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SNOW ACCUMULATION, MELT, AND SOIL MOISTURE RECHARGE UNDER VARIOUS LODGEPOLE PINE STAND DENSITIES IN WESTERN MONTANA

By

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INTRODUCTION

Lodgepole pine appears to be the species of choice for most snow/forest influences studies in the Rocky Mountain region (e.g. Wilm and Dunford 1948, Miner and Trappe 1957, Berndt 1965, Golding and Swanson 1978, Gary and Troendle 1982). With the exception of Miner and Trappe (1957), these studies have been conducted in mid- to high elevation zones in well-defined continental climatic regimes.

Much of the lodgepole pine in western Montana is found in locations meeting neither of these criteria. Lower elevations with definite maritime climatic influence result in substantial winter cloudiness, high humidities, high snow density and rain-on-snow events. The potential for great changes in water yield is limited in these locations. Nevertheless, our concern for increased wood production demands that we investigate the effects of levels of forest management on soil moisture utilization and recharge. In doing so, we may be able to answer some long-standing questions concerning the significance of snow redistribution and interception loss in this environment.

STUDY AREA

This study was part of a multidisciplinary effort undertaken in a 50 year-old lodgepole pine stand located on the Lubrecht Experimental Forest about 72 kilometers due east of Missoula, Montana. The original stand, about 3.85 hectares, was divided into 5 treatment subunits of approximately equal area in the summer of 1982: 1) Control (1750 stems/ha; 28.9 m^2/ha), 2) 3m X 3m thinning (16.8 m^2/ha), 3) 4.5m X 4.5m thinning (14.5 m^2/ha), 4) 6m X 6m thinning (8 m^2/ha), and 5) Clearcut.

The elevation of the study site is approximately 1200 m. Except for a slight draw and access road running north-south through the middle of the stand, slopes are generally less than 10%. Primary aspects are northeast and northwest. Underlying soils are silt loams of Tertiary origin. Complete soil analysis is still underway, but preliminary observations indicate very high bulk densities in the B and C horizons. Soil water depletion curves for the summer of 1983 clearly indicate the primary root occupancy zone limited to a depth of between 45 and 60 cm. Numerous perched water tables (shallow zones of subsurface saturation) were observed during access tube installation in the spring of 1983.

Climatic data for the site has been monitored since 1957 at the Lubrecht Forest Headquarters which is less than 3 km away at the same elevation. Relevant parameters for the soil moisture recharge period appear in table 1.

Table 1. Climatic data for the Lubrecht soil moisture recharge period (1957-1982)

	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	TOTAL
PRECIPITATION (ave. ann. 45.5cm)	2.9cm	3.3	4.8	6.0	3.2	3.0	23.2
AVE. DAILY MAX. TEMP.	12°C	2.7°	-2.2°	-3.1°	1.9°	5.9°	
AVE. MONTHLY TEMP.	4.2°	-2.8°	-6.5°	-8.2°	-4.3°	-1.1°	
AVE. DAILY MINIMUM RELATIVE HUMIDITY (%)	42.8	56.7	66.0	64.6	51.1	41.3	

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METHODS

Snow measurements

A systematic grid of permanent snow course stakes was installed across the entire study area at 12m X 12m spacing (262 total stakes). Snow depths were measured at roughly 2 week intervals beginning December 31, 1983. Snow depths were measured to the nearest cm above ground surface. Snow water equivalents were not measured in this first year of study. The initial intent was to do so, but following the original snow deposition associated with the "Siberian Express", little precipitation was measured during January 1984. Warmer weather and light rain brought about snowmelt events late in January and in February, so it was assumed that snow density was nearly uniform during this period. Mean snow depths per treatment and sampling date appear in table 2 and figure 1. SYMAP distribution maps of snow depths across the study area for selected dates appear in figures 4 through 6.

Table 2. Snow depth characteristics during the soil moisture recharge period

DATE		Control	3mX3m	4.5mX4.5m	6mX6m	c.c.
12/31/83	$\overline{X}$	29.5 (cm)	34.2	35.1	37.6	42.7
	c.v.	.23	.14	.21	.14	.10
	% of c.c.	69	80	82	88	
1/28/84	$\overline{X}$	6.3	12.7	13.3	17.8	17.5
	c.v.	.74	.34	.43	.30	.24
	% of c.c.	36	73	76	105	
2/8/84	$\overline{X}$	1.9	7.0	7.0	10.0	12.0
	c.v.	1.52	.63	.81	.56	.51
	% of c.c.	16	58	58	83	
2/26/84	$\overline{X}$	3.2	9.3	9.0	13.6	15.2
	c.v.	1.05	.60	.80	.57	.51
	% of c.c.	21	61	59	89	
3/14/84	$\overline{X}$	1.7	2.6	3.6	4.4	6.5
	c.v.	1.05	.94	1.00	.86	.85
% of 12/31/83 snow pack as of 3/14/84		6%	8%	10%	12%	15%

Soil moisture measurements

Nine aluminum soil moisture access tubes were systematically placed in each treatment. The total of 45 access tubes results in a sampling density of greater than 1 tube per tenth hectare.

Moisture content (% by volume) was measured with a Troxler Model 3222 depth-moisture probe. Measurements were taken at 15 cm depth increments at each access tube. Analysis of 30 cm and 1 m depth moisture measurements taken on four dates during the recharge period are reported in this paper. These data appear in tables 3 and 4 and figures 2 and 3.

Selected SYMAP distribution maps of soil moisture at 30 cm depth appear in figures 7 through 9 .

Table 3. Soil moisture content at 30 cm depth during the soil moisture recharge period.

DATE		Control 28.9m^2/ha	3mX3m 16.8m^2/ha	4.5mX4.5m 14.5m^2/ha	6mX6m 8m^2/ha	c.c.
9/24/83	$\overline{X}$	11.4% by vol.	20.7	16.4	21.3	23.6
	c.v.	.27	.29	.36	.40	.09
	% of c.c.	48	88	69	90	
10/23/83	$\overline{X}$	17.2	23.8	23.3	28.3	29.6
	c.v.	.16	.24	.25	.30	.07
	% of c.c.	58	80	79	96	
11/15/83	$\overline{X}$	18.1	24.2	23.5	28.9	31.5
	c.v.	.17	.23	.24	.29	.07
	% of c.c.	58	77	75	92	
2/26/84	$\overline{X}$	26.0	31.7	32.1	30.5	30.7
	c.v.	.21	.28	.20	.14	.06
	% of c.c.	85	103	104	99	

Table 4. Soil moisture content at 1 m depth during the soil moisture recharge period.

DATE		Control 28.9m^2/ha	3mX3m 16.8m^2/ha	4.5mX4.5m 14.5m^2/ha	6mX6m 8m^2/ha	c.c.
9/24/83	$\overline{X}$	21.0% by vol.	21.4	20.4	20.1	26.3
	c.v.	.31	.37	.19	.26	.18
	% of c.c.	80	81	77	77	
10/23/83	$\overline{X}$	26.3	23.7	25.8	25.8	31.9
	c.v.	.24	.23	.17	.19	.19
	% of c.c.	82	74	81	81	
11/15/83	$\overline{X}$	26.6	24.1	25.2	25.4	31.6
	c.v.	.25	.22	.17	.21	.17
	% of c.c.	84	76	80	82	
2/26/84	$\overline{X}$	27.1	24.9	26.8	26.2	34.0
	c.v.	.24	.19	.15	.16	.15
	% of c.c.	80	73	79	77	

DISCUSSION

Snow accumulation and melt

The early winter of 1983-1984 was atypical for western Montana. The position of the jet stream allowed continental polar air masses to flood much farther west than usual. The snowcover measured on December 31, 1983 was a product of low density snow, much below normal temperatures, and persistant northeasterly winds.

During January and February, the jet stream shifted from north-south to west-east orientation over western Montana. Temperatures moderated with the arrival of moist maritime air, but major storms all passed to the south. March brought maritime extremes. Temperatures were above normal, precipitation (rain or very wet at low elevations) was above normal, and 25 of 31 days were officially "overcast".

As has been observed in most snow studies, snow accumulation in the lodgepole pine stand was inversely proportional to basal area or canopy density (table 2, figure 1). The relative variability of snow depth, as measured by the coefficient of variation (c.v.), generally generally increased with surface roughness (basal area) and as snowpack ablation advanced in all treatments.

The "imprint" of the December 31 snowpack remained on the site throughout the winter. The lines drawn in figure 1 were determined by least squares regression. While no tests have been made for significance of slope differences it appears as though the lines remain nearly parallel through the end of February. This implies that during this period, the ablation rate was independent of canopy cover, or more likely, not reliant on the availability of shortwave radiation. In fact, the percentage of the original December snowpack in each treatment remaining as of March 14 was inversely proportional to canopy cover. Longwave and convective energy appear to be dominant in the snowmelt process. Indeed, the presence of canopy accelerated rather than prolonged the timing of snowmelt.

The question remains as to whether the December 31 snowpack was the result of snow redistribution and interception loss during the continental polar outbreak or a result of the same sources of longwave and convective energy

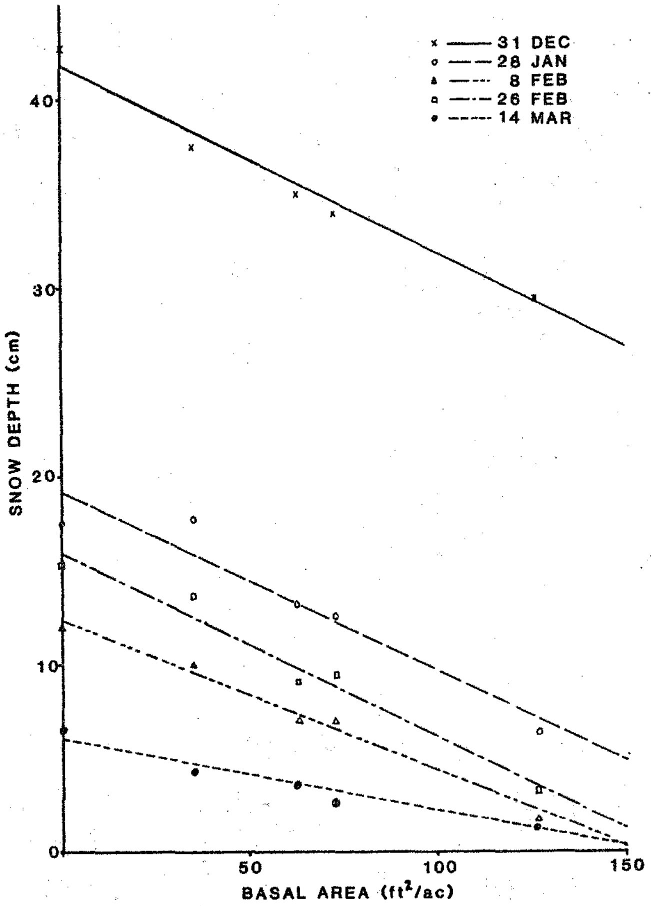


Figure 1. Mean snow depths through the winter of 1983-1984.

NOTE: 1 ft^2/ac = .2296 m^2/ha

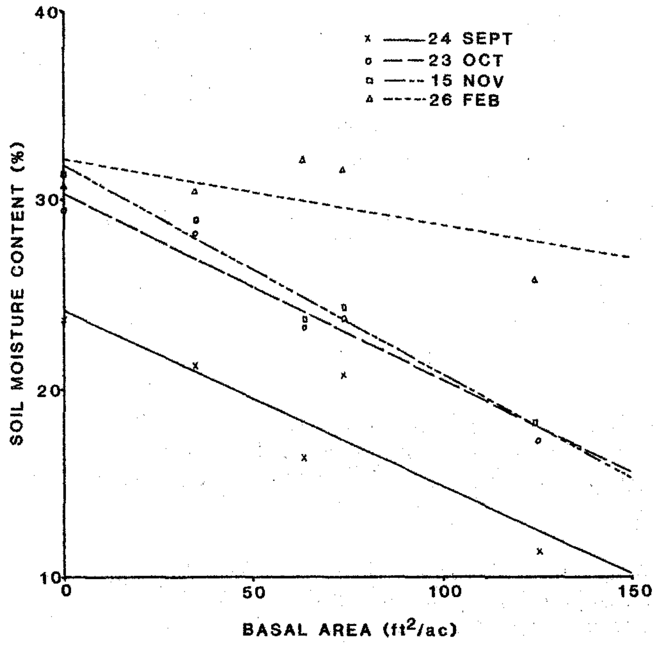


Figure 2. Soil moisture at 30 cm depth through the recharge period.

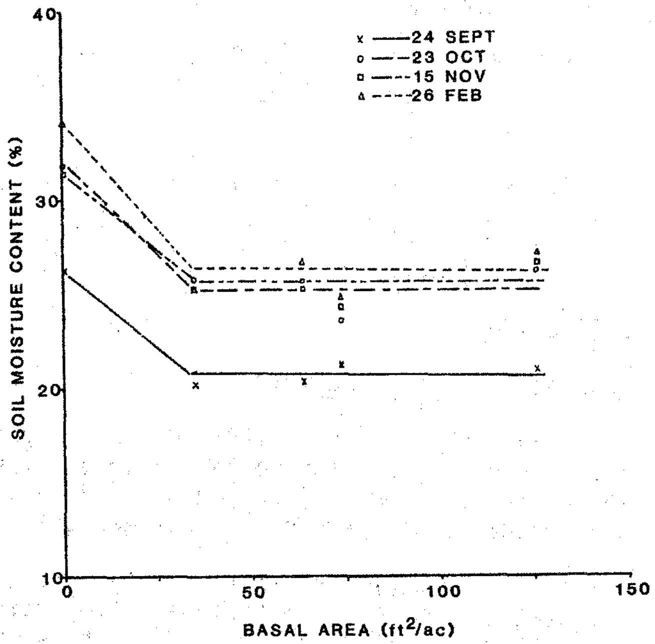


Figure 3. Soil moisture at 1 m depth through the recharge period.

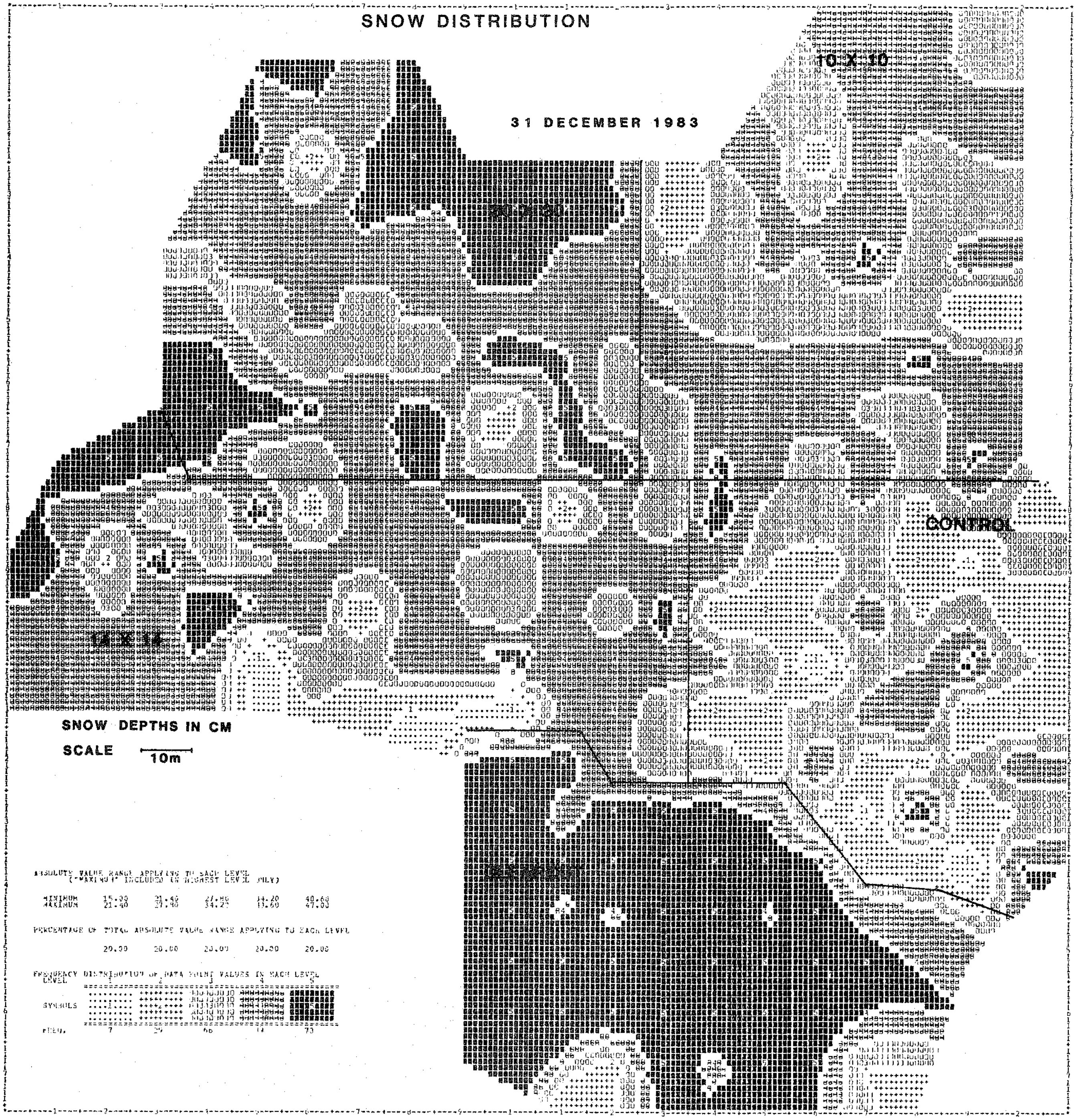
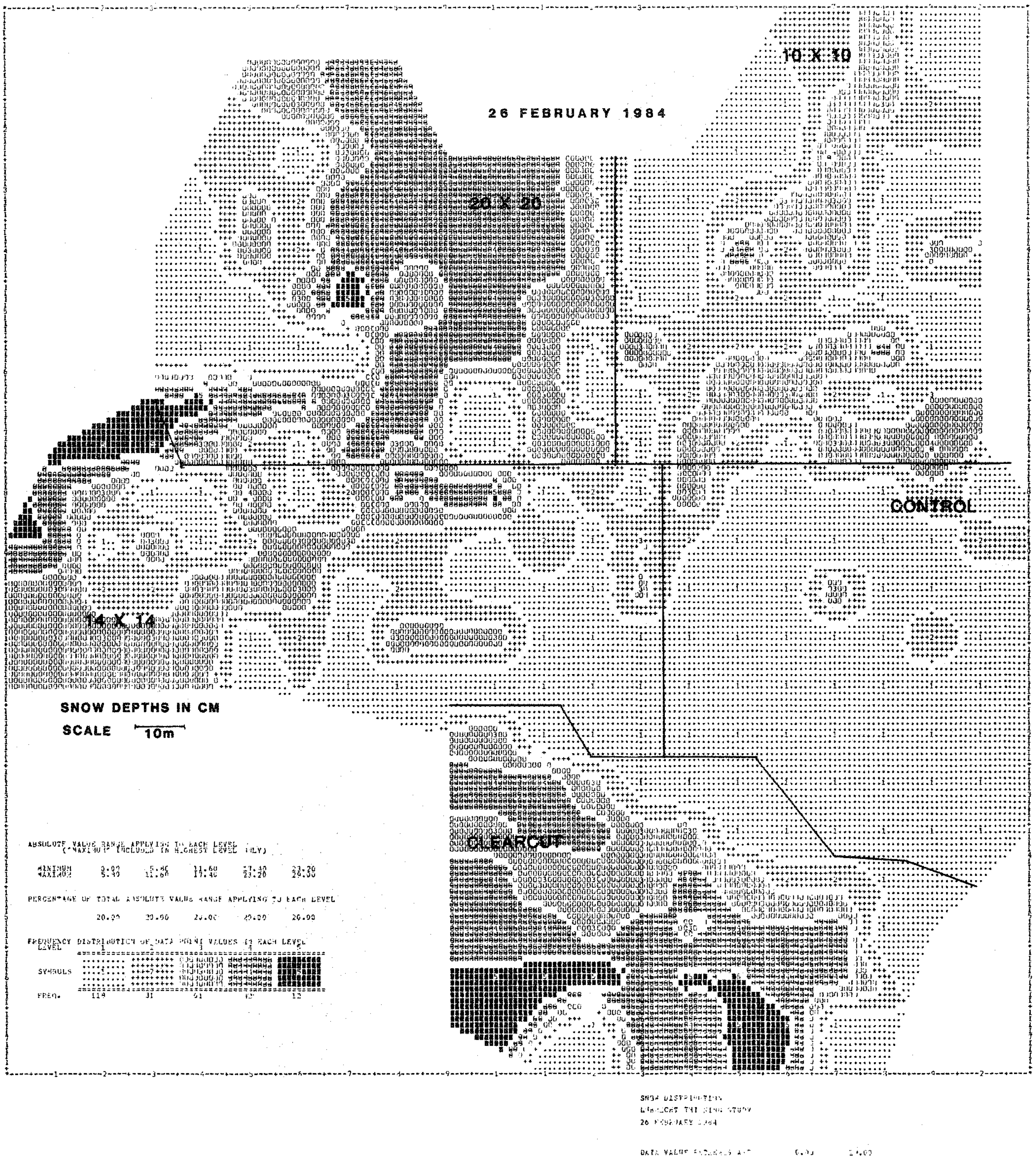


Figure 4. Spatial distribution of snow depth on December 31, 1983.

NOTE: In this figure and subsequent figures, the 10X10, 14X14 and 20X20 captions refer to 3mX3m, 4.5mX4.5m and 6mX6m thinning treatments, respectively.



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ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
     (*MAXIMUM INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM      0.00     5.80     11.60     17.40     23.20
  MAXIMUM      5.80    11.60     17.40     23.20     29.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

              20.00    20.00     20.00     20.00     20.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL          1         2         3         4         5

  FREQ.        118        31        61        42        12

SNOW DISTRIBUTION
LUBRECHT THINNING STUDY
26 FEBRUARY 1984

DATA VALUE EXTREMES ARE          0.00        29.00
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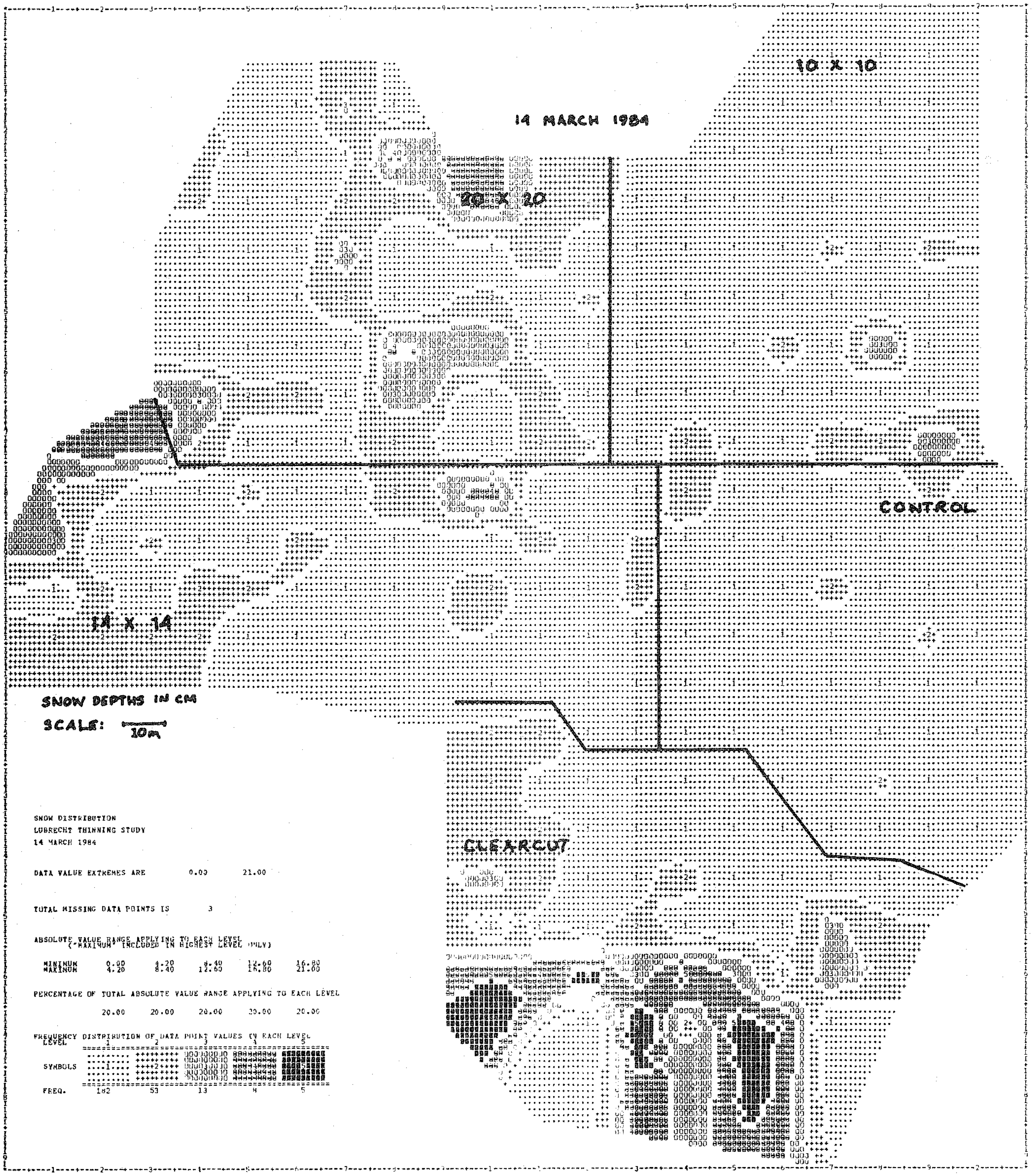
Figure 5. Spatial distribution of snow depth on February 26, 1984.



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SNOW DISTRIBUTION
LOBRECHT THINNING STUDY
14 MARCH 1984

DATA VALUE EXTREMES ARE          0.00        21.00

TOTAL MISSING DATA POINTS IS          3

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM        0.00       4.20       8.40      12.60      16.80
  MAXIMUM        4.20       8.40      12.60      16.80      21.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

                20.00      20.00      20.00      20.00      20.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL          1          2          3          4          5
             ==================================================
              .........  +++++++++  000000000  888888888  █████████
              .........  +++++++++  000000000  888888888  █████████
  SYMBOLS     ....1....  ++++2++++  000030000  8888488888  ████5████
              .........  +++++++++  000000000  888888888  █████████
              .........  +++++++++  000000000  888888888  █████████
             ==================================================
  FREQ.         182         53         13          8          5
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Figure 6. Spatial distribution of snow depth on March 14, 1984.

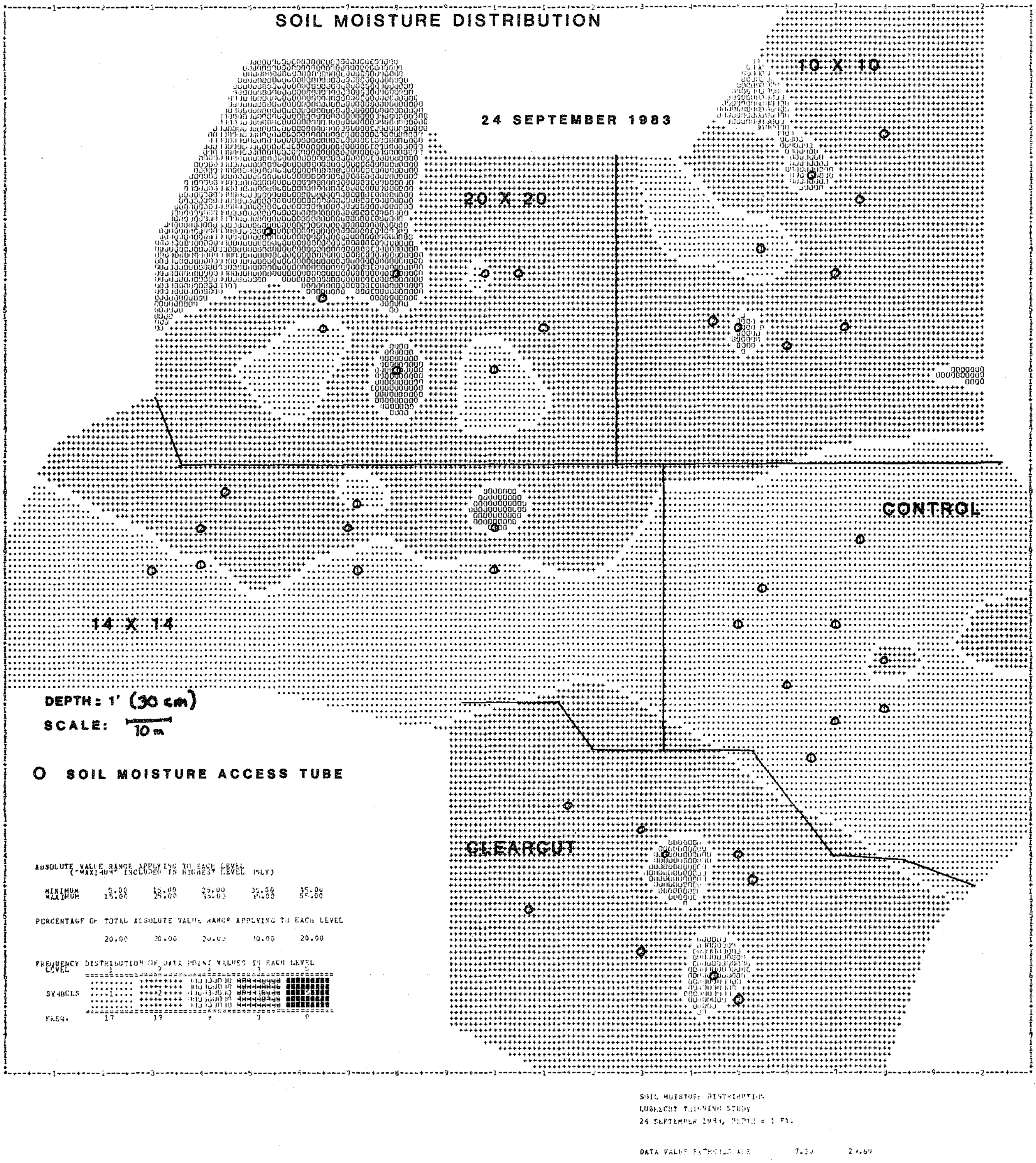

Figure 7. 30 cm depth soil moisture distribution on September 24, 1983.

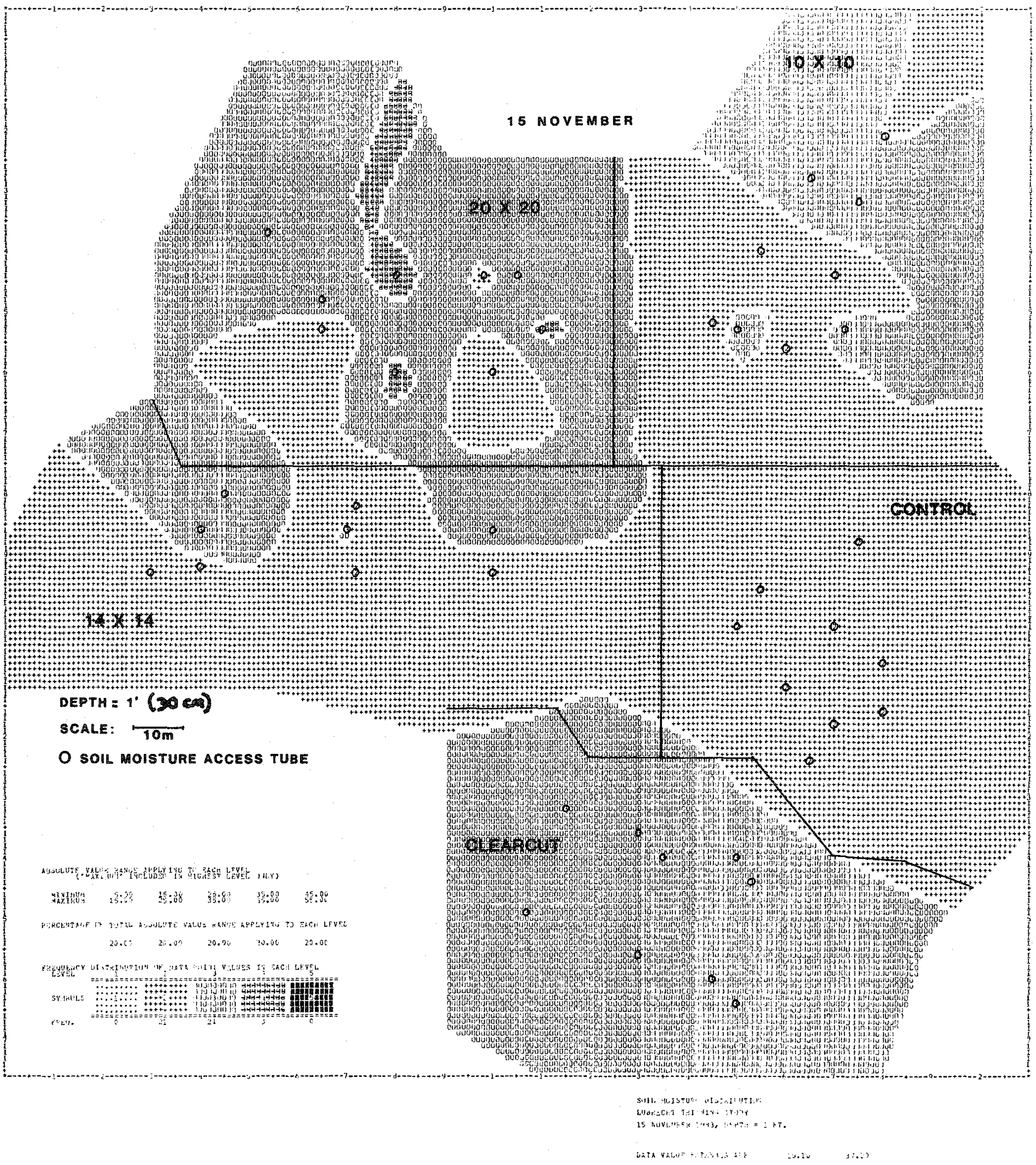

Figure 8. 30 cm depth soil moisture distribution on November 15, 1983.

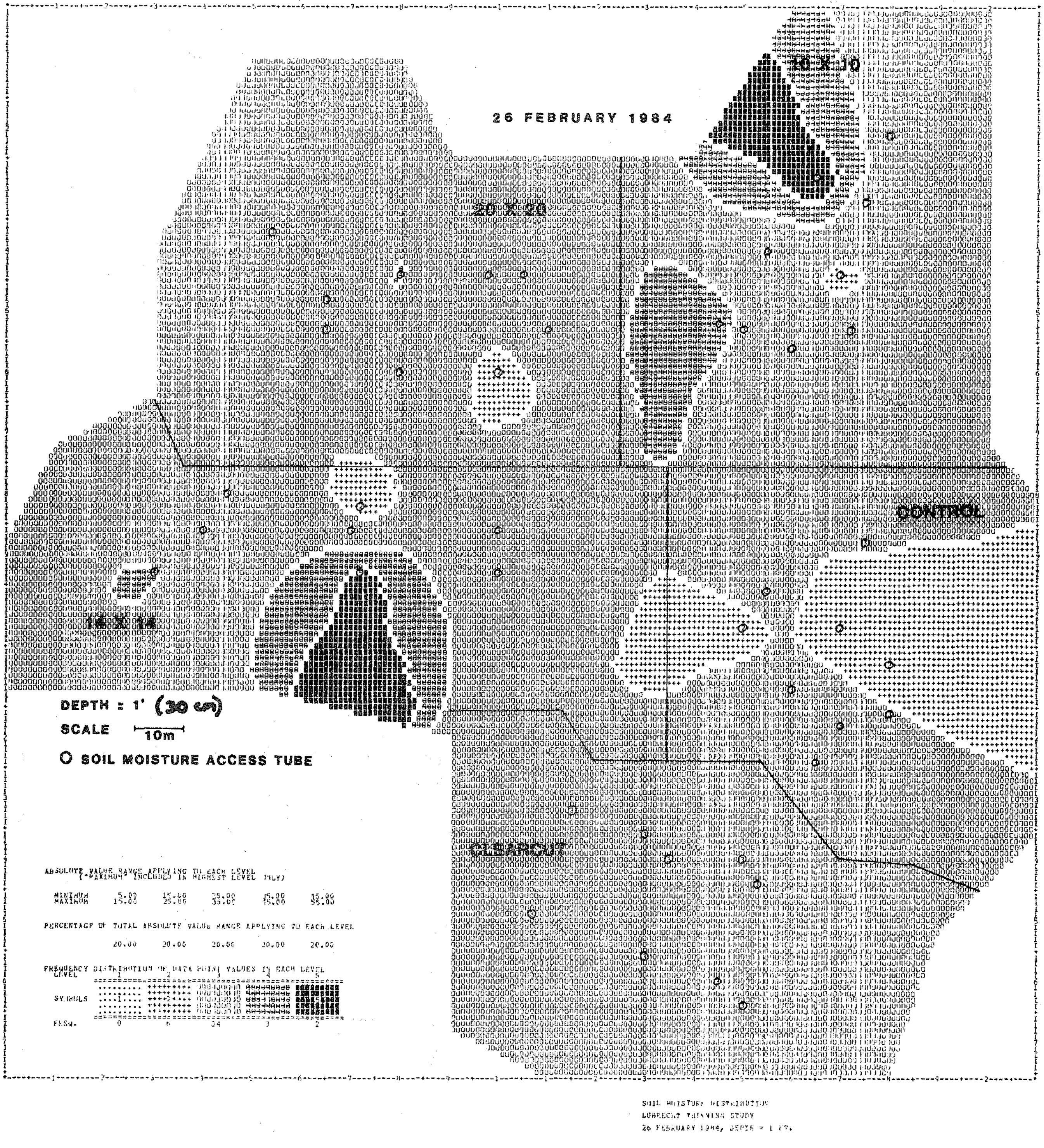

Figure 9. 30 cm depth soil moisture distribution on February 26, 1984.

slowing the rate of snow accumulation under the canopy in the preceding weeks. This question might be answered by looking at the patterns of soil moisture recharge.

Soil moisture recharge

Soil moisture recharge was assumed to begin after successive hard frosts had occurred. On September 24, mean soil moisture at 30 cm depth (figure 2) was inversely proportional to basal area as expected. The relative variability in soil moisture was least in the clearcut and control. This was expected because of greatest uniformity in utilization or non-utilization. At 1 meter depth (figure 3)- below primary rooting occupancy- all treatments except the clearcut had nearly identical mean moisture content. This was also expected.

For the October and November sampling dates, at both 30 cm and 1 m depths, the "imprint" of the September soil moisture distribution remained intact. Fall rains and rapidly melting wet snow have uniformly recharged soil moisture across the stand. In terms of total evaporation losses, there seems to have been a tradeoff between intercepting surface area and exposure.

The 30 cm depth regression line for February 26 is a little misleading (figure 2). In the clearcut and 6mX6m treatments there were still 15.2 and 13.6 cm, respectively, of ripe snow on the ground. The additional 7 cm of water could easily bring those treatments up to mean soil moisture contents of 35% by volume or greater. This would bring a subsequent regression line close to parallel with the fall regressions indicating uniform soil moisture recharge during the entire recharge period, regardless of basal area. Unfortunately, equipment malfunction did not allow a March soil moisture sample to verify this speculation. Nevertheless, it seems safe to conclude that snow redistribution and differential interception loss had minimal impact on soil moisture recharge this past winter.

ACKNOWLEDGMENTS

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