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IONOSPHERIC SOUNDER AS A MEANS OF MONITORING GROUND MOISTURE

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ABSTRACT

An experimental investigation was carried out on the possibility of monitoring the moisture content M of the ground by measuring its effective reflection coefficient R. This was done via the use of an ionospheric sounder. In addition, the effect of temperature change on M and R was also examined. It is found that the correlation coefficient between M and R is 0.82 indicating a reasonably high possibility of monitoring M by R.

As a by-product, it is found that no further magneto-ionic splitting occurs on the ionospheric echoes beyond the first.

IONOSPHERIC SOUNDER AS A MEANS OF MONITORING GROUND MOISTURE

I. INTRODUCTION

This experiment is the continuation of the one reported earlier (CRES Report 37-1[1], 37-2[2]). It concerns the measurement of the effective ground reflection coefficient k_g via the use of an ionospheric sounder. The ultimate aim is to determine the correlation between this reflection coefficient k_g and the ground moisture content M. Possible effects on k_g and M due to temperature variations are also studied.

In Report 37-1, Section IV-E there is a brief discussion of the expected results about this experiment. Report 37-2 contains a detailed analysis of the functions and characteristics of all equipments used, such as the transmitter, the transmission line, the antenna and the receiving system. There is also a detail description of the data handling operations and calibration procedures in Report 37-2.

The data used in this report were recorded from September 1966 to December 1966 and from November 1967 to March 1968. Due to some adverse weather conditions which led to equipment shutdowns, it was not possible to record continuously during these two periods. However, it is felt that enough data have been gathered to give an indication of the possible relation that may exist between k_g and M.

The information on daily moisture content of the ground was furnished by the Water Resources Laboratory of the Civil Engineering Department at The University of Kansas. The daily temperature used was the average value of the temperatures over the hours of the day when the experiment was being performed. This is available from the monthly report of climatological data published by the Environmental Data Service, U.S. Department of Commerce, Environmental Science Service Administration.

II. EFFECTIVE REFLECTION COEFFICIENTS

Before going into the calculation of the effective reflection coefficients, let us summarize briefly the quantities involved so as to obtain an overall view of the problem. Basically we need to know the total transmitted power and the total received powers of both the first and the second echoes. Thus, on the transmitter side we have to measure the current output, the transmission line loss and the transmitting antenna impedance at the operating frequency 5.3 MHz. This is a pulse system and the pulse width used was 100 sec. On the receiver side, we need the echo voltage, the gain of the entire receiver system, the transmission line loss and the receiving antenna impedance. The entire receiving system (excluding the transmission line and the antenna) was actually calibrated with a known signal (Report 37-2). With the above quantities known, the average received power from the first echo is[3]

$$P_{ra} = \frac{P_{ta} G_t}{4\pi (2h)^2} k_1^2 G_r \frac{\lambda^2}{4\pi} = \frac{P_{ta} G^2 \lambda^2}{64\pi^2 h^2} k_1^2 \qquad (1)$$

where P_{ra} = average power received at the receiving antenna terminals

P_{ta} = power radiated at the transmitting antenna terminals

G $= G_t = G_r =$ transmitting or receiving antenna gain = 1.64 for half-wave folded dipole

λ = operating wavelength = velocity of propagation/5.3 MHz

h = height of the layer of the ionosphere where reflection took place $(= (1/2) f \lambda \tau)$

τ = the delay time of the first return signal

k_1 = effective reflection coefficient of the ionosphere.

Hence,

$$k_1 = \frac{8\pi h}{G\lambda} \left(\frac{P_{ra}}{P_{ta}}\right)^{1/2} = \frac{4\pi f \tau}{G} \left(\frac{P_{ra}}{P_{ta}}\right)^{1/2} \qquad (2)$$

Now P_{ra} may be written in terms of the antenna impedance and the average received voltage V_{ra} at the antenna terminals. Due to magneto ionic splitting the first echo is actually made up of two echoes coming in at about the same time. This is evidenced by the display on the scope that on many occasions the first echo assumed two peaks. Thus,

$$P_{ra} = \frac{(2\,V_{ra})^2\,R_{ra}}{|Z_{ra}|^2}$$

where $Z_{ra} = R_{ra} + jX_{ra} = 364 + 552.4\ \Omega$. We can also write $P_{ta} = |I_{ta}|^2 R_{ta}$, where I_{ta} is the effective current entering the transmitting antenna and R_{ta} is the transmitting radiation resistance $= 336\ \Omega$. Hence, k_I can be expressed in terms of V_{ra}, I_{ta} and τ

$$k_I = \frac{4\pi f}{G}\sqrt{\frac{R_{ra}}{R_{ta}}}\;\frac{2\tau}{|Z_{ra}|}\;\frac{V_{ra}}{I_{ta}} = 128\,\tau\,\frac{V_{ra}}{I_{ta}} \tag{3}$$

where τ is measured in milliseconds (normally around 1.7 milliseconds). We can get k_I in terms of the corresponding transmitter and receiver end quantities, V_{rs}, I_{ts}, instead of the antenna end if we take into account the transmission line losses. For impedance match purpose we used two types of transmission lines for both transmitter and receiver. The properties of these lines are tabulated as follows:

	Transmitter side	Receiver side
Length	$\ell_{t1} = 1.383\ \lambda$	$\ell_{r1} = 1.237\ \lambda$
	$\ell_{t2} = 0.25\ \lambda$	$\ell_{r2} = 0.713\ \lambda$
Attenuation	$\alpha_{t1} = 0.107$ nep/λ	$\alpha_{r1} = 0.107$ nep/λ
	$\alpha_{t2} = 0.0612$ nep/λ	$\alpha_{r2} = 0.0612$ nep/λ

Hence, $$= 180\tau \frac{V_{rs}}{I_{ts}} \tag{4}$$

where V_{ra}, I_{ta}, and V_{rs}, I_{ts} are related as follows

$$I_{ta} = I_{ts} \exp -(0.107 \times 1.383 + 0.0612 \times 0.25)$$
$$= I_{ts} \exp(-0.1633)$$
$$V_{ra} = V_{rs} \exp -(0.107 \times 1.737 + 0.0012 \times 0.713)$$
$$= V_{rs} \exp(0.176)$$

The value of I_{ts} is usually around 1.2 amp for our system. V_{rs} is also related to the recorded voltage via the Edin amplifier by $V_{rs} = (An/A)\ V_{r1}$ where V_{r1} is the average first return signal voltage on the recorder, An is the attenuation added to the receiving system and A is the total gain of the receiving system. The average received voltage V_{r1} is obtained by averaging the recorded voltage over a five-minute interval.

The ground reflection coefficient can be calculated from the first and the second return signals, as follows:

The average power received from the first return signal

$$P_{r1} = \frac{P_t G^2 \lambda^2}{64\pi^2 h^2} k_I^2 \tag{5}$$

The average power received from the second return signal

$$P_{r2} = \frac{P_t G^2 \lambda^2}{(4\pi)^2 (4h)^2} k_I^4 k_{g1}^2 \tag{6}$$

Dividing (6) by (5), we get

$$\frac{P_{ra}}{P_{r1}} = \frac{k_I^2 k_{g1}^2}{4}$$

or (7)

$$k_{g1} = \frac{2}{k_I}\sqrt{\frac{P_{r2}}{P_{r1}}} = \frac{2\,V_{rs2}}{k_I\,V_{rs1}} = \frac{2}{k_I}\frac{V_{r2}}{V_{r1}}\frac{A_{n2}}{A_{n1}}$$

where V_{r2} = second return average voltage on recorder

V_{r1} = first return average voltage on recorder

A_{n2} = attenuation added for second return

A_{n1} = attenuation added for first return.

Note that there is no observable magneto ionic splitting effect on the echoes beyond the first. Calculation of k_{g1} assuming further splitting would lead to k_{g1} 's greater than one on many occasions which seems to verify our observation.

The third returns are also monitored for double check purpose. The ratio of the ground reflection coefficients calculated from the second and the third echoes may be shown to be

$$\frac{k_{g1}}{k_{g2}} = \frac{2\, V_{rs2}}{1.5\, V_{rs1}\, V_{rs3}} \tag{8}$$

where V_{rs1}, V_{rs2}, V_{rs3} = first, second and third return average voltages at receiver terminals.

Within the same hour of the day, it is expected that (k_{g1} / k_{g2}) is approximately one.

III. DATA ANALYSIS AND CONCLUSIONS

Possible relations between the effective reflection coefficient of the ground, moisture content and temperature have been examined by use of conventional scatter-diagrams. Some typical values of the three variables are tabulated in Table 1. Table 2 summarizes the statistics of M and R and their correlation. The three scatter diagrams obtained using the data taken between November 1967 and March 1968 are shown in Figure 1-3. The relationships among the three variables indicated in the Figures are in general agreement with the related predictions advanced by Albrecht.[4] Results suggest the possibility of monitoring ground moisture and perhaps crop conditions for crop-covered ground through the study of the effective ground reflection coefficient. Effect due to seasonal changes would require a lot more data than is presently available.

TABLE 1

Some Typical Values of M, R, and Temperature

Moisture (%)	Reflection Coefficient	Temperature F°
13	0.28	47
17	0.35	47
18	0.42	43
18	0.45	52
20	0.38	52
23	0.44	47
24	0.61	43
15	0.28	34
37	0.65	39
36	0.50	41
22	0.34	42
28	0.44	49

TABLE 2

Statistics of M and R

	Moisture Content (%)	Reflection Coefficient
Mean value	24.5	0.42
Standard deviation	7.4	0.19
Correlation coefficient	0.82	

Acknowledgement

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1. Chia, R. C., H. H. Doemland and R. K. Moore. "A Study of Earth Radar Returns from Alouette Satellite," Center for Research, Inc., University of Kansas, Technical Report 37-1, April 1967.

2. Doemland, H. "An Ionosphere-Image Radar System," Center for Research, Inc., University of Kansas, Technical Report 37-2, June 1967.

3. Chia, R. C., A. K. Fung and R. K. Moore, "High Frequency Back-scatter from the Earth Measured at 1000 km Altitude," Radio Science, vol. 69D, no. 4, April 1965, pp. 641-649.

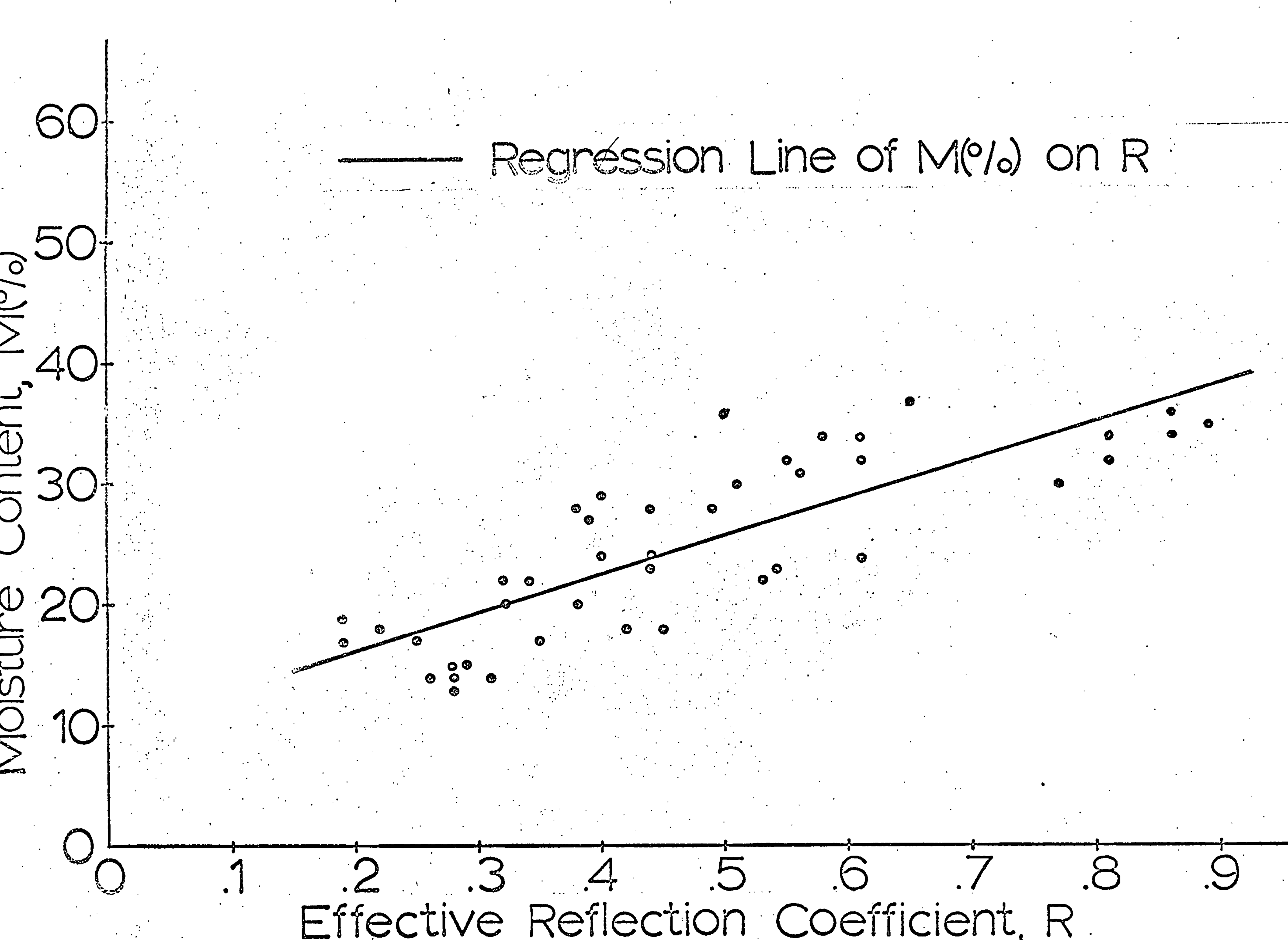
4. Albrecht, H. J. "On the Relationship Between Electrical Ground Parameters," Proc. IEEE, vol. 53, no. 5, May 1965, p. 544.

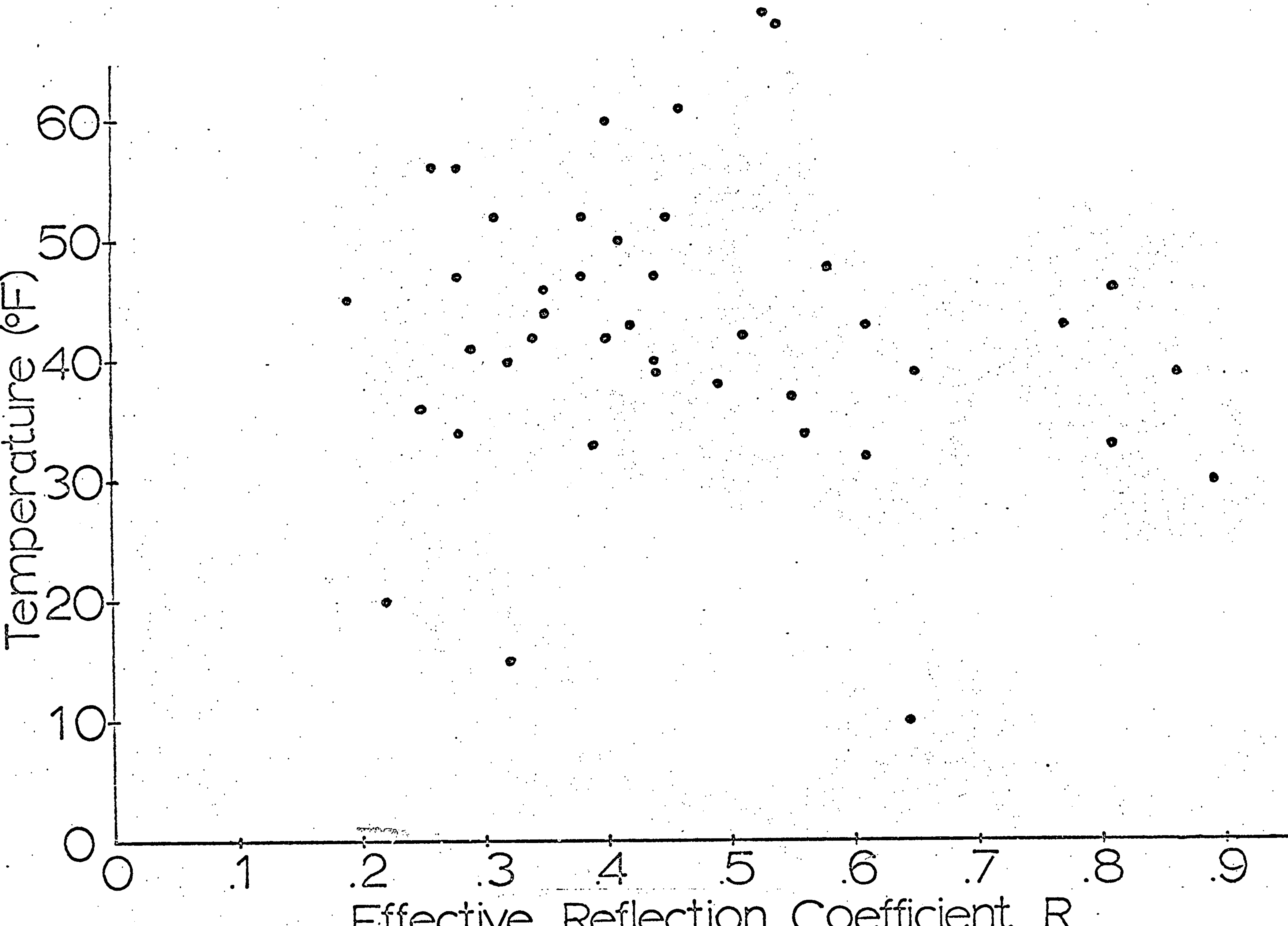
Figure Legends

Figure 1. Scatter diagram for moisture content and reflection coefficient.

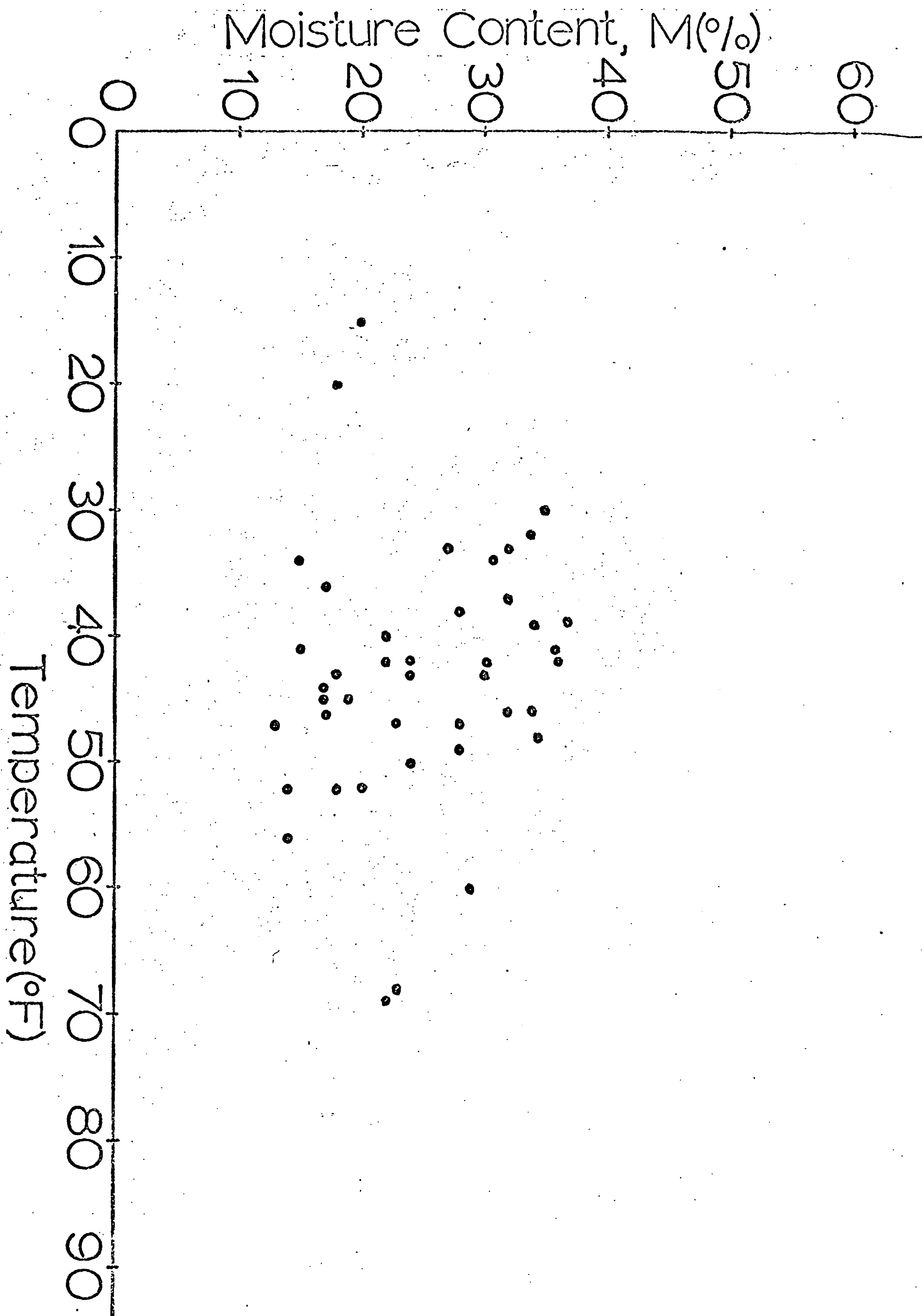
Figure 2. Scatter diagram for temperature and reflection coefficient.

Figure 3. Scatter diagram for moisture and temperature.


Regression Line of M(%) on R
Moisture Content, M(%)
0
10
20
30
40
50
60
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
Effective Reflection Coefficient, R



Temperature (°F)
60
50
40
30
20
10
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
Effective Reflection Coefficient R



Moisture Content, M(%)
0
10
20
30
40
50
60
0
10
20
30
40
50
60
70
80
90
Temperature(°F)

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