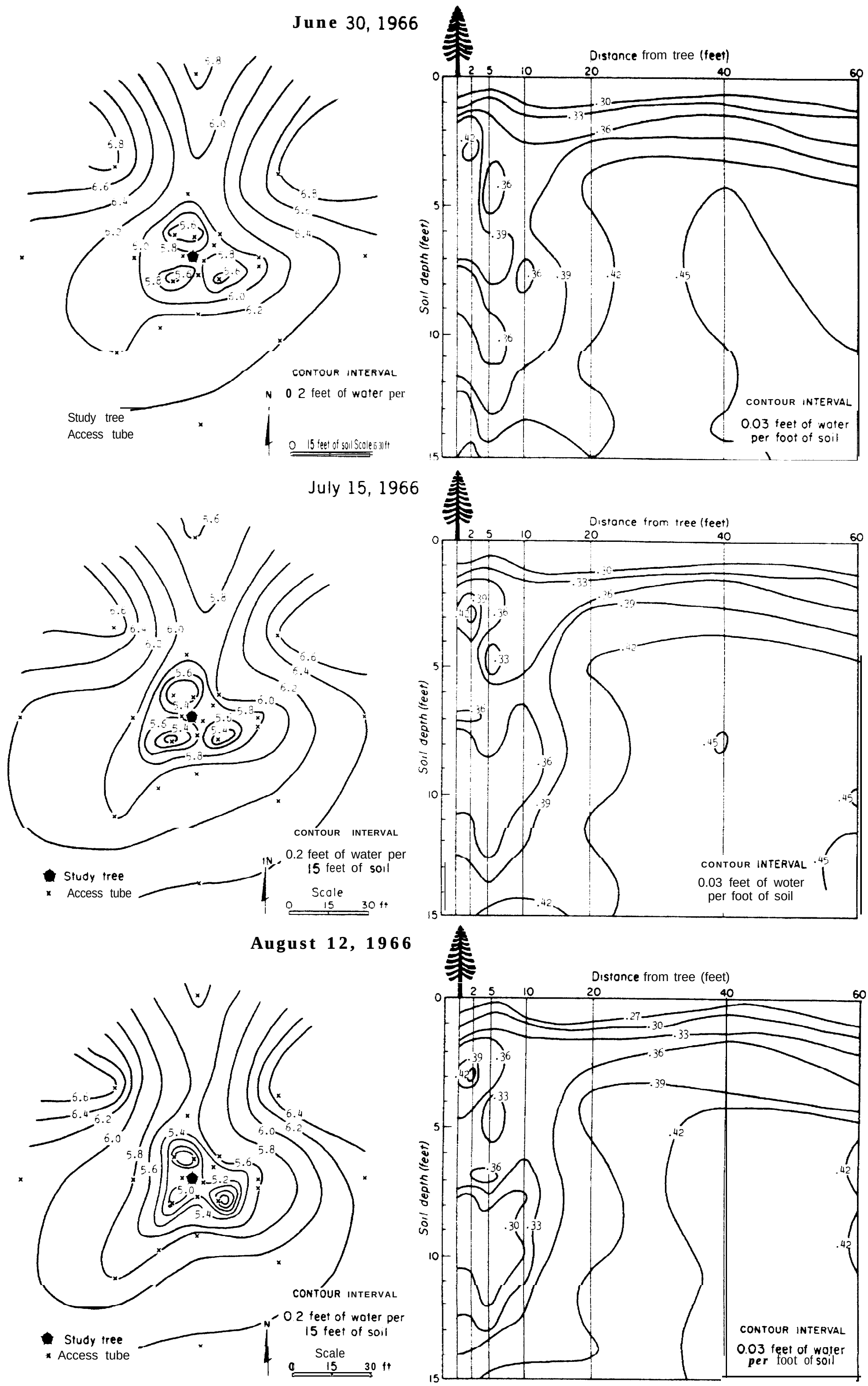


Figure 5. --*Patterns of total soil moisture in the surface 15 feet of soil, left; and of distribution of soil moisture* **as** *related to depth and distance from the study* **tree,** *right; on dates shown.*

diagrams were drawn by interpolating the position of iso-moisture lines around the plotted location of the 23 access tubes and the measured moisture content at those points. They represent "best guess" patterns of the total soil moisture around the tree and of the mean soil moisture of each l-foot depth measurement point at each of the six distances from the study tree. They provide a reasonable estimate of the vertical and horizontal distribution of soil moisture in the plot.

On November 30, 1965, after heavy rainfall, soil moisture was low near the study tree, showing the same general pattern as that observed a month earlier (fig. 3). The vertical profile revealed that a wetting front had penetrated about 8 feet deep near the tree and to about 10 to 12 feet deep away from the tree. At depths greater than 10 feet under the tree, the soil moisture remained unchanged, and--in some cases--it was slightly lower than in the October 19 measurement. A pocket of low soil moisture at the 11-foot depth noted earlier was still in evidence.

By January 17, 1966, when an additional 17.14 inches of precipitation had fallen, the soil moisture content in the plot had approached a nearly uniform condition (fig. 3). The moisture content near the study tree remained slightly less than that away from the tree, but the differences had become less obvious. The vertical profile indicated that the wetting front had moved below the measurement depth and that the entire profile was being recharged.

Another soil moisture measurement was made on February 11, 1966 (fig. 3). Since the previous measurement, 5.09 inches of rain had fallen. The soil moisture profile was approaching greater uniformity. Very slight differences existed between soil moisture contents near the tree and away from the tree.

THE 1966 DEPLETION SEASON

CLIMATE

Only two significant storm periods occurred after March 19, 1966: April 10-13, when 3.65 inches of rain were recorded, and May 9-11, when 0.45 inch of rain fell (table 2). The remainder of the spring and summer was unusually dry. Temperatures were higher and humidities lower than normal, particularly in late spring (table 3). The summer depletion season began in mid-April and continued until the first fall rain, on November 6, 1966.

SOIL MOISTURE

The first soil moisture measurement of the 1966 season was taken on May 6 (fig. 4). The soil moisture profiles were fairly uniform, with moisture content generally increasing as distance from the tree increased. Soil moisture 10 feet from the study tree was lower than it was closer or farther away. And it was lowest to the southeast, where several 6- to 10-inch diameter trees grew. Another area of low moisture was about 60 feet north of the study tree and within 25 feet of a 31.2-inch diameter ponderosa pine. The vertical profile on May 6, 1966 showed the greatest change in moisture content occurring in the surface 3 feet. The vegetation was then just breaking winter dormancy, and the largest cause of moisture loss was probably surface evaporation.

Throughout the depletion period we made repeated soil moisture measurements--May 19 (fig. 4), June 9 (fig. 4), June 30 (fig. 5), July 15 (fig. 5), August 12 (fig. 5), August 28 (fig. 6), September 9, and October 25 (fig. 6). As the season progressed, the point of the lowest total moisture content remained about 10 feet from the study tree. The difference between the moisture content near the tree and that at greater distances from it became more pronounced later in the summer. The large ponderosa pine north of the plot had a continuing effect on moisture content. The vertical pattern of soil moisture indicated a zone of low soil moisture at a depth of 8 to 13 feet extending from the tree to about 10 feet away. An area of high moisture content centered 3 feet under the tree may have been due to the presence of large non-absorbing roots used by the tree for support. The primary zone of soil moisture depletion extended outward to a distance of slightly over 20 feet from the tree and somewhat deeper than 15 feet under the tree.

By October 25, 1966, when the last measurement of the depletion season was made, the low moisture content near the tree was quite evident (fig. 6). Again, the moisture content 10 feet from the tree was lower than that next to the tree; the moisture content 40 to 60 feet from the tree had changed little from previous measurements. The vertical profile showed an expanded zone of low moisture content centered at a depth of 8 to 11 feet under the tree and extending a distance of about 15 feet away. The high moisture pocket at the 3-foot depth was still evident. And the moisture content 60 feet from the tree was lower than that 40 feet from the tree. These differences were probably due to the large trees outside the plot.

DISCUSSION AND CONCLUSIONS

The depletion patterns reported in this note are only indicative of the depletion within the zone of influence of a tree surrounded by soil moisture sampling points.

To obtain a better idea of the moisture distribution in the plot on an areal basis, I computed the area between the iso-moisture lines which lie within each distance class. In this manner, we obtained weighted mean moisture contents representative of conditions in the area between the study tree and 2 feet from the tree, from 2 feet to 5 feet from the tree, 5 to 10 feet from the tree, 10 to 20 feet, 20 to 40 feet, and 40 to 60 feet from the tree (fig. 7).

As the depletion season progressed differences between the moisture content of those areas near the tree and those further away became greater.

If the entire plot were completely bare of vegetation, the depletion of soil moisture would be due to evaporation and to subsurface drainage and lateral water movement. We could then hypothesize that depletion from these two causes was the same at each access tube and, in addition, that moisture content at each tube was equal. If the hypothesis were true and if a tree were then situated so that moisture depletion from it was negligible at some distance from the tree, we could then estimate the amount of water used.

The estimate could be made by measuring the difference in moisture content at sampling points not under the influence of the tree and those closer to it. If each series of sampling points were considered to be representative of the plot, the volume of the water use by the tree could be estimated by subtracting the moisture content near the tree from that outside its influence and multiplying by the representative area.

We cannot be sure that these assumptions are valid because we did not have a completely isolated tree, Several small trees within the plot contributed to moisture depletion near the test tree. And several large trees outside the plot probably affected moisture depletion. Therefore, we had no area outside the influence of vegetation.

Some initial estimates of the volumetric soil moisture differences between the area farthest from the test tree and that closer to the tree may be useful. In addition, it may be possible to make some preliminary estimates of the volumetric moisture use by the test tree.

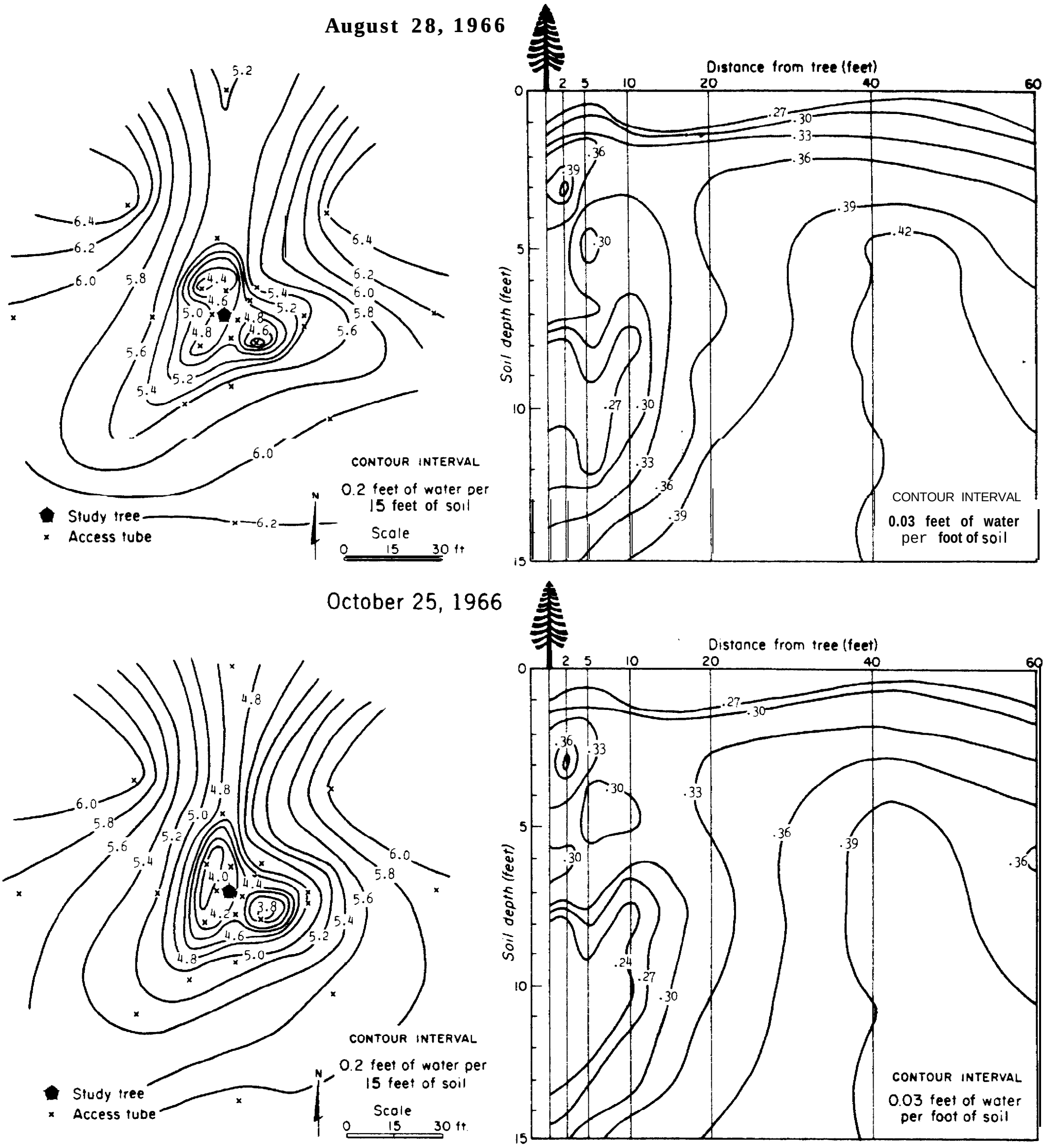


Figure 6. --*Patterns of total soil moisture in the surface 15 feet of soil left; and of distribution of soil moisture as related to depth and distance from the study tree, right; on dates shown.*

The quantity of soil moisture depleted by the small residual vegetation within the plot is probably smaller than that depleted by the study tree. In addition, the moisture depletion within the farthest distance class is undoubtedly affected to some extent by large trees outside the plot. The moisture depletion measured in the 40- to 60-foot distance class is probably greater than that which would be found after these trees are removed. Consequently, if the moisture content of the area close to the tree is subtracted from that of the outer distance class, the difference can be considered an estimate of the moisture use by the study tree plus the small vegetation in the plot--provided the foregoing assumptions are correct.

I multiplied the area of each of the six distance classes by the difference between the weighted mean soil moisture content in each distance class and that in the 40- to 60-foot distance class, and totaled these differences (table 4). The result is a volumetric difference, in cubic feet, of water. By early February 1966,

Table 4. --*Soil moisture measurements at six distances from the study tree and their differences from that at the 40- to 60-foot distance class, Challenge Experimental Forest, Yuba County, California, 1965-1966.*

MEAN SOIL MOISTURE

Distance from study tree (feet)	Winter recharge season			Summer depletion season							
	11/30/65	1/17/66	2/11/66	5/6/66	S/20/66	6/8/66	6/30/66	7/15/66	8/12/66	9/6/66	10/25/66
	Ft. water/15 ft. soil										
0 - 2	5.89	7.08	7.30	6.90	6.70	6.30	5.86	5.65	5.10	4.68	4.16
2 - 5	6.01	7.04	7.28	6.87	6.67	6.23	5.77	5.56	5.06	4.68	4.17
5 -10	6.12	7.02	7.16	6.75	6.59	6.17	5.74	5.50	5.19	4.76	4.19
10 -20	6.29	7.03	7.12	6.66	6.62	6.28	5.95	5.77	5.46	5.06	4.43
20 -40	6.72	7.18	7.25	6.83	6.75	6.47	6.25	6.11	5.86	5.52	5.33
40 -60	7.00	7.37	7.32	7.00	6.95	6.63	6.43	6.27	6.11	5.88	5.66
Weighted mean	6.81	7.27	7.28	6.91	6.84	6.53	6.31	6.15	5.94	5.65	5.39

DIFFERENCES IN MEAN SOIL MOISTURE FROM THAT IN 40- TO 60-FT DISTANCE CLASS[1]

Distance from study tree (feet)	11/30/65	1/17/66	2/11/66	5/6/66	S/20/66	6/8/66	6/30/66	7/15/66	8/12/66	9/6/66	10/25/66
	Ft. water/15 ft. soil										
0 - 2	1.11	.29	.02	.10	.2s	.33	.57	.62	1.01	1.20	1.50
2 - 5	.99	.33	.04	.13	.28	.40	.66	.71	1.05	1.20	1.49
5 -10	.88	.3s	.16	.2s	.36	.46	.69	.77	.92	1.12	1.47
10 -20	.28 71	..34 19	..07 20	.34.17	.33	.35	.48	.50	.65	.82	1.23
20 -40					.20	.16	.18	.16	.25	.36	.33
40 -60	--	--	--	--	--	--	--	—	--	—	--

VOLUME DIFFERENCES IN MEAN SOIL MOISTURE FROM THAT IN 40- to 60-FT. DISTANCE CLASS[2]

Distance from study tree (feet)	11/30/65	1/17/66	2/11/66	5/6/66	S/20/66	6/8/66	6/30/66	7/15/66	8/12/66	9/6/66	10/25/66
	Cubic ft.										
0 - 2	[illegible]	29.04	3.52	[illegible]	7.75	10.23	17.67	19.22	31.31	37.20	46.50
2 - 5	239.36	9s. 20	43.52	68.00	24.64	35.20	58'08	62.48	92.40	105.60	131.12
5 -10	720.65	345.10	203.00	345.10	97.92	125.12	187.68	209.44	250.24	304.64	399.84
10 -20	1,096.20	743.85	274: OS	665.55	[illegible]	[illegible]	[illegible]	[illegible]	659.75	832.30	1,248.45
20 -40									978.75	1,409.40	1,291.95
40 -60	--	--	--	--	--	--	--	--	--	--	--
Total	2,177.74	1,222.18	524.71	1,093.19	1,248.26	1,152.20	1,455.33	1,425.04	2,012.45	2,689.14	3,117.86
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
	4.91	2.76	1.18	2.47	2.82	2.60	3.28	3.21	4.54	6.06	7.03

[1]Computed by subtracting mean soil moisture in 40- to 60-ft. distance class from that in each of the other distance classes for each date.

[2]Computed by multiplying the difference in soil moisture from that in the 40- to 60-ft. distance class by the area of each distance class.

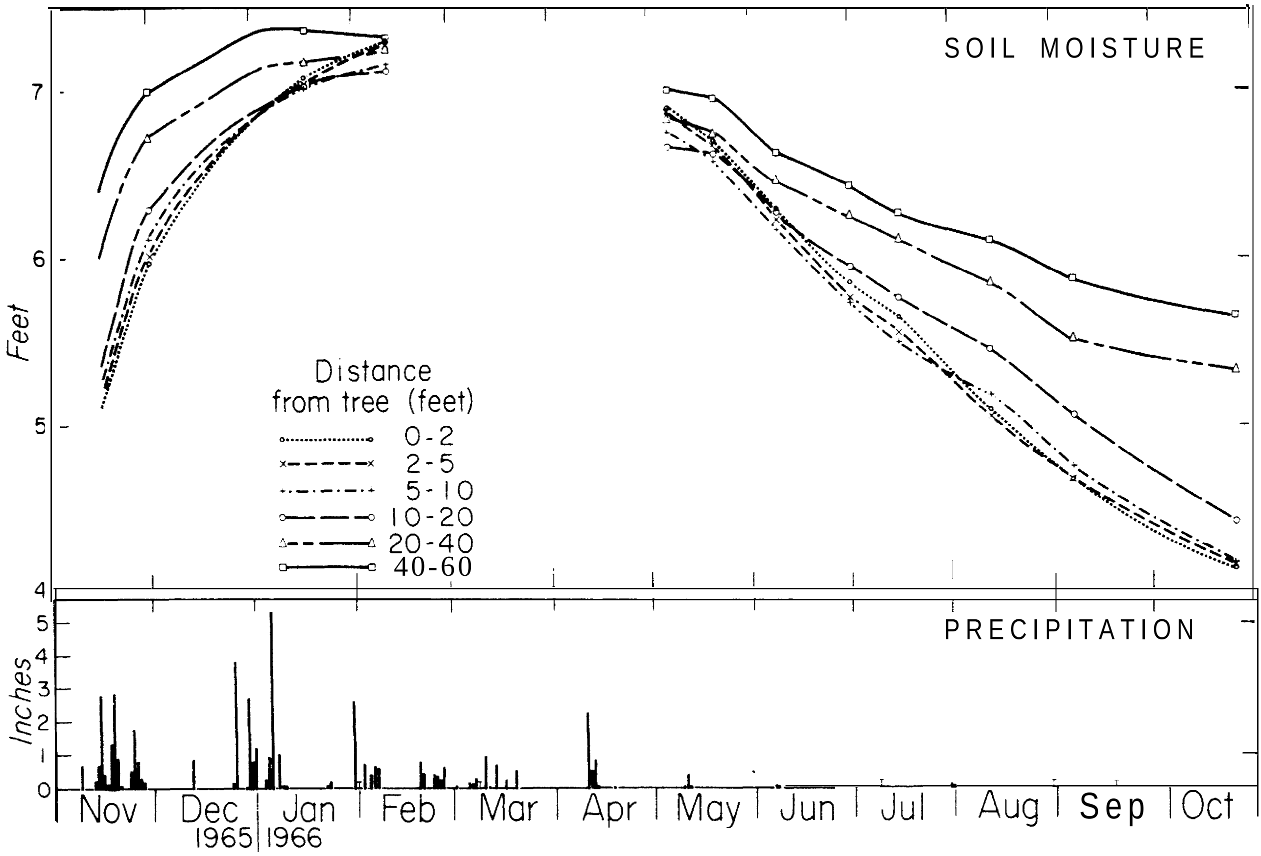


Figure 7. --*Soil moisture recorded in the six distance classes from the study tree. Measurements were taken from November 1965 to October 1966.*

after substantial recharge, the volumetric difference of soil moisture between the area from 0 to 40 feet from the tree and the area from 40 to 60 feet from the tree amounted to about 525 cubic feet. This difference is equivalent to 1.18 inches of water over the 41.15-foot radius area. By early September, the areas showed a volumetric difference of 2,689 cubic feet. And by the end of October 1966, it had increased to 3,118 cubic feet or about 7.03 inches of water.

The total water content of the 15-foot profile on January 17, 1966 was 7.27 feet or 87.24 inches, and on February 11 it was 7.28 feet or 87.36 inches. We could assume these values to be reasonable approximations of field capacity for the study plot. The difference between the moisture content on October 25, 1966--5.39 feet or 64.73 inches--and that of the February measurement amounted to 22.57 inches of soil moisture depletion for the summer.

FOOTNOTE

[1] Wyssotzky, G. N. Von. *Bodenfeuchtigkeitsuntersuchungen in Waldbeständen der Ukrainiselen Steppen und Waldssteppenzone.* Tharandter Forstliches Jarhbuch 83:521-534. 1932.

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