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THE EFFECTS OF SOIL MOISTURE AND PLANT MORPHOLOGY ON THE RADAR BACKSCATTER FROM VEGETATION

Remote Sensing Laboratory

RSL Technical Report 177-51

Fawwaz T. Ulaby
Thomas F. Bush
Percy P. Batlivala
Josef Cihlar

July, 1974

Supported by:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lyndon B. Johnson Space Center
Houston, Texas 77058

CONTRACT NAS 9-10261

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ABSTRACT

This report presents the results of experimental studies on the backscattering properties of corn, milo, soybeans and alfalfa. The measurements were made during the summer of 1973 over the 8-18 GHz frequency band. The data indicate that soil moisture estimation is best accomplished at incidence angles near nadir with lower frequencies while crop discrimination is best accomplished using two frequencies at incidence angles ranging from 30° to 65°. It is also shown that temporal plant morphology variations can cause extreme variations in the values of the scattering coefficients. These morphological changes can be caused by growth, heavy rain and in the case of alfalfa, harvesting.

1.0 INTRODUCTION

In an earlier paper by Ulaby [1] measurements of radar backscatter from vegetated fields were reported covering the frequency range 4-8 GHz (2.5-3.75 cm in wavelength). During the 1972 summer growing season the backscattering coefficient was measured using a truck-mounted boom at incidence angles of 0° (nadir)—70° in 10° steps for all four linear polarization combinations. The data was analyzed to determine the utility of radar in mapping soil moisture through vegetation and in crop separation. The present paper is an extension of the work reported in the above paper [1] into a higher frequency region. Using the same measurement technique, an 8-18 GHz (3.75-1.67 cm in wavelength) radar spectrometer was constructed and employed to collect data from corn, soybeans, milo and alfalfa over a period of seven weeks (during 1973). In addition to the radar data, ground-truth information was collected and analyzed.

To avoid repetition of a literature review and of a discussion of the target parameters (roughness and dielectric properties) and the sensor parameters (frequency, polarization and incidence angle) involved in the target-sensor interaction process, the reader is referred to Ulaby [1].

2.0 SPECTROMETER DESCRIPTION, GROUND TRUTH AND DATA ACQUISITION TECHNIQUE

2.1 The MAS 8-18

The system used in collecting the data presented herein is the MAS 8-18 (8-18 GHz Microwave Active Spectrometer) system [2]. Two antennas were employed each consisting of a 61.0 cm parabolic reflector fed by a linearly polarized log-periodic antenna feed. The antennas are mounted on the shafts of small electric motors to allow 90° rotation providing both HH and VV polarizations.

To insure that the antenna beams were coincident with one another, they were mounted adjacently on an aluminum plate with provisions being made such that their relative pointing directions could be adjusted and then fixed. The plate was in turn mounted on the receiving tower of the University of Kansas antenna range. The principle plane antenna patterns were then plotted while mechanical adjustments were made so that the beams of the antennas overlapped at all frequencies and ranges of interest.

As a transmitter source, two Hewlett-Packard 8690 series sweep oscillators were used. One covered the 8.0-12.4 GHz band while the second covered the band from 12.6-18.0 GHz. Both oscillators were frequency modulated by a triangle wave with a peak to peak amplitude providing a $\pm$ 200 MHz deviation from the carrier frequency. A 3.0 dB power divider was used to split the signal, half being transmitted while the remaining portion was used as the local oscillator drive. The scattered signal was then beaten against the local oscillator, amplified and filtered. An intermediate frequency of 60 kHz was chosen and the modulation rate F_m was varied so as to place the IF in the filter passband. Knowing F_m and the filter response,both range and resolution information were available. The filtered signal was fed to a true RMS voltmeter from which the mean signal was read.

By mounting the RF components on a hydraulic boom which could be raised to a height of 26.0 m, the antennas could be pointed at incidence angles ranging from 0° (nadir) to 70° measured from nadir. The boom was mounted on a truck for the sake of mobility. A second van truck contained IF circuitry and controls.

To reduce the data to absolute values of the backscattering coefficient σ^{o}, the entire system was calibrated against a 22.5 cm Luneberg lens reflector of known cross section. The lens was suspended from a large wooden tripod during calibration. It should be noted that the signal level dropped approximately 25 dB when the lens was removed from the antenna beam indicating that background clutter did not introduce any appreciable calibration errors. Slow variations in the transfer function of the radar itself were reduced by using a delay line injection calibration system. This simply involved the effective replacement of the antennas by a 21.8 m coaxial cable which provided a simulated, controlled echo. Figure 1 is a basic block diagram of the 8.0-18.0 GHz radar while Table 1 presents the major pertinent system specifications.

2.2 Ground Truth

A considerable amount of effort was made in collecting adequate ground truth data with which to correlate the spectrometer data. The ground truth collection procedure has been reported by Cihlar [3]. Four crop types were investigated during the period July 16, 1973 to September 6, 1973; the crops included corn, milo, soybeans and alfalfa. Although an attempt was made to acquire a continuous time history of data, both weather conditions and system problems often hampered the data acquisition procedure. It is for this reason that time history gaps are present within the data. All crops were grown on the Kansas River floodplain, 14km east of

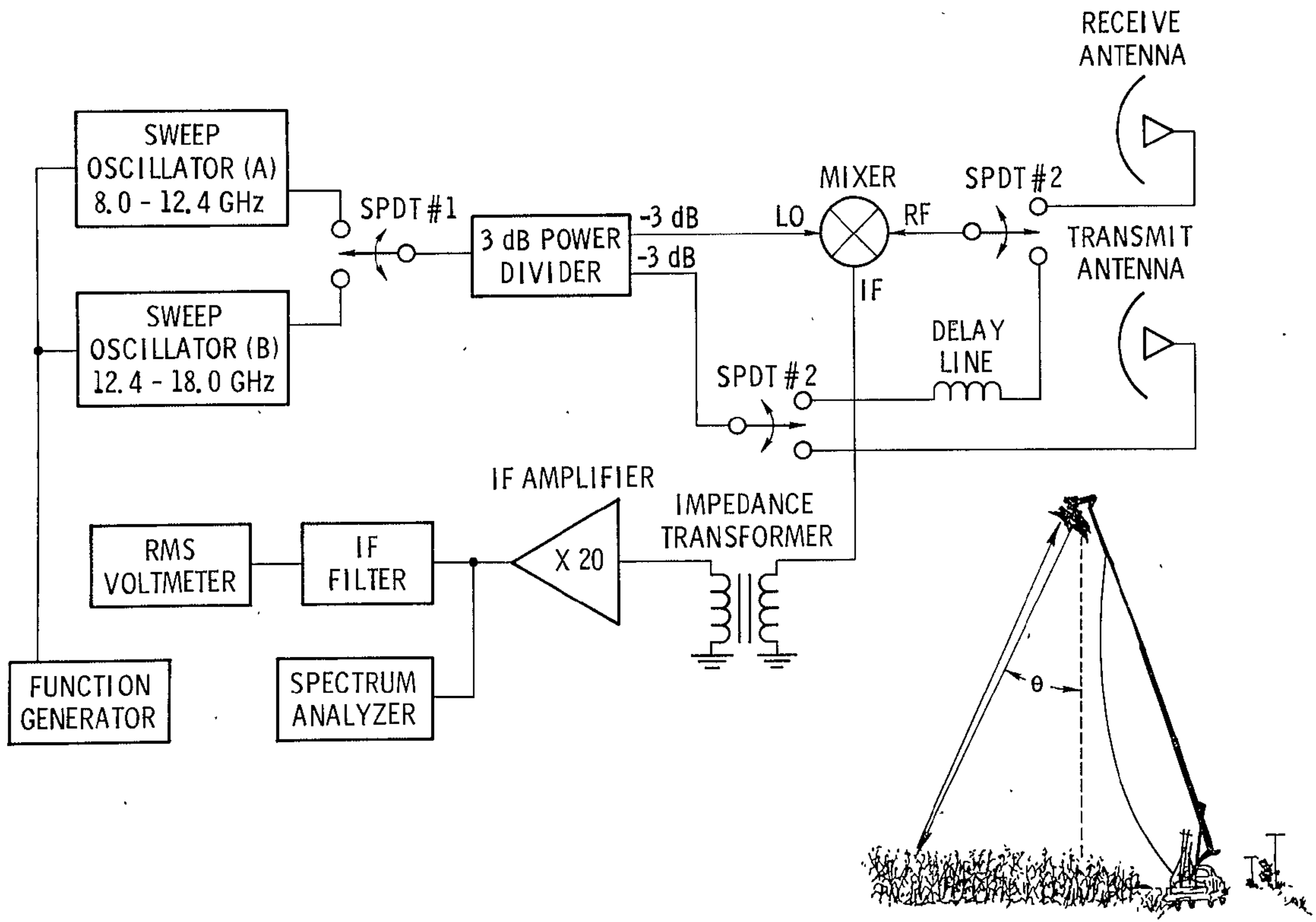


Figure 1. Block diagram of the MAS 8-18 system.

TABLE 1.

MAS 8-18 System Specifications

Type	FM-CW
Modulating Waveform	Triangular
Frequency	8-18 GHz
FM sweep: Δf	400 MHz
Transmitter Power	10 dBm (10 mW)
Intermediate Frequency	60 kHz
IF Bandwidth	3.58 kHz
Antennas	
Height above ground	26 m
Reflector Diameter	61 cm
Feeds	Cavity backed, log-periodic

Frequency (GHz)	Calculated Antenna Gain (dB)	Effective Beamwidths of Product Patterns (Degrees) Azimuth	Elevation
8	31.2	2.94	3.43
10	33.0	3.07	3.24
12	34.6	2.42	2.38
14	35.9	2.35	2.34
16	37.1	1.65	1.46
18	38.1	2.02	3.20

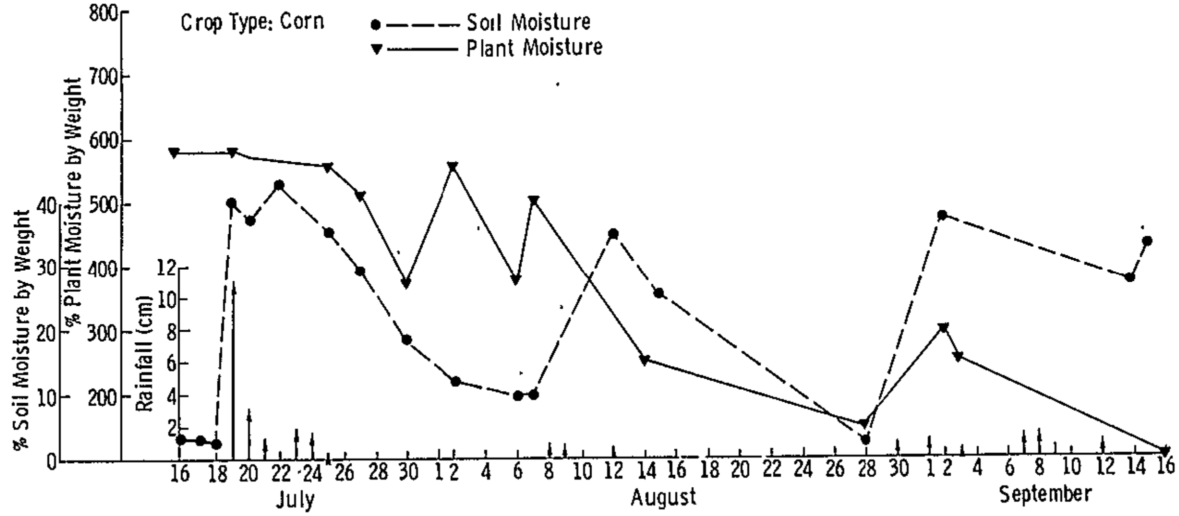
Lawrence, Kansas. In addition to determining the "constant" ground-truth parameters such as soil phase, slope and bulk density data, information was collected (at the time of the scattering measurements) on each of the following variables:

a) Soil moisture by dry weight at depths of 0-1, 1-2, 2-5, 5-9 and 9-15 cm (based on skin depth considerations [4] soil moisture data reported in this paper is the average of the top 2.0 cm),
b) Crop height,
c) Crop plant density,
d) Crop moisture content by dry weight, and
e) Visual qualitative description of the test site.

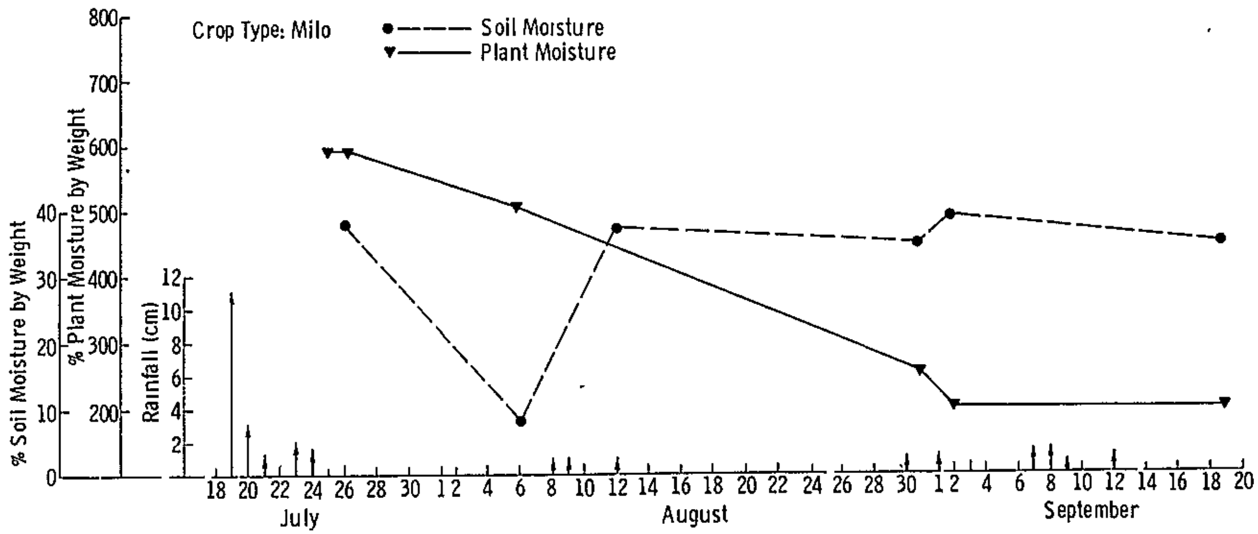
These and other ground information are listed in the Appendix. Time histories of rainfall and plant and soil moisture contents are presented in Figures 2a through 2d for the test fields. It might be noted that whereas rainfall is directly responsible for the soil moisture content level, no obvious dependence of plant moisture on soil moisture is apparent for any of the crop types.

2.3 Data Acquisition Technique

The data acquisition technique employed in this study was directed chiefly toward exploiting the frequency averaging properties of the panchromatic system. Being an FM system with a 400 MHz peak to peak frequency deviation it inherently provided a good deal of sample averaging. Between 8 GHz and 18 GHz a total of 24 measurements were performed, each representing a 400 MHz average. Due to the small size of the illuminated cell, particularly at incidence angles close to nadir, frequency averaging alone did not provide what was felt to be an adequate amount of fading reduction for acceptable data accuracy. Hence in addition to frequency averaging, spatial averaging was also employed. The number of spatially discrete measurements made at the angles shown in Table 2 were based on previous work by Birkmeier and Wallace [5], Ray [6], and Waite [7]. Assuming Rayleigh fading and utilizing fading data from the same fields [8] the total number of independent samples available for averaging was calculated. With these data, 80% confidence limits applicable to all scattering data presented herein were calculated and are also shown in Table 2.

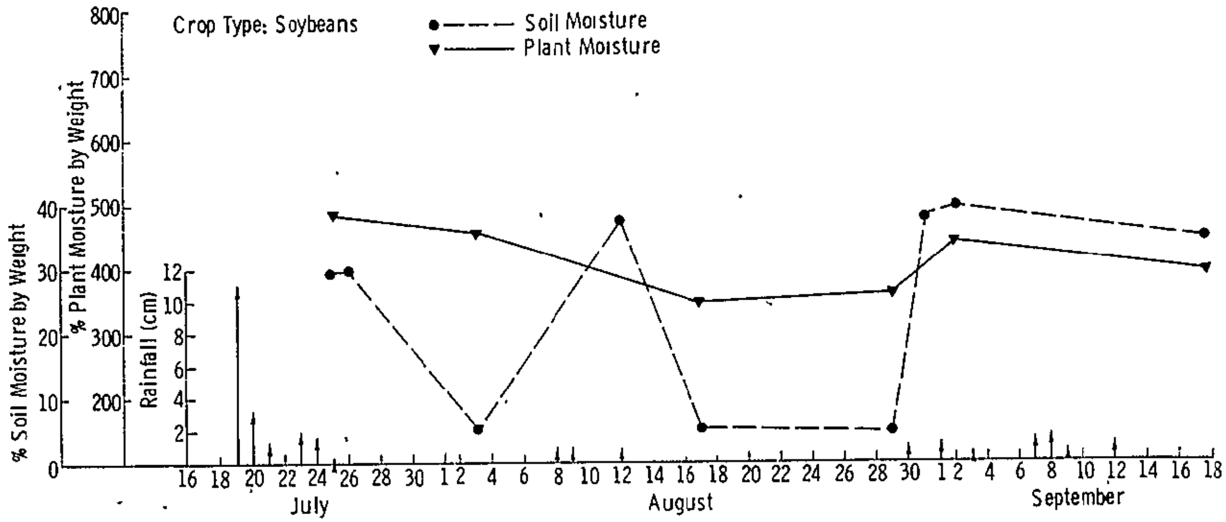


2a. Corn

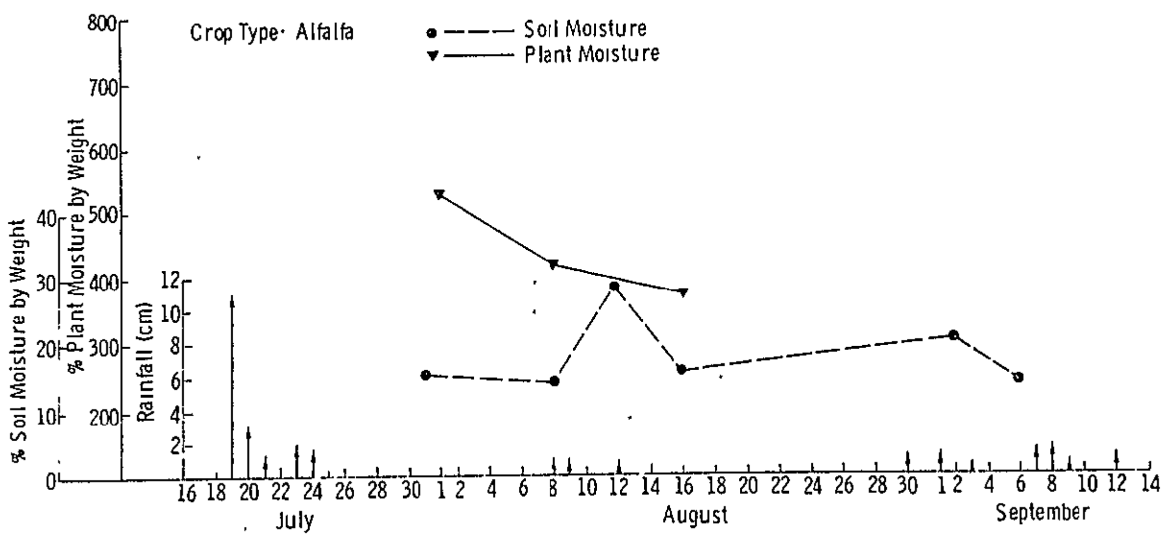


2b. Milo

Figure 2. History of plant moisture, soil moisture, and daily precipitation for fields planted with a) corn, b) milo, c) soybeans, and d) alfalfa.



2c. Soybeans



2d. Alfalfa

TABLE 2

Number of Spatially Discrete Measurements Collected
per Data Set with 80% Confidence Limits
for Each Crop Type

Incidence Angle	Number of Spatially Discrete Measurements Collected	80% Confidence Limits (dB)			
		Corn	Milo	Soybeans	Alfalfa
0°	9	+1.4 -1.8	+1.0 -1.3	+1.0 -1.3	+1.3 -1.6
10°	8	+1.0 -1.3	+1.0 -1.3	+1.0 -1.3	+1.3 -1.6
20°	7	+0.7 -1.05	+1.0 -1.3	+1.0 -1.3	+1.3 -1.6
30°	6	+0.7 -1.05	+1.0 -1.3	+1.0 -1.3	+1.3 -1.6
40°	5	+0.7 -1.05	+1.0 -1.3	+1.0 -1.3	+1.05 -1.40
50°	5	+0.7 -1.05	+0.95 -1.25	+0.95 -1.25	+0.95 -1.25
60°	5	+0.65 -0.95	+0.80 -1.20	+0.80 -1.20	+0.80 -1.20
70°	5	+0.60 -0.90	+0.60 -0.90	+0.60 -0.90	+0.60 -0.90

Most of the recorded data sets include 0°-70° incidence angles for both HH (horizontal) and VV (vertical) polarizations. In a few cases, system problems or time limitations did not permit the acquisition of 60° and 70° data.

3.0 DISCUSSION OF RESULTS

The variables affecting the scattering process can be grouped into two basic categories: a) system variables and b) target variables. System variables include frequency, polarization and incidence angle while target variables include geometry and permittivity. Since system variables are under the investigator's control, their effects on σ° can often be studied more effectively than the target variables whose values are governed by the target environment. To help in the analyses of the scattering data, the target variables were restricted to basically include: 1) crop type, 2) crop height, 3) soil moisture, and 4) crop morphology. After presenting spectral response data in section 3.1, subsequent analysis will be limited to three frequencies, 9.0, 13.0 and 16.6 GHz. These frequencies were chosen as representatives of the lower end, the middle part and the upper end of the 8-18 GHz band.

3.1 Spectral Response

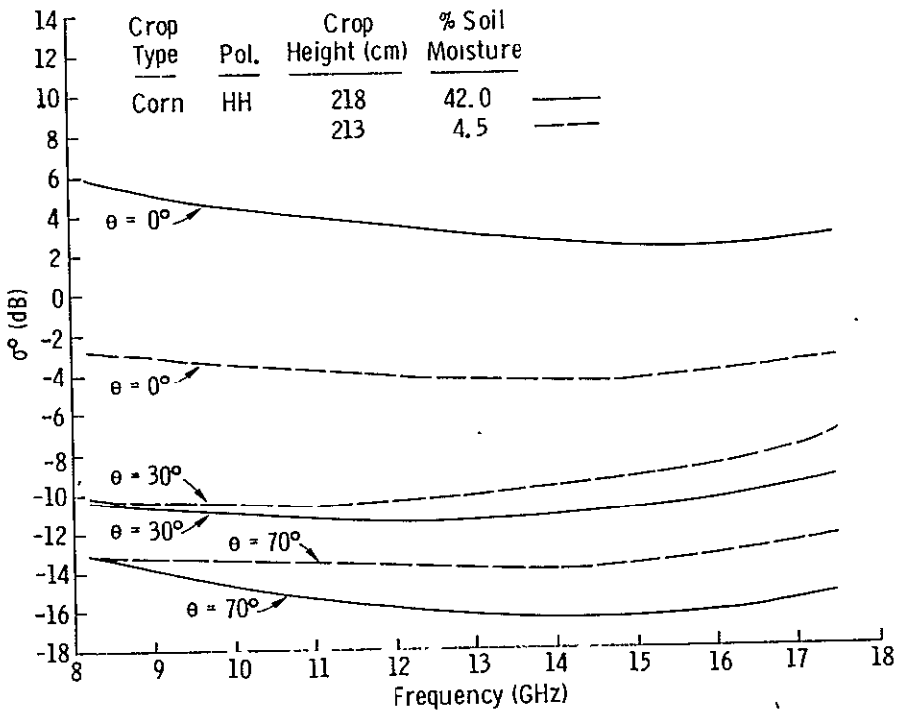
The spectral response of σ° over the 8-18 GHz band is shown in Figure 3 for corn, soybeans, milo and alfalfa. For the first three crops each figure contains curves at three different incidence angles for each of two extreme soil moisture conditions. In the case of alfalfa, only two data sets were recorded, both at approximately the same moisture content but considerably different growth stages. In terms of the overall spectral response of σ°, no significant differences appear in the data due to polarization differences (compare HH curves to corresponding VV curves). Hence, only HH polarization data will be discussed in this section. Between 8 and 18 GHz, 24 data points were recorded for each curve; the curves represent smooth fits within the confidence limits indicated in Table 2.

The two major target variables influencing the radar return from a given crop are soil moisture and plant morphology. The latter is in general a function of growth stage, but can be influenced (temporarily) by some external factors such as heavy rain. As will be shown later in section 3.3, heavy rain can greatly modify the backscattering coefficient σ^o at large angles of incidence although no significant penetration through the vegetation is possible. Perhaps a simple way of describing plant morphology, in terms of scattering theory, is as a facet-slope distribution, where each leaf is considered to be composed of one or more plane facets. Detailed discussion of this model is deferred until section 3.3.

The complex dependence of σ^o on the above variables makes it difficult at this stage to render a detailed analysis of the data presented in Figure 3. Hence, only general remarks will be made in this section, to be followed, in section 3.3 on the angular response of σ^o, by more detailed investigations of the influence of each of the sensor and target parameters under consideration.

At normal incidence ($\theta = 0^o$), corn, soybeans and milo show considerable differences in magnitude of σ^o between the dry and wet soil moisture conditions. For corn (Figure 3a), the difference between σ^o of the wet case and σ^o of the dry case starts at about 9 dB around 8 GHz and decreases slowly to about 6 dB at the high end of the frequency band. The decrease is attributed to increased attenuation (through the vegetation) with frequency. Milo (Figure 3c) shows a pattern similar to corn except that the difference in the magnitude of σ^o between the wet and dry cases (about 6 dB) decreases by only about 0.5 dB between 8 and 18 GHz. The apparent absence of increased attenuation by the vegetation as a function of frequency may be a misleading conclusion, however. Whereas for the wet case the soil contribution to the backscattered energy dominates over the vegetation contribution, it is not possible to determine the relative contributions by the soil and vegetation in the dry case. This is also true for corn. Another factor that may be related to the difference in behavior between corn and milo is the fact that the milo plants were denser but only 2/5 as tall as the corn plants.

Unlike corn and milo, soybeans (Figures 3e) shows what at first appears to be a peculiar behavior; at $\theta = 0^o$, the difference in magnitude of σ^o between the wet and dry soil cases increases from 2.2 dB at around 8 GHz to over 11.7 dB at the other end of the band. Based on arguments presented in section 3.3.3, it appears that the difference in σ^o noted above is not exclusively a consequence of soil moisture changes, as was



3a. Corn, HH polarization

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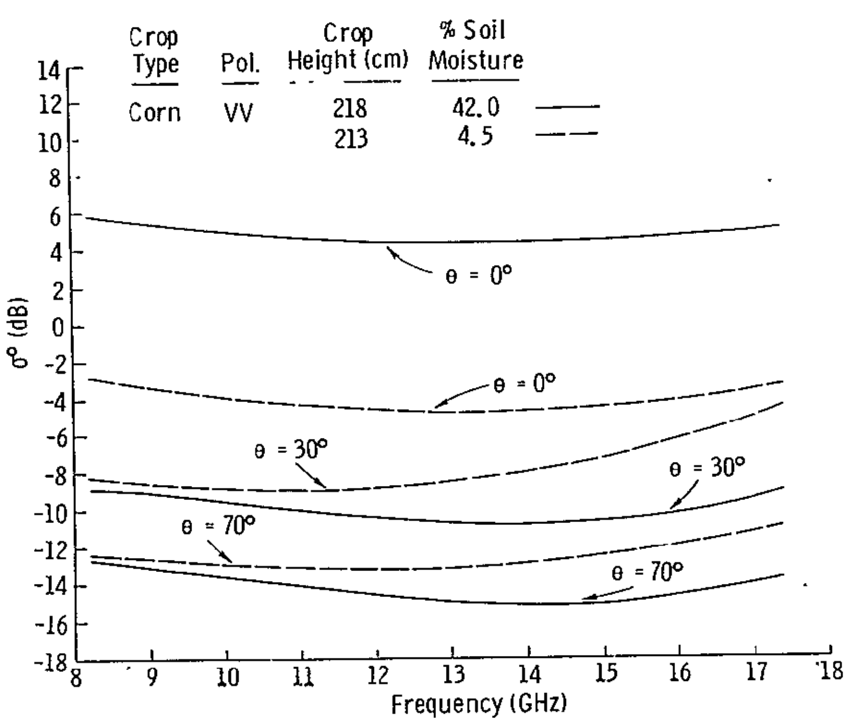
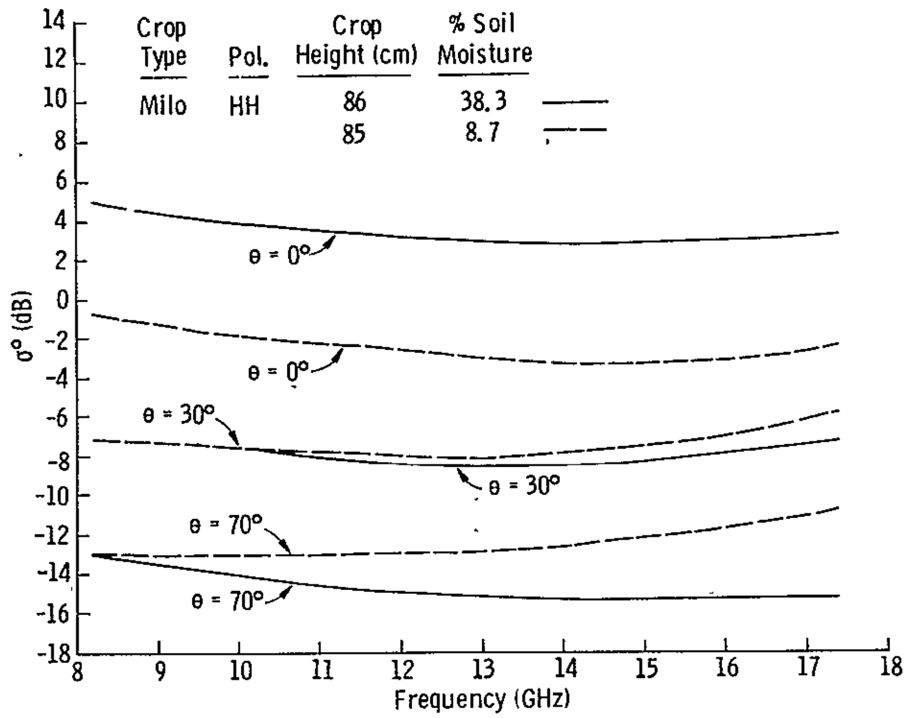
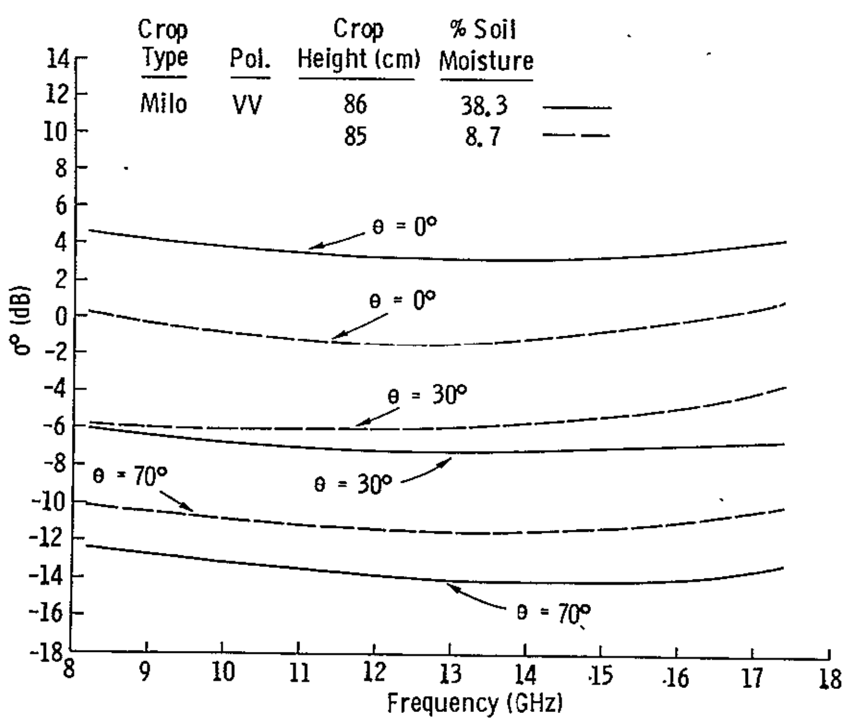


3b. Corn, VV polarization

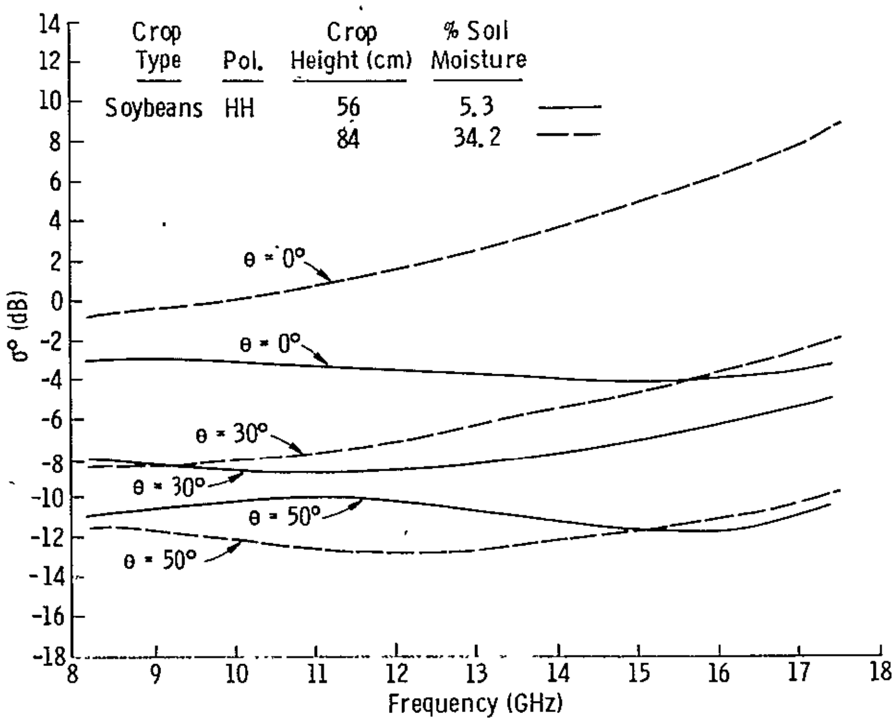
Figure 3. Spectral response of corn (3a and 3b), milo (3c and 3d), soybeans (3e and 3f) and alfalfa (3g and 3h).



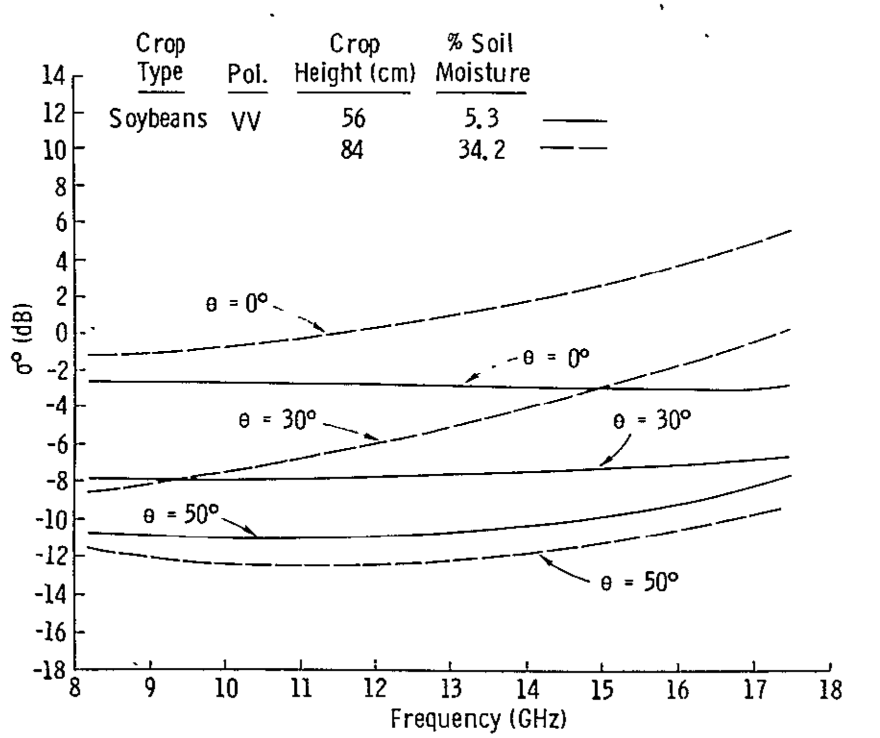
3c. Milo, HH polarization.



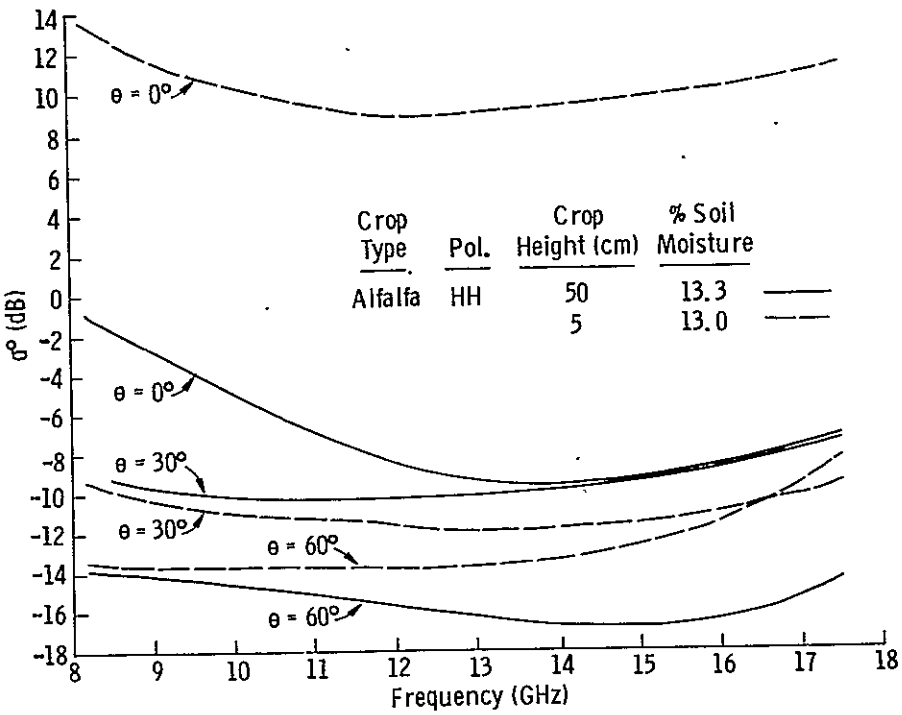
3d. Milo, VV polarization.



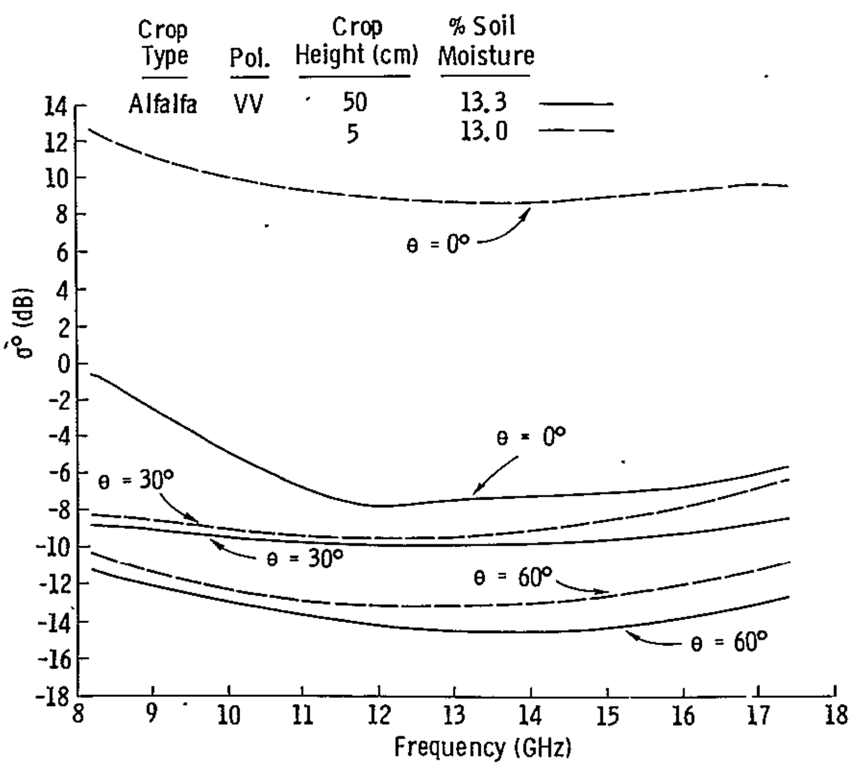
3e. Soybeans, HH polarization.



3f. Soybeans, VV polarization.



3g. Alfalfa, HH polarization



3h. Alfalfa, VV polarization

suggested to be the case for corn and milo; instead it is suspected that the responsible factor is the change in the morphology of the plant as a result of growth (from 56 cm in height to 84 cm in height) and, possibly, heavy precipitation during the two days prior to recording the wet soil data set. The wet soil data sets of corn and milo were also recorded after days of heavy precipitation; however, upon inspecting the angular behavior of their scattering coefficients (in section 3.3.1 and 3.3.2), it was concluded that the rain mostly affected the change in σ^o (due to morphological changes) at large angles of incidence and high frequencies. It should be noted that mature soybeans is a much denser crop than corn and milo and that soybean plants have a distinctly different shape than corn and milo plants. Hence, it should not be very surprising that the effect of rain on the morphology of soybeans may be different from its effects on the morphology of corn and milo.

As we go from $\theta = 0^o$ to $\theta = 70^o$, we observe a reversal in the relative magnitudes of the curves corresponding to the dry and wet soil data sets of corn (Figures 3a and 3b) and milo (Figures 3c and 3d). Furthermore, the difference in magnitude of σ^o between the two soil moisture conditions (which has the opposite sign of the difference observed at $\theta = 0^o$) is both incidence angle (compare 30^o and 70^o curves) and frequency sensitive. The apparent cause of this inversion phenomenon is attributed to morphological changes induced by heavy rain (section 3.3).

In Figures 3e and 3f the spectral behavior of soybeans at 30^o and 50^o (50^o was chosen as opposed to 70^o because some of the data points at 60^o and 70^o were not recorded due to time limitation) is attributed to the morphology of the plants, as will be shown in later sections.

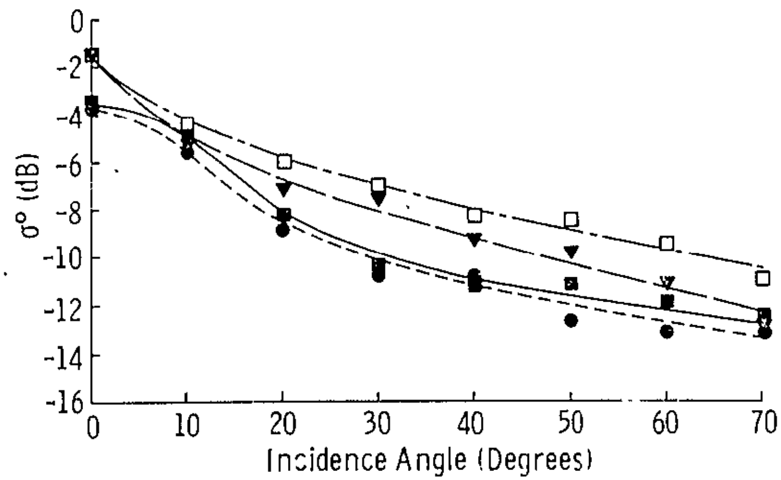
One of the two sets of curves shown in Figures 3g and 3h represents mature alfalfa having an average plant height of about 50 cm while the other set represents the radar response from alfalfa after mowing and baling, and hence having an average height of only 5 cm. The soil moisture in both cases is approximately the same. At all three incidence angles shown, the short alfalfa produces a stronger return than the tall alfalfa, particularly at normal incidence where the difference varies between 14 dB at 8 GHz and 18 dB at frequencies above 13 GHz. Visual observation of the soil surface of alfalfa fields indicates that the soil surface is very smooth. The field had been first seeded over two years prior to the date of the experimental measurements reported herein. When alfalfa reaches sufficient height, it is cut and baled. Then the field is untouched until it grows up again. Such a process may continue for several years. Hence over a two year period, the surface can assume a very smooth character. It is then suggested that the return observed from the short alfalfa field is actually a measure of the backscatter from the underlying soil surface; penetration loss through 5 cm of alfalfa is expected to be negligible. When alfalfa grows to a height of 50 cm, it is difficult to visually see the soil surface due to the high density of the alfalfa plants. Hence it is suspected that σ^o of the mature alfalfa case includes negligible contributions from the underlying soil. This statement is supported by observations over the 4-8 GHz band [1] which indicate no positive sensitivity to variations in soil moisture at nadir under identical plant height (50 cm) conditions.

3.2 Polarization Effects

Figure 4 presents curves of σ^o versus θ for the four crop types at each of the three frequencies: 9.0, 13.0 and 16.6 GHz. Low soil moisture content data sets were chosen to minimize soil contributions to the total backscatter. Each figure includes both HH and VV polarization curves.

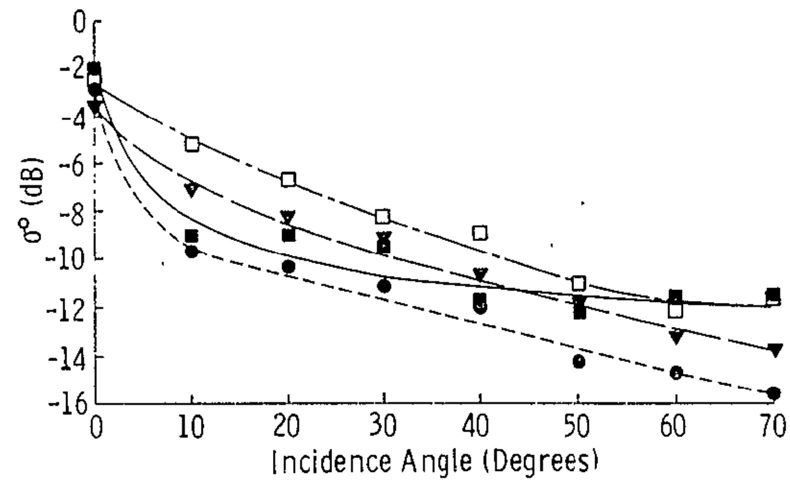
Figure 4a, 4c and 4e indicate that corn is extremely polarization independent at all frequencies. Milo on the other hand seems to be more sensitive to polarization effects, especially at the lower frequencies. At all frequencies, vertically polarized backscatter from milo is higher than horizontally polarized backscatter although the difference is quite small, 1 dB or less. As with milo, soybeans and alfalfa (Figures 4b, 4d and 4f) have a stronger VV return at 9.0 GHz, but the difference is negligible at 13.0 and 16.6 GHz. This seems to be in agreement with data collected by Ohio State University [9, p. 43] where it was noted that "when a terrain has a heavy vegetation cover, little difference is noted in the value of $\gamma(=\sigma^o/\cos\theta)$ for vertical and horizontal polarization." On an absolute scale, milo and soybeans appear to produce the strongest returns at all polarizations and frequencies. Comparison of the shape of the 9 GHz angular response curves of the four crops around 0^o suggests that different mechanisms are responsible for the backscatter from alfalfa as opposed to the other three crops. Whereas the maximum drop in the magnitude of σ^o between 0^o and 10^o is 3.5 dB for the other three crops, σ^o of alfalfa drops by 8 dB (Figure 4b). This behavior supports the slightly smooth surface description advanced by Ulaby [1] for alfalfa in the 4-8 GHz band. As a dense cover crop, the major contributions to the total backscattered energy may be the result of surface rather than volume

Crop Type	Freq. (GHz)	Pol.	Crop Height (cm)	% Soil Moisture	Date	
Corn	9.0	HH	213	4.5	8/7/73	- - - - - ●
		VV				——— ■
Milo	9.0	HH	85	8.7	8/6/73	— — ▼
		VV				——— □



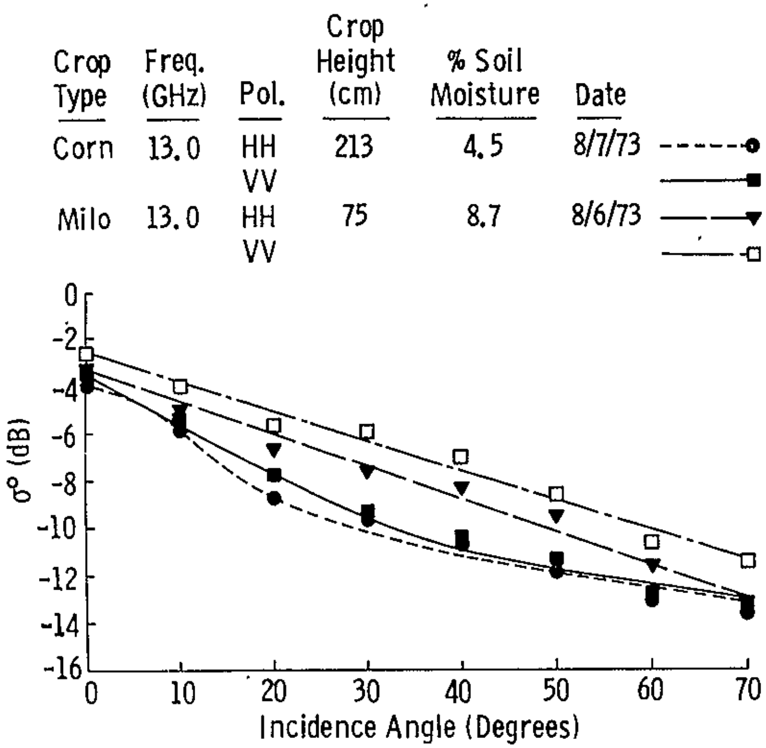
4a. Corn and Milo at 9 GHz.

Crop Type	Freq. (GHz)	Pol.	Crop Height (cm)	% Soil Moisture	Date	
Soybeans	9.0	HH	56	5.3	8/29/73	— — ▼
		VV				——— □
Alfalfa	9.0	HH	50	13.3	8/8/73	- - - - - ●
		VV				——— ■

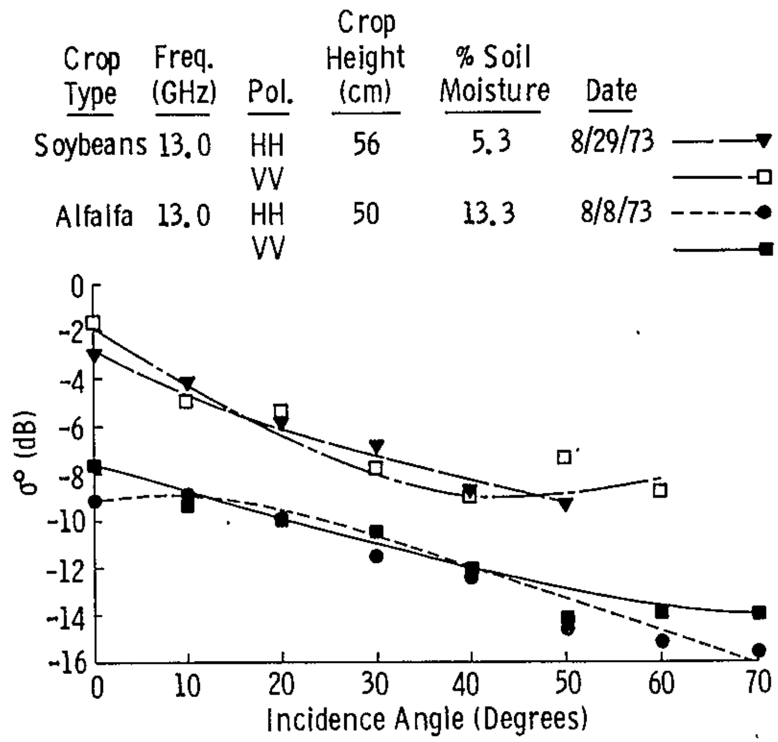


4b. Soybeans and Alfalfa at 9 GHz.

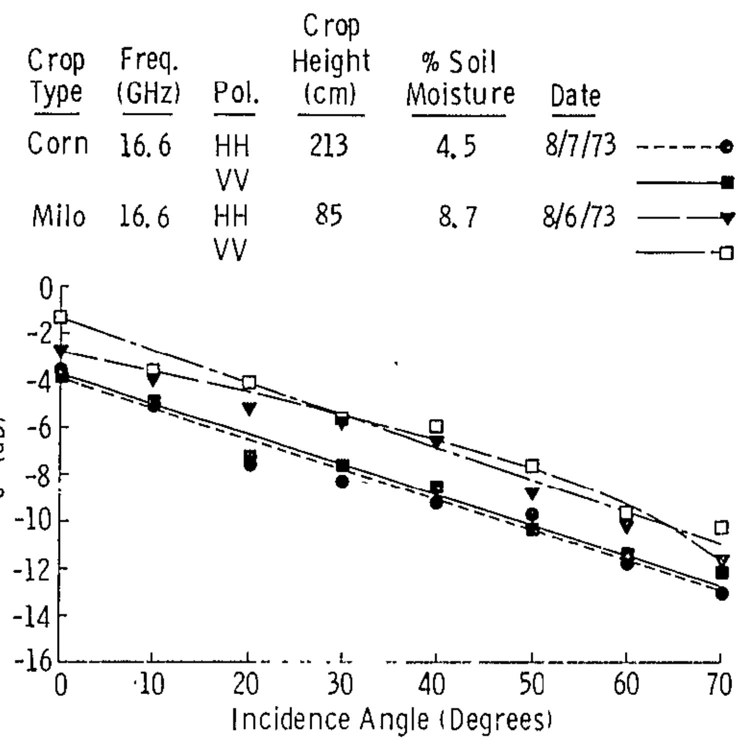
Figure 4. σ^o angular response for HH and VV polarization at 9 GHz (4a and 4b), 13 GHz (4c and 4d), and 16.6 GHz (4e and 4f).



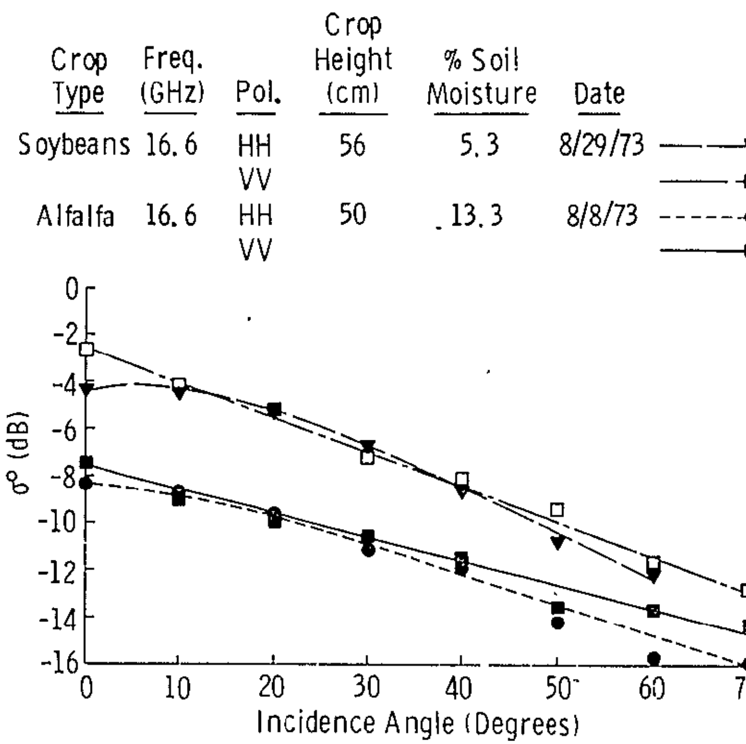
4c. Corn and Milo at 13 GHz.



4d. Soybeans and Alfalfa at 13 GHz.



4e. Corn and Milo at 16.6 GHz.



4f. Soybeans and Alfalfa at 16.6 GHz.

scatter. This is in contrast to corn, milo and soybeans which are row crops. In addition to the behavior around nadir, the surface model description of alfalfa is also supported by the fact that σ^o of alfalfa off-nadir is consistently smaller than σ^o of the other crops at any angle-frequency combination shown in Figure 4. As the frequency is increased, alfalfa appears electromagnetically rougher, thereby producing a gentler slope between 0^o and 10^o at 13.3 GHz (Figure 4d) and 16.6 GHz (Figure 4f).

3.3 Soil Moisture Effects on Radar Backscatter

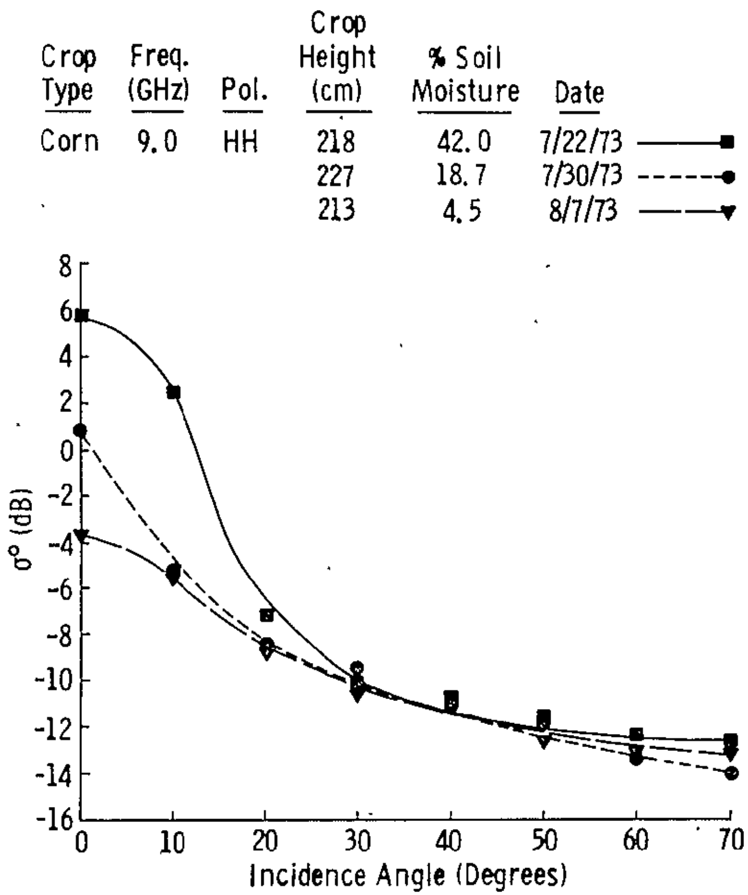
3.3.1 Corn

Figures 5a through 5f indicate the effects of varying soil moisture on the backscatter response of corn. As might be expected, σ^o is more sensitive to soil moisture at nadir, with the sensitivity quickly decreasing as θ increases. At $\theta = 30^o$ at 9.0 GHz, σ^o shows no response to the extreme case of 42% soil moisture. In fact for the case where soil moisture is 18.7% there is no sensitivity at $\theta = 10^o$. It is only at nadir where we see any appreciable sensitivity of σ^o to soil moisture. This points out the importance of signal attenuation by vegetation. Whereas Ulaby [1] reported some sensitivity of σ^o to soil moisture at 40^o for corn at 5.9 GHz, we now see that an increase of 3.1 GHz causes any moisture effects to be masked.

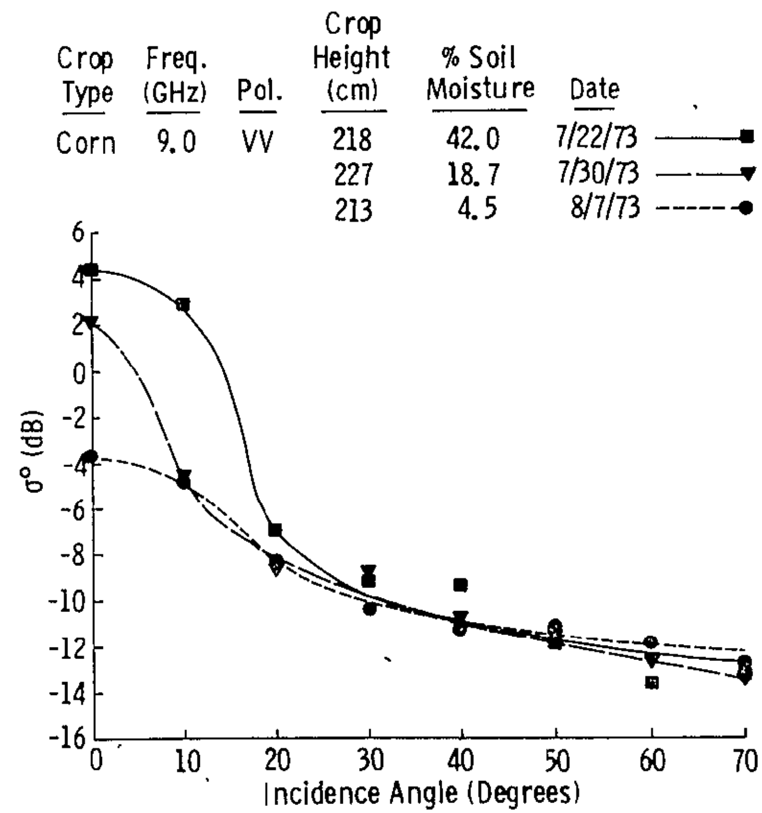
An important observation that should be noted is the inversion phenomenon of the σ^o versus θ curves as frequency and θ are increased. This behavior is attributed to changes in the plant morphology and is discussed in detail in the latter part of this section.

Following the procedure established by Ulaby [1,4] for the quantitative analysis of the radar response to soil moisture in the 4-8 GHz band, σ^o has been plotted versus soil moisture as shown in Figures 6a-6f. For each particular angle, frequency and polarization a regression line has been fitted. Eight data points are shown with soil moisture contents ranging from 4.5 to 42.0%.

Having calculated the slopes of these regression lines, the parameter $S = \Delta\sigma^o / \Delta\%m$ is plotted as shown in Figures 7a through 7c. S, having the dimensions of dB/per cent soil moisture, provides a good indicator of the effects of varying soil moisture. The magnitudes and trends of S near nadir are certainly what is to be expected in view of Figures 6a-6f; the trend of a decreasing S with frequency is also in line with earlier

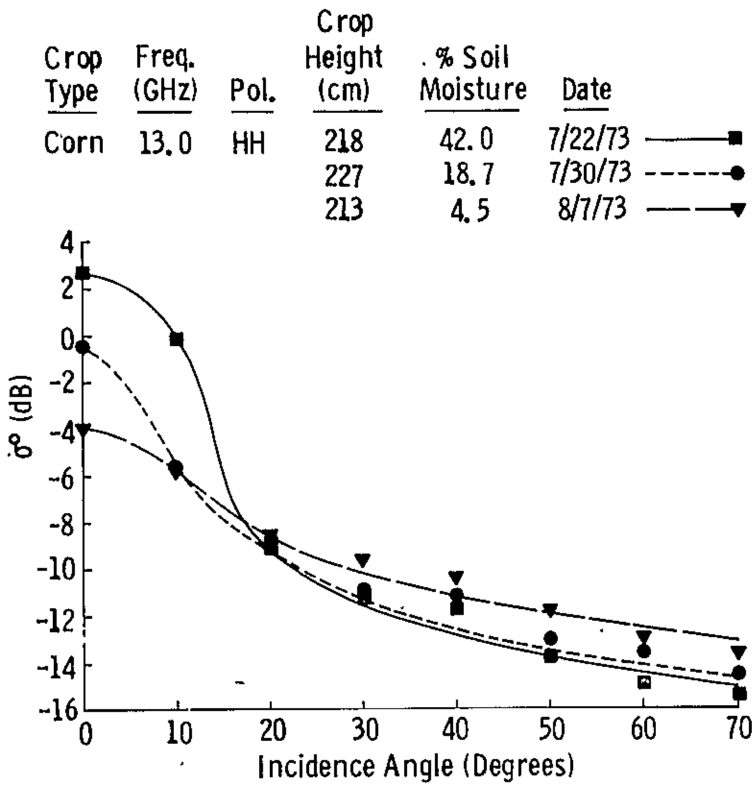


5a. 9 GHz, HH polarization.

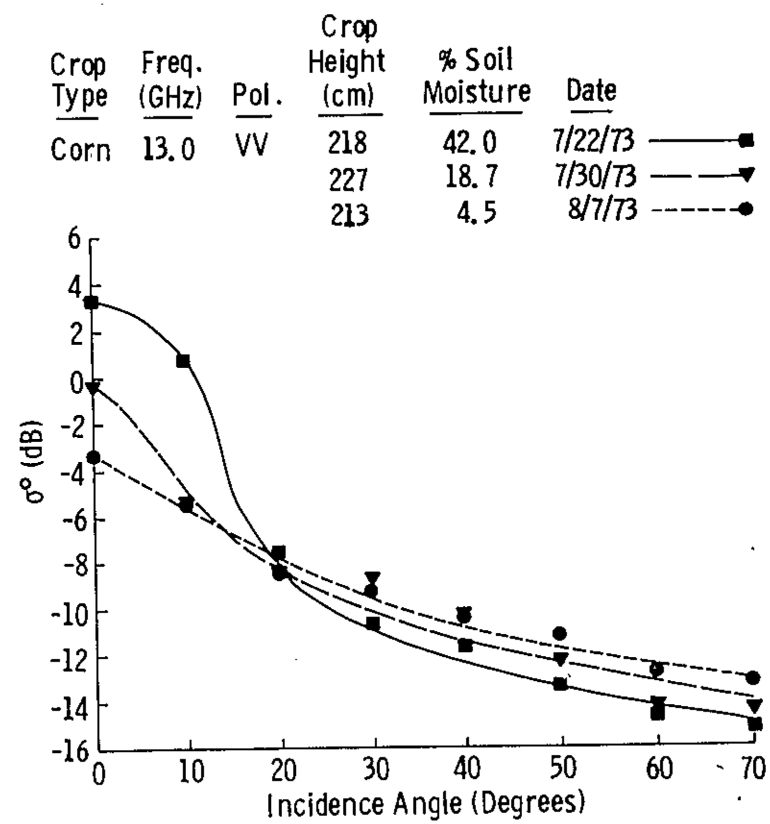


5b. 9 GHz, VV polarization.

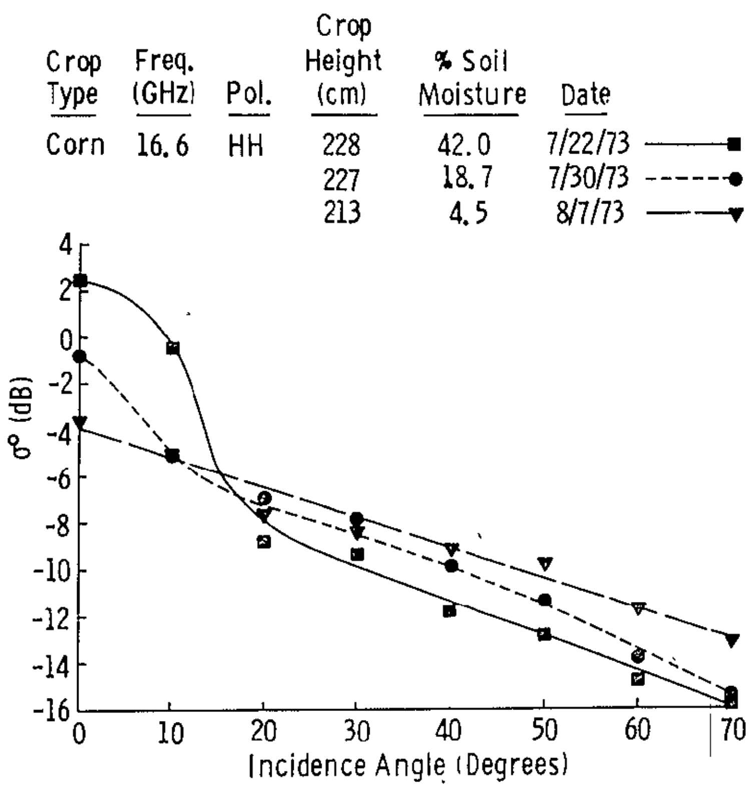
Figure 5. Angular response of σ^o of corn for three different soil moisture contents at 9 GHz (5a and 5b), 13 GHz (5c and 5d) and 16.6 GHz (5e and 5f).



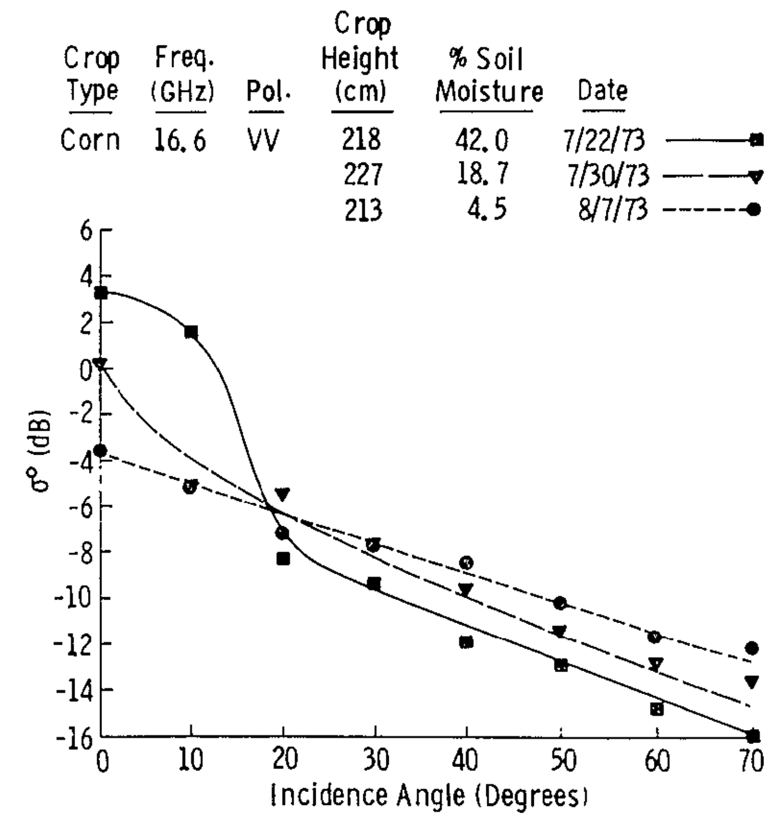
5c. 13 GHz, HH polarization.



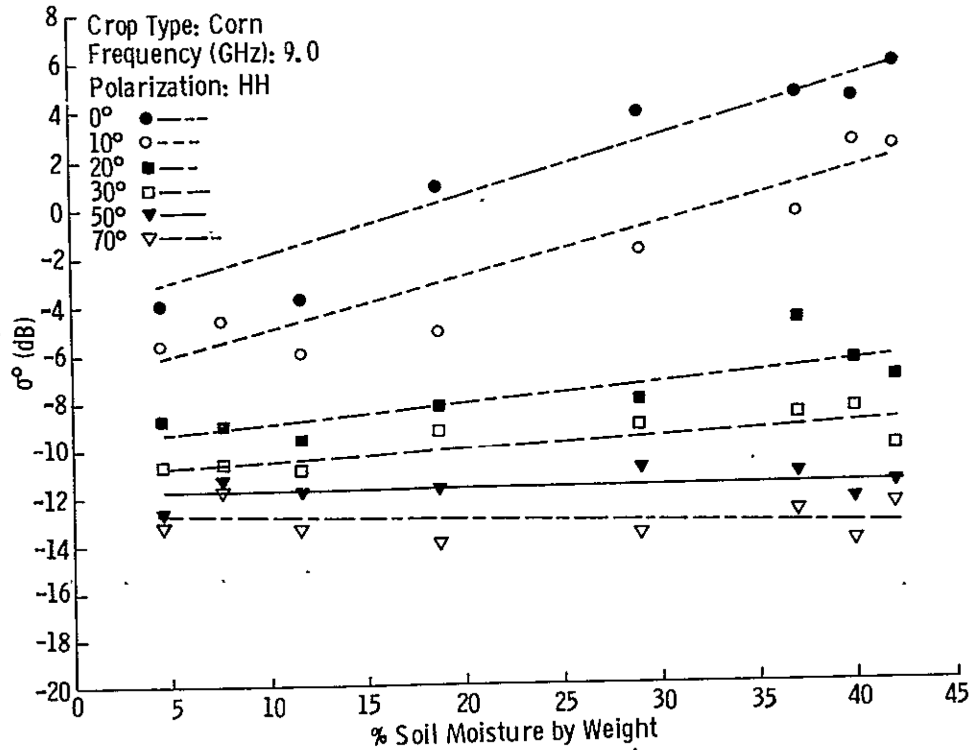
5d. 13 GHz, VV polarization.



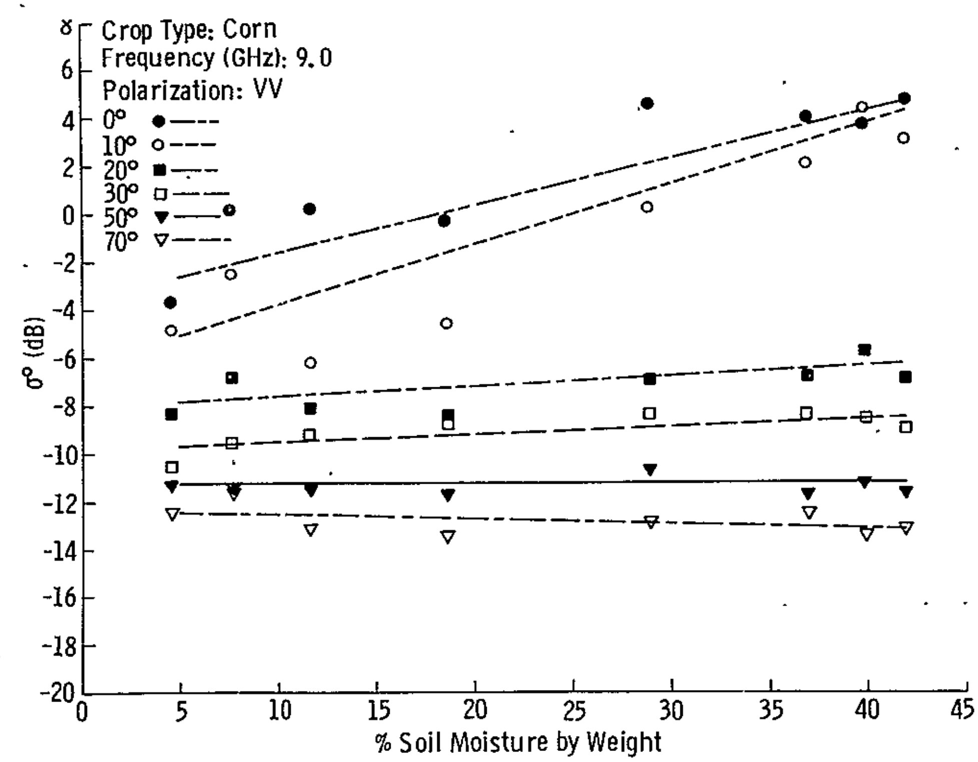
5e. 16.6 GHz, HH polarization.



5f. 16.6 GHz, VV polarization.

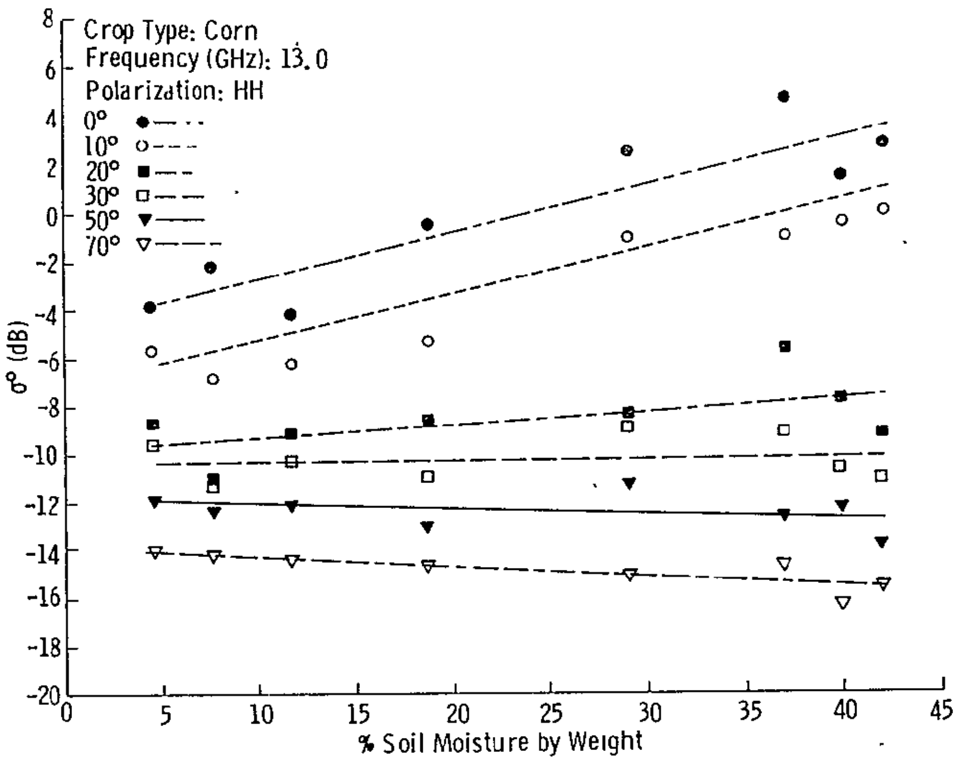


6a. 9 GHz, HH polarization.

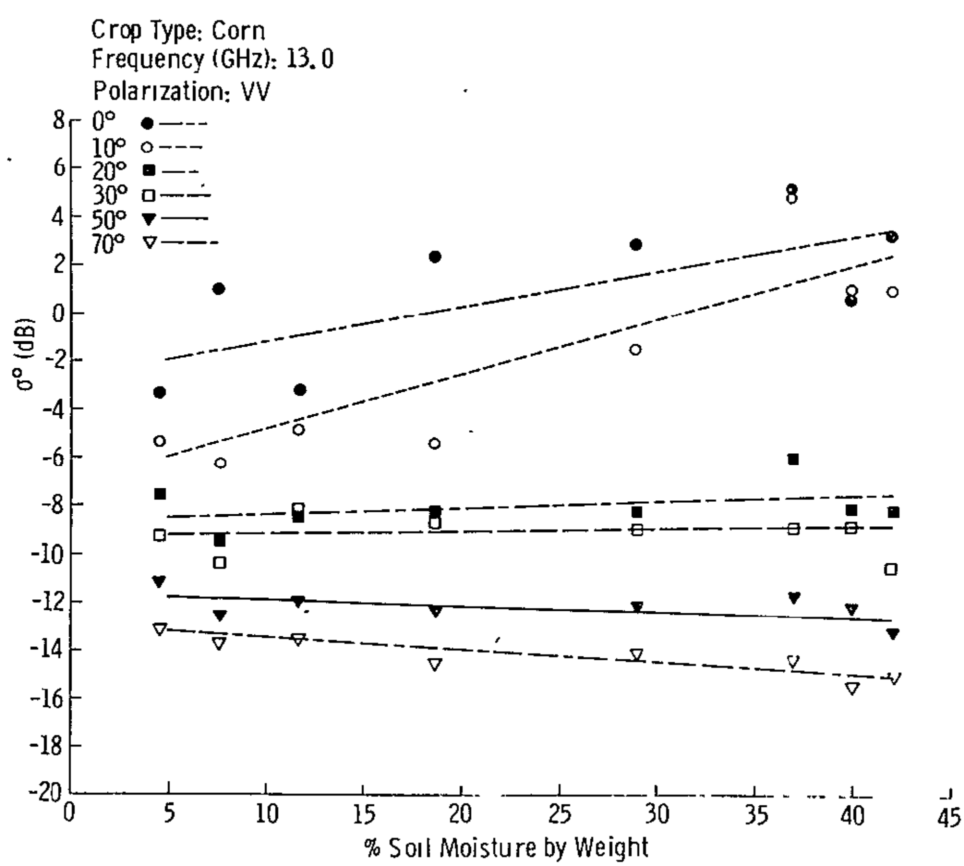


6b. 9 GHz, VV polarization.

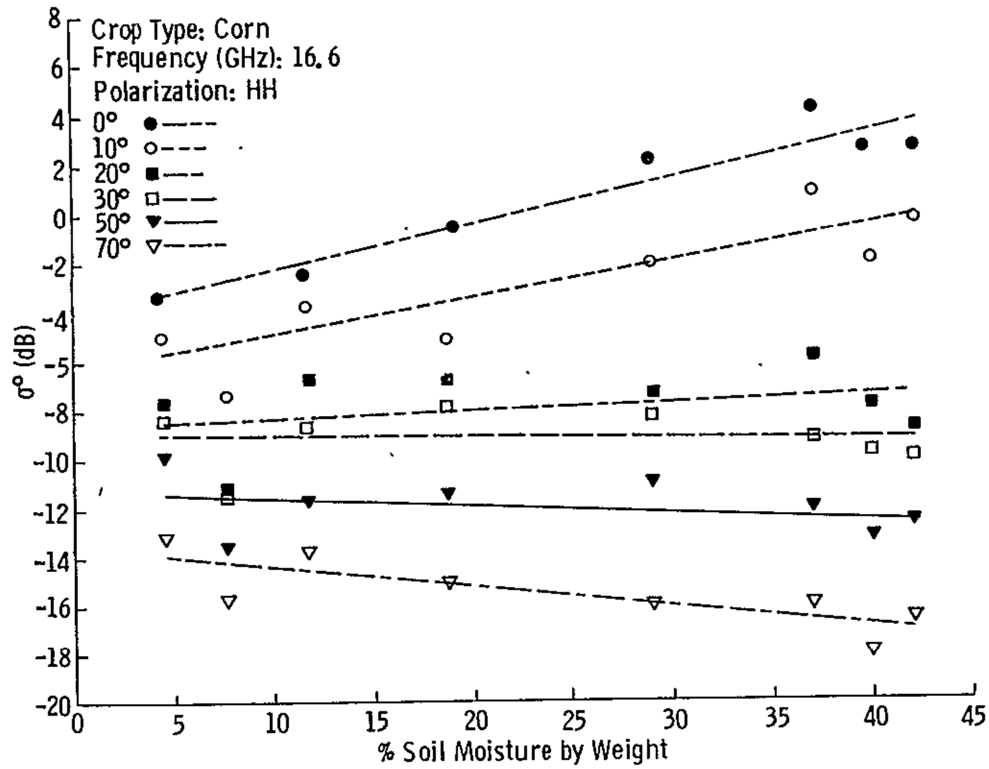
gure 6. Measured scattering coefficient of corn as a function of soil moisture and incidence angle. The lines are least square fits. (a) 9 GHz, HH polarization, (b) 9 GHz, VV polarization, (c) 13 GHz, HH polarization, (d) 13 GHz, VV polarization, (e) 16.6 GHz, HH polarization, and (f) 16.6 GHz, VV polarization.



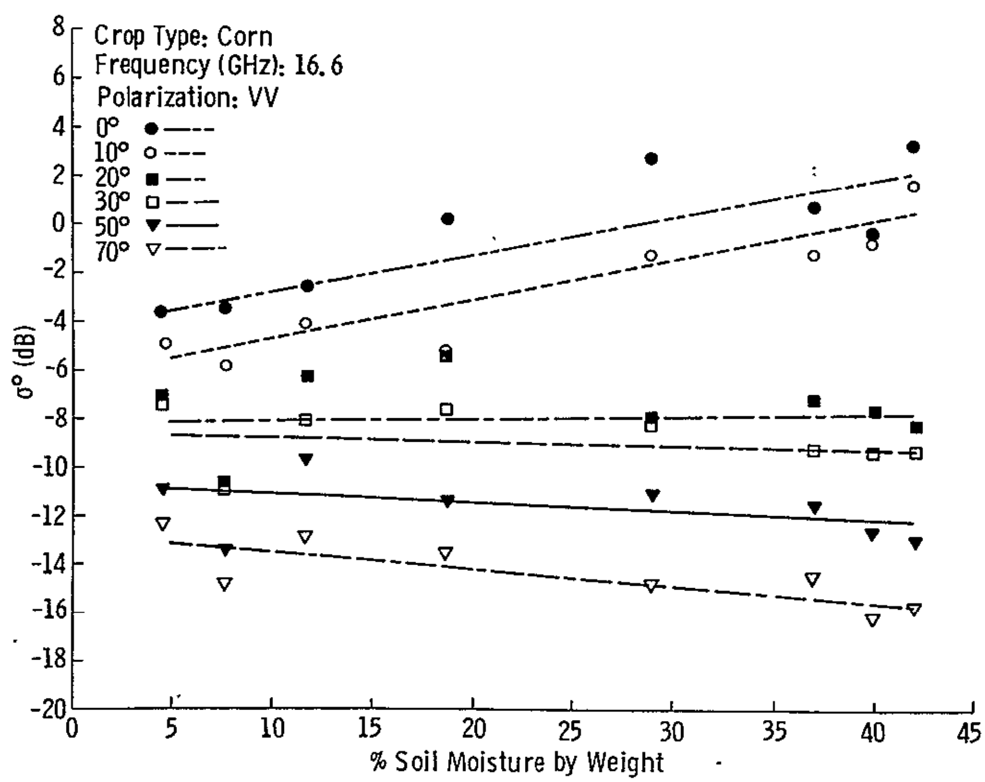
6c. 13 GHz, HH polarization.



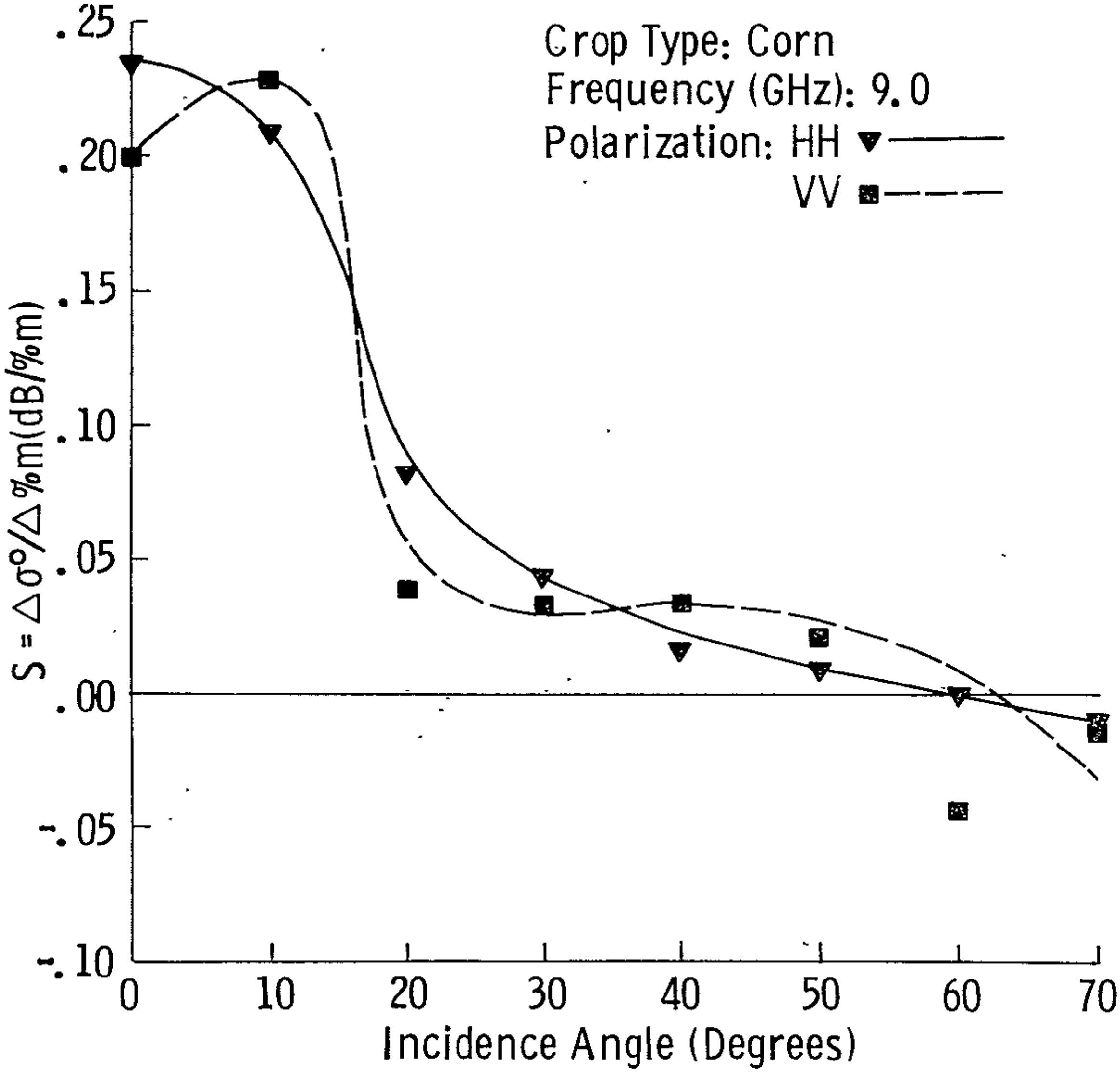
6d. 13 GHz, VV polarization.



6e. 16.6 GHz, HH polarization.

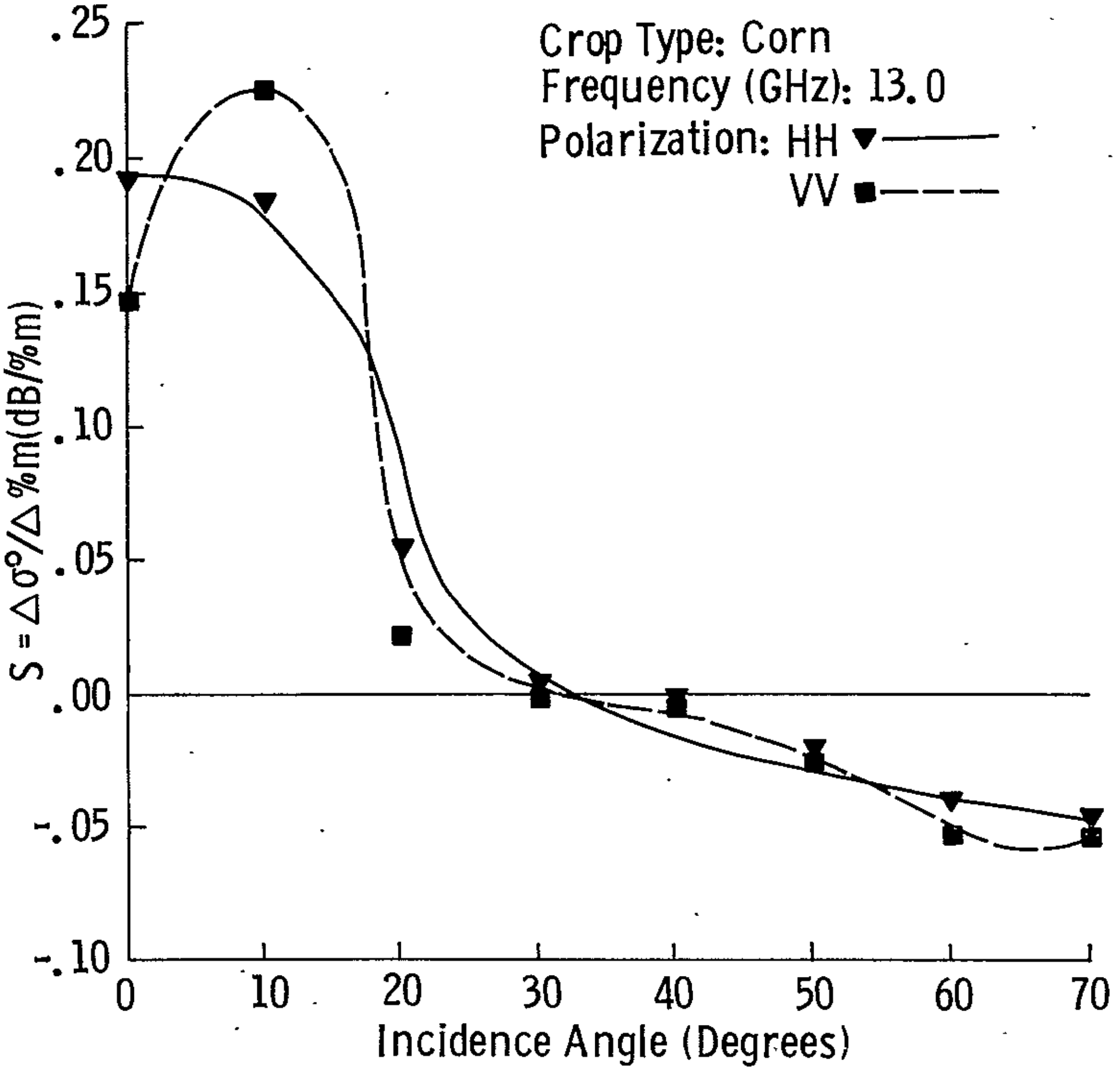


6f. 16.6 GHz, VV polarization.

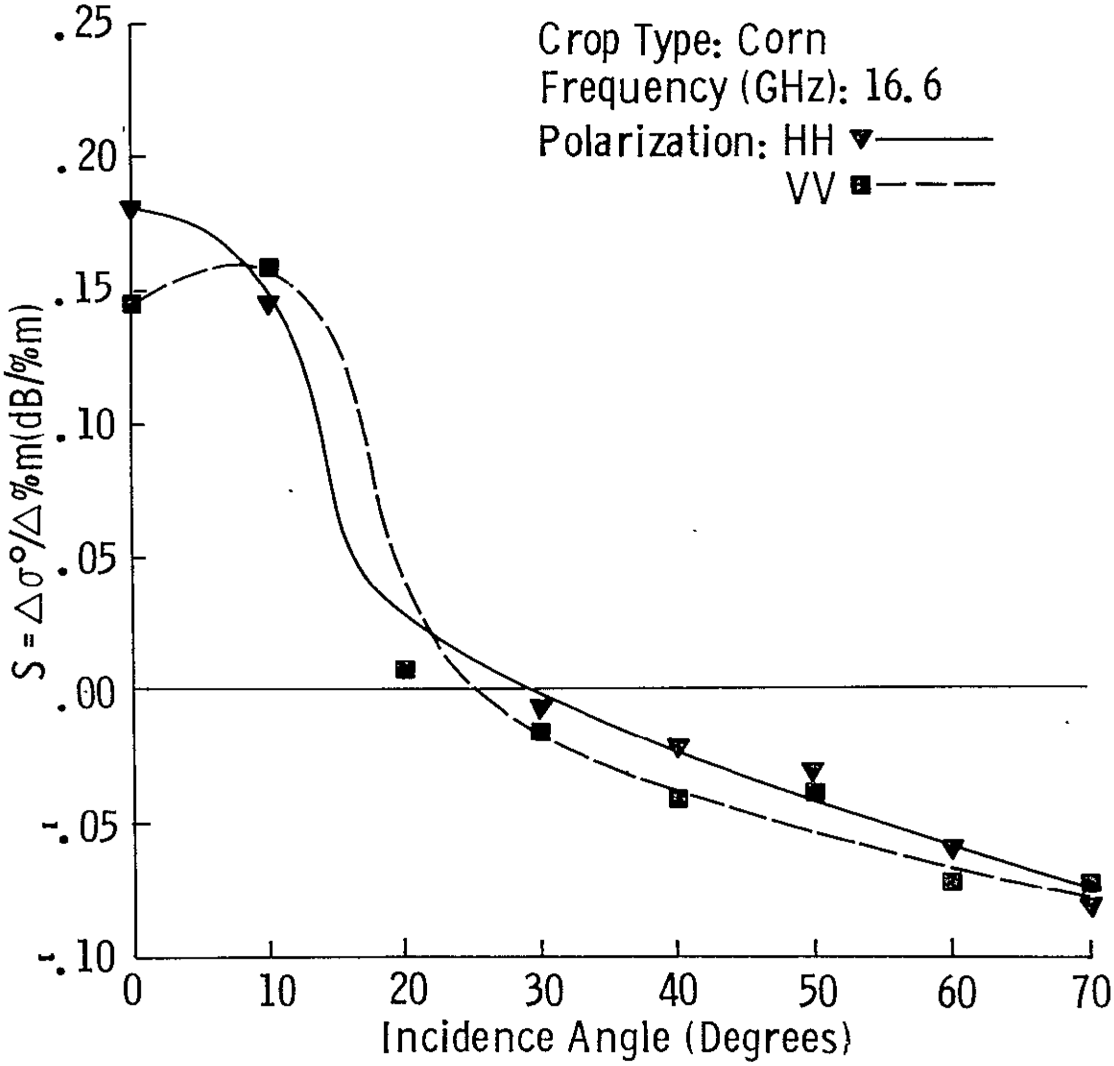


7a. S at 9 GHz.

Figure 7. Curves depicting S, the sensitivity of σ^o of corn to soil moisture as a function of incidence angle at (a) 9 GHz, (b) 13 GHz, and (c) 16.6 GHz.


Crop Type: Corn
Frequency (GHz): 13.0
Polarization: HH
VV
S = Δσ°/Δ%m(dB/%m)
.25
.20
.15
.10
.05
.00
-.05
-.10
0
10
20
30
40
50
60
70
Incidence Angle (Degrees)

7b. S at 13 GHz.

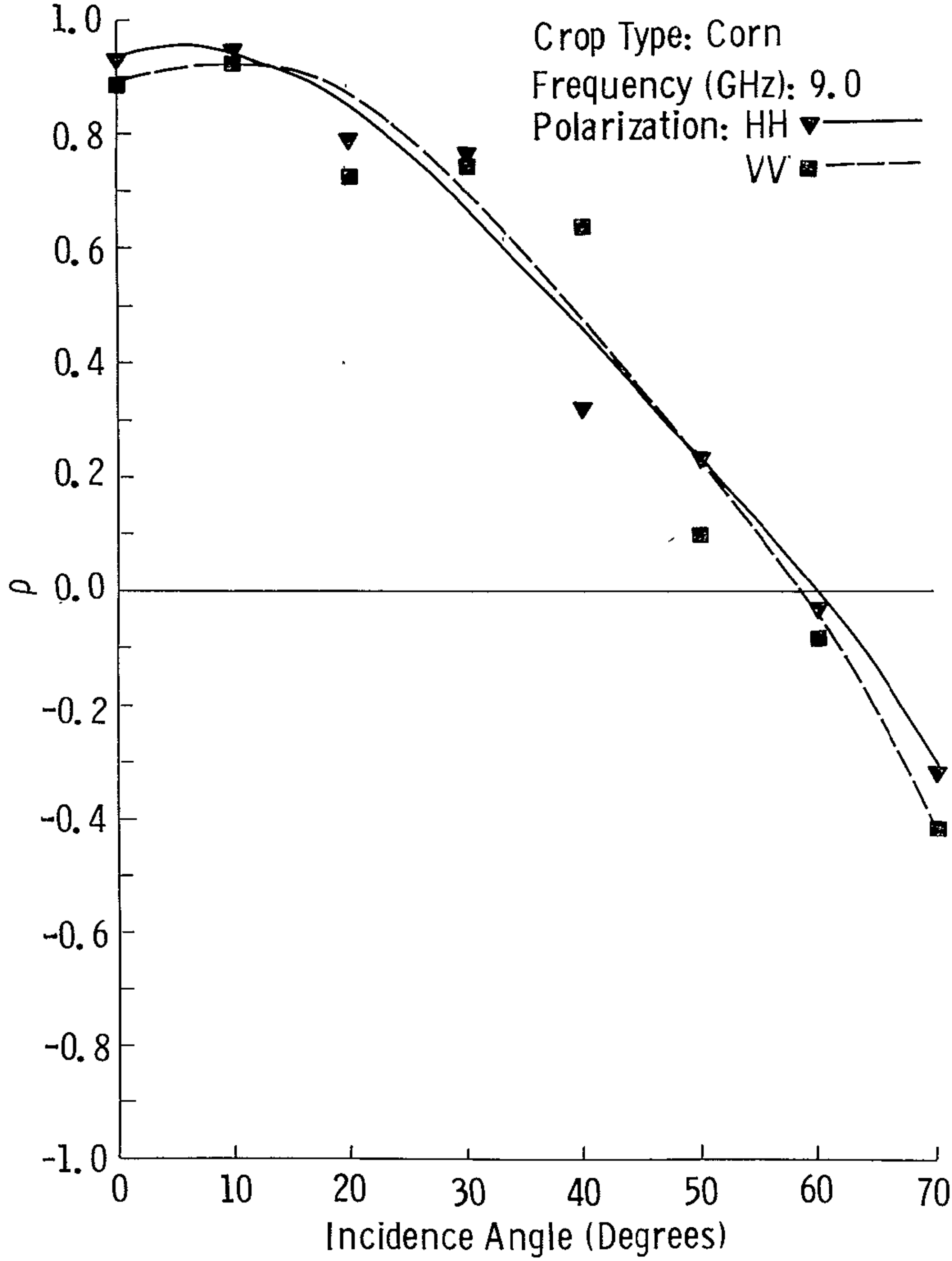


7c. S at 16.6 GHz.

observations. Finally we observe that S takes on negative values at large incidence angles and that the change in sign of S is both incidence angle and frequency dependent. This observed behavior is simply a quantitative expression of the inversion phenomenon noted earlier.

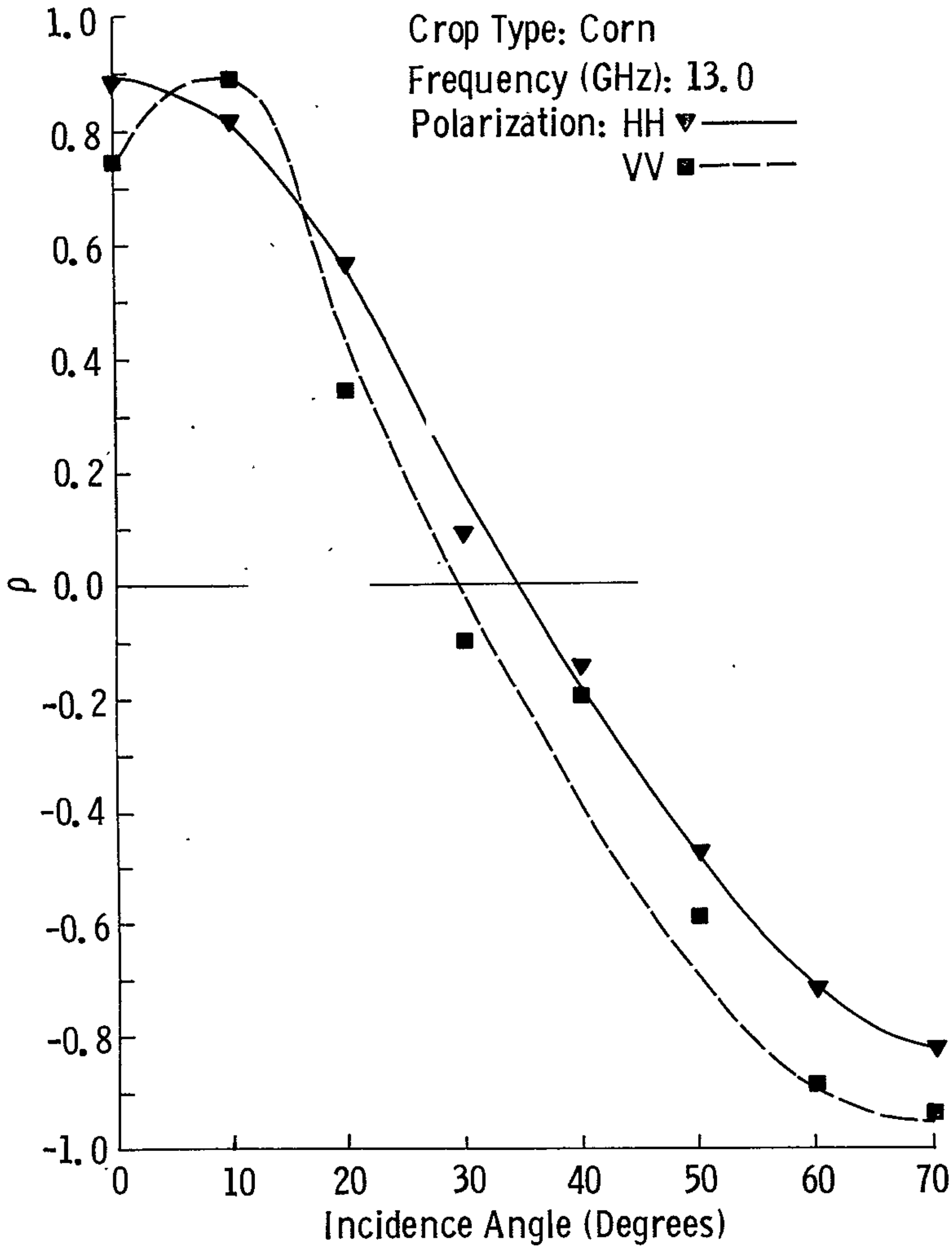
Figure 8a through 8c are now presented to show the correlation coefficients, ρ, as were calculated during the regression analysis. These plots indicate that not only are the values of S high at angles near nadir but that the correlation of σ^o with soil moisture content is extremely high, approaching 0.95 in some cases. Again as frequency and incidence angle are increased we observe a change in sign of the correlation coefficient. The reason for this strong negative correlation of σ^o with soil moisture is not immediately apparent particularly since the inversion occurs at high frequencies and incidence angles where the signal has virtually no chance of penetrating to the soil. Variations of σ^o with plant moisture and of plant moisture with soil moisture were calculated with no definitive correlations observed.

Having determined that the moisture content of the plant (and hence its dielectric properties) is not the parameter responsible for the observed inversion phenomena, we contend that changes in the plant morphology due to rain provides an answer. Our contention is based on the following analysis. Consider the time history curves shown in Figure 9; σ^o of corn at 70^o is plotted as a function of time along with vertical bars indicating the precipitation amount reported during each day over the period July 16 through August 8, 1973. The last rain prior to this period was on July 4, approximately two weeks before the heavy rainfall (11 cm) reported on July 19, 1973. Upon consulting with a plant physiologist [10], it was learned that heavy precipitation can cause the leaves of a plant to bend downward (droop), thereby changing the geometry of the scattering volume. In particular, if we consider each leaf as consisting of one or more major facets and associated with a collection (population) of leaves is a facet-slope distribution function, then the effect of the precipitation can be described as a modifier of the slope distribution function. The rain droplets falling on the leaves tend to reduce the mean square slope of the leaves (facets). By applying Katzin's [11] facet model, an explanation for the inversion phenomena can be found. After the heavy rains of July 19 and 20 (Figure 2a), the soil began to dry. In conjunction with this process the plants started to recover their original geometry so that the slope of the corn leaves (facets) progressively increased towards the distribution they assumed before the rain. Consequently, the radar return increased in the post-precipitation period, in spite of the decreasing soil

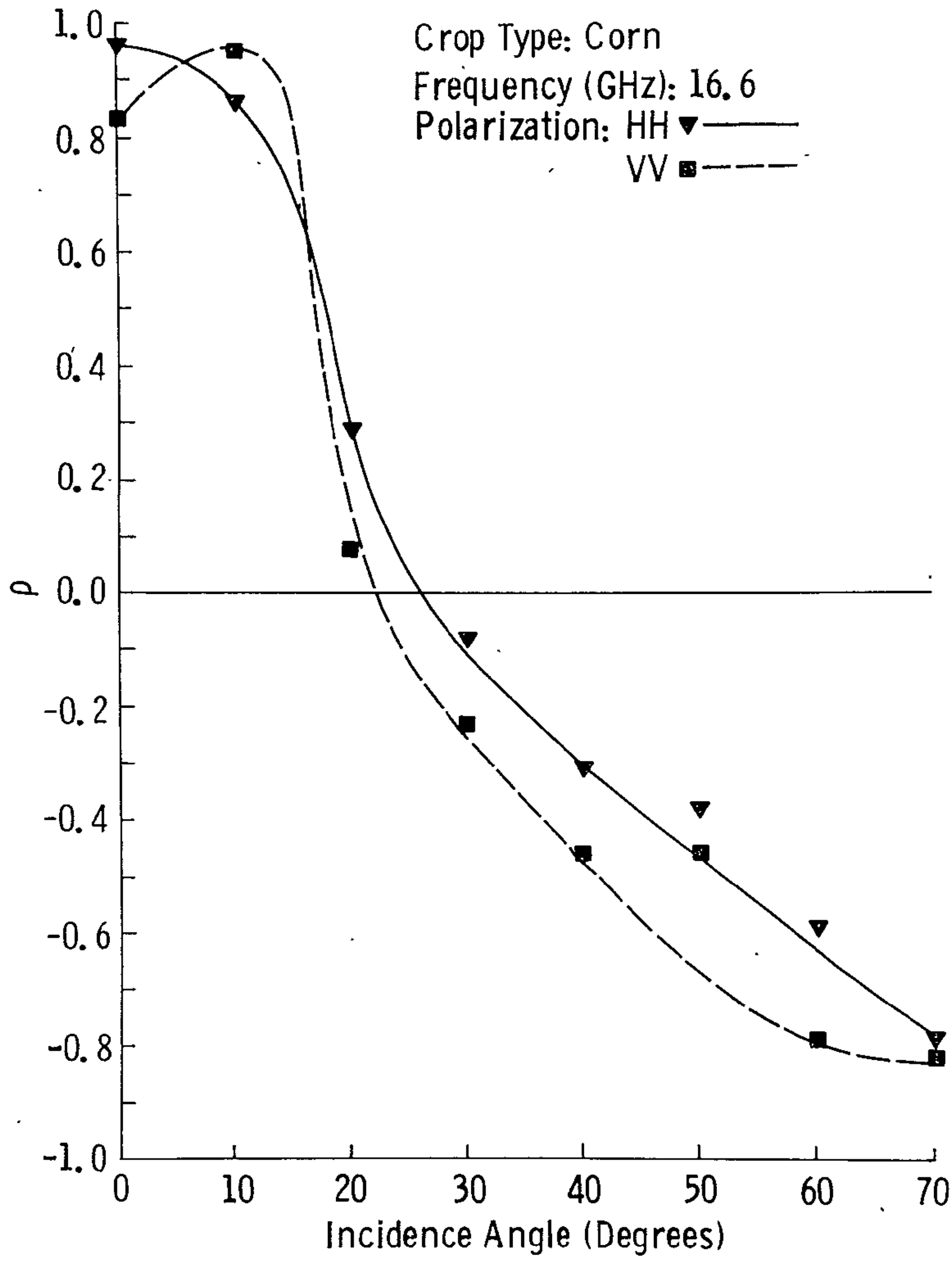


8a. ρ at 9 GHz.

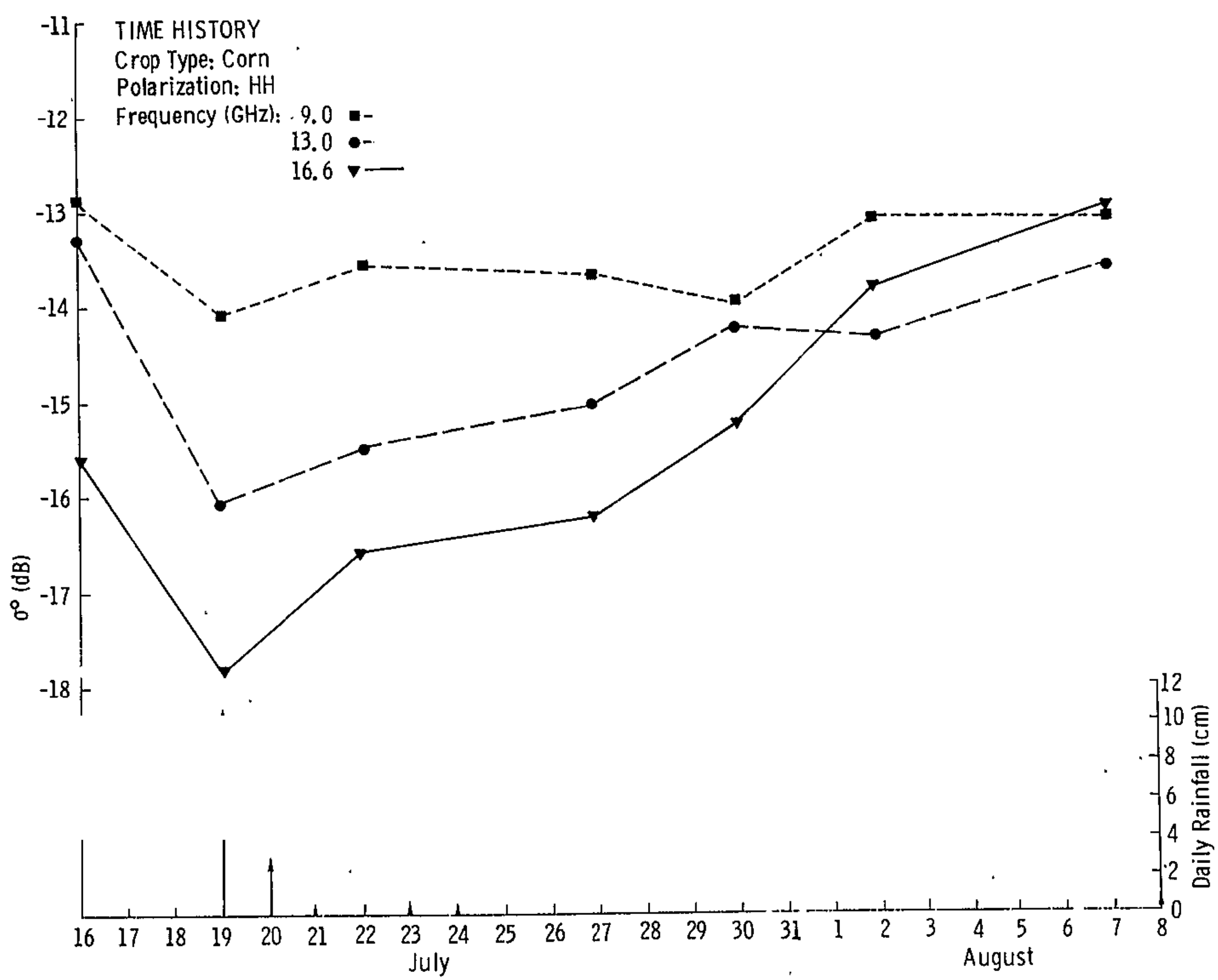
Figure 8. Curves depicting the variation of ρ, the correlation coefficient of σ^o and soil moisture, with incidence angle at (a) 9 GHz, (b) 13 GHz, and (c) 16.6 GHz.


Crop Type: Corn
Frequency (GHz): 13.0
Polarization: HH
VV
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
ρ
0
10
20
30
40
50
60
70
Incidence Angle (Degrees)

8b. ρ at 13 GHz.

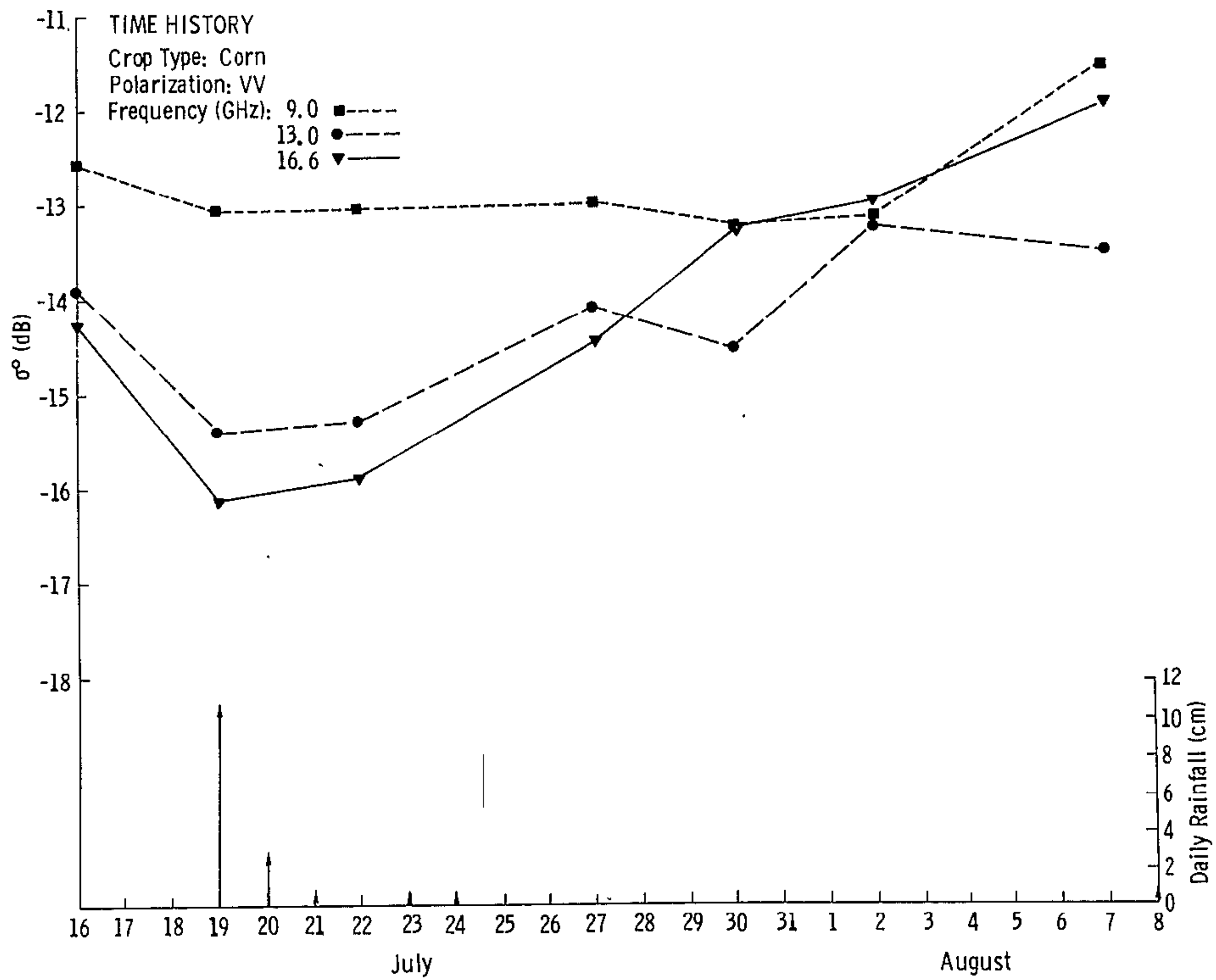


8c. ρ at 16.6 GHz.



9a. HH polarization.

Figure 9. Time history of (a) σ^o_{HH} and (b) σ^o_{VV} of corn at 9, 13, and 16.6 GHz.

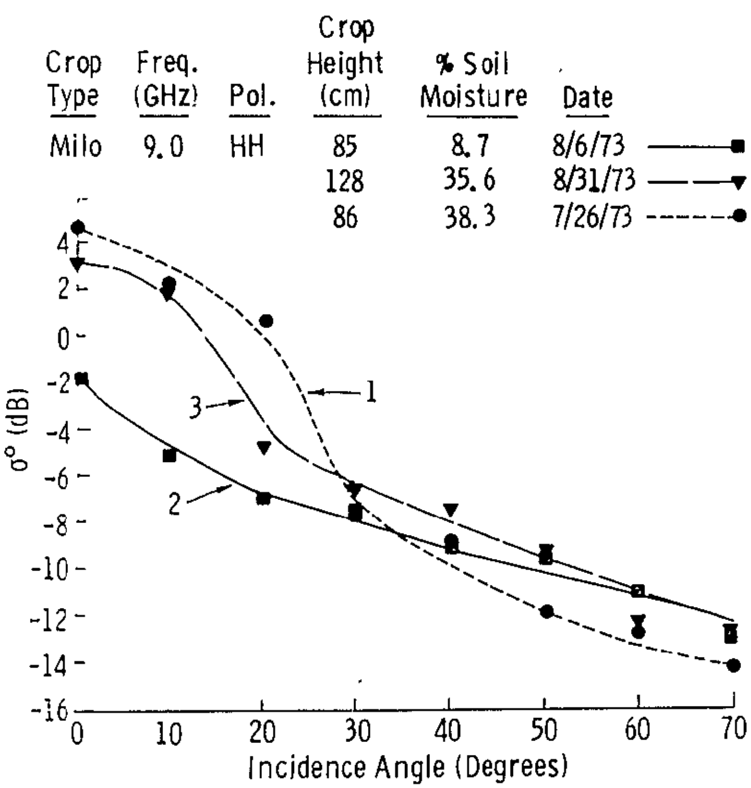


9b. VV polarization.

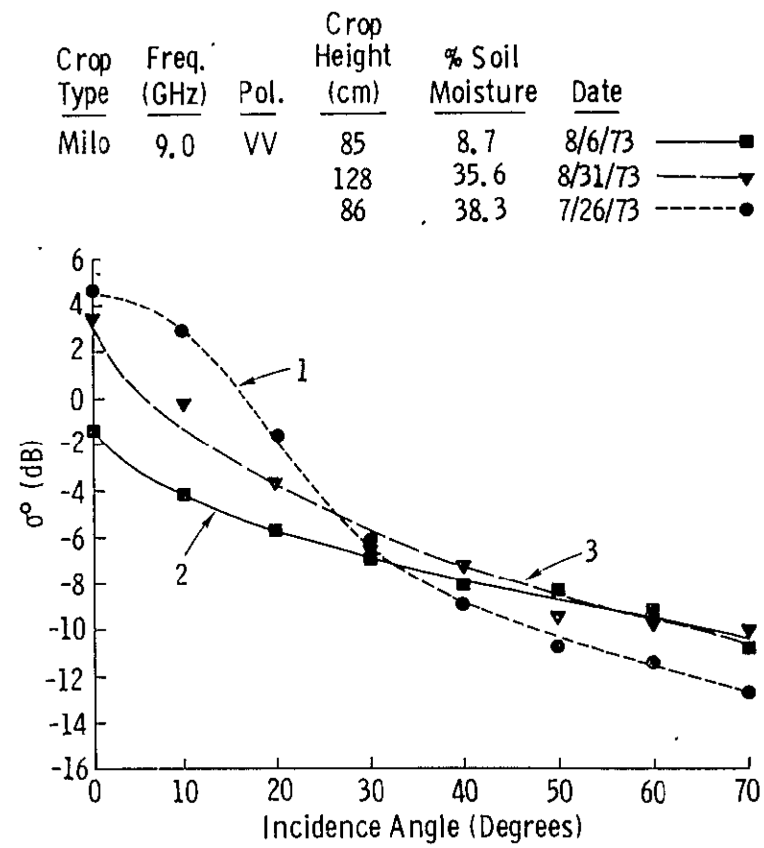
moisture content. Furthermore, it is noteworthy that the return eventually increased to values higher than before the rain of July 19, especially at the high frequency (Figure 9). Ground observations (see Appendix) indicated that neither plant height nor plant moisture content changed substantially between July 22 and August 7. Thus the net increase in radar return between July 16 and August 7 is attributable to changes in the plant, particularly leaf geometry. Such changes have not been studied previously in sufficient detail to permit an accurate explanation here. Data in Figure 9 indicate, however, that the slopes of the various facets probably increased to values greater than those before the heavy rain of July 19. As shown by Katzin [11], the backscattering coefficient increases as the mean square slope of the large facet distribution function increases and varies with wavelength as λ^{-2} to λ^{-6} depending on the size of the facet. Thus, if plotted versus time, one would expect the scattering coefficient to have an increasing trend. Furthermore, the increase would be expected to be much more pronounced at 16.6 GHz than at 9 GHz. That this is indeed the case is shown in Figures 9a and 9b. In these figures corn data recorded between July 16 and August 8 are plotted against time in days. The 70° incidence angle data set was chosen because the inversion phenomena was observed to get more pronounced as θ increased. In terms of the frequency sensitivity to change in the plant morphology, at 9 GHz the change in σ^o between July 19 and August 8 is about 0.3 dB for both HH and VV polarizations whereas the change at 16.6 GHz is 5 dB for HH and 4.2 dB for VV.

3.3.2 Milo

The backscattering behavior of milo appears similar to that of corn. In Figure 10, the angular response of σ^o is plotted for each of three plant-soil conditions. The curves designated "1" and "2" represent approximately the same plant height, but almost extreme (opposite) soil moisture states. The 38.3% moisture content associated with curve 1 was a result of the heavy rain reported during the preceding week (Figure 2b), which, as we observed in the previous section, caused a noticeable change in the morphology of the corn plants. The same phenomenon is observed in Figure 10 for milo. At small angles of incidence (0°–10°), curve 1 (high soil moisture) exceeds σ^o of curve 2 by about 6–8 dB (for the various frequency-polarization combinations shown in Figure 10). The difference is attributed to contributions by the underlying

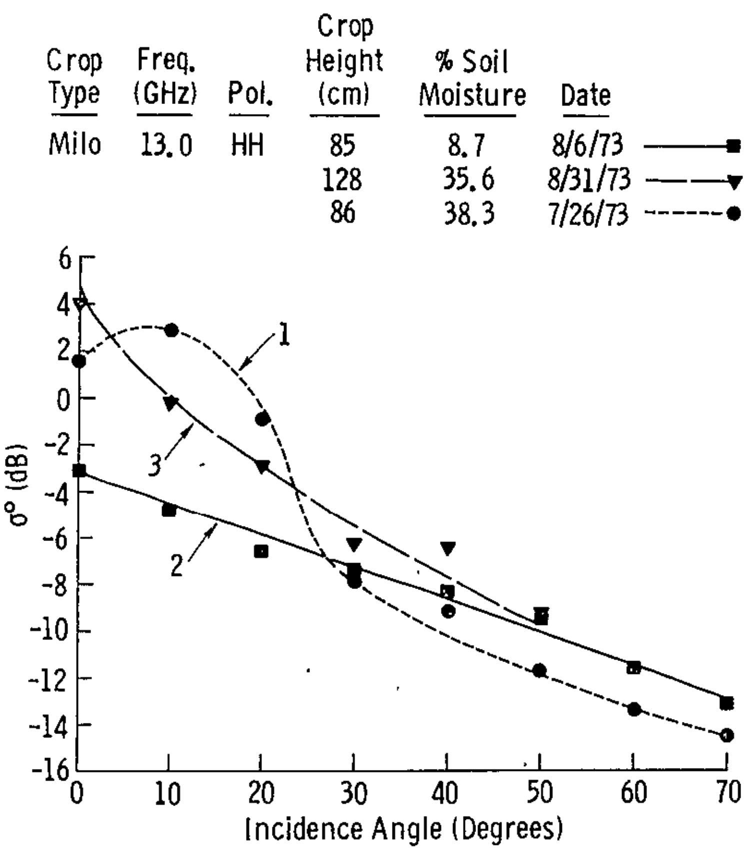


10a. 9 GHz, HH polarization.

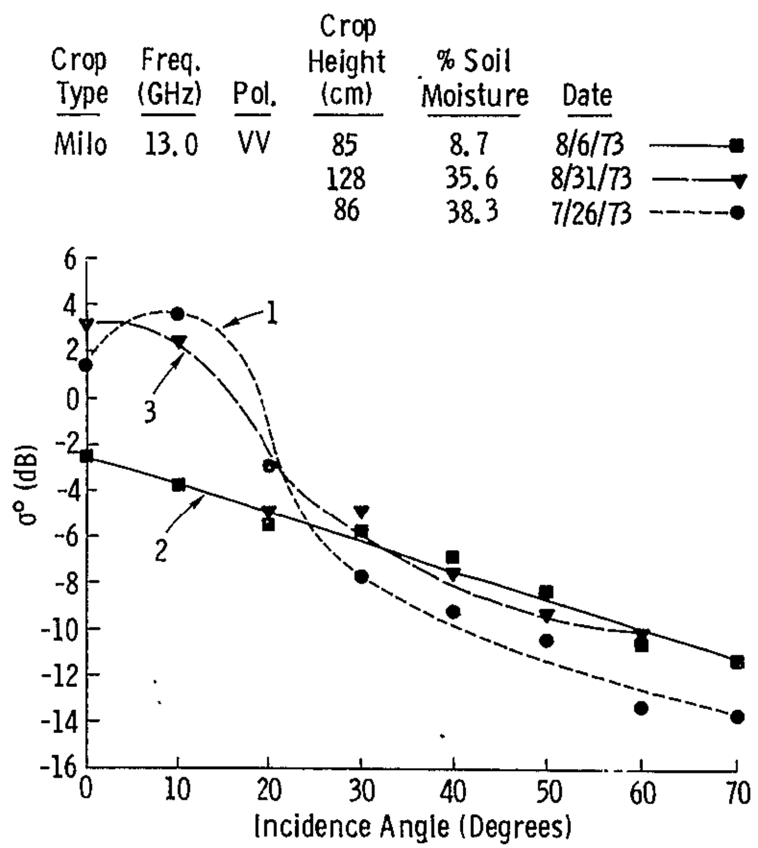


10b. 9 GHz, VV polarization.

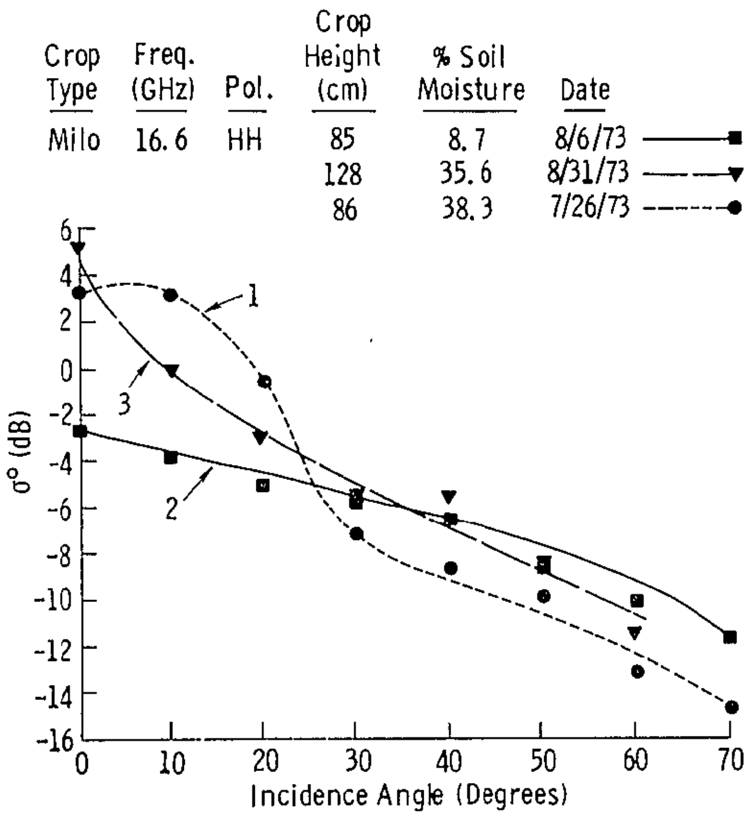
Figure 10. Angular response of σ^o milo for three different soil moisture or plant conditions at 9 GHz (10a and 10b), 13 GHz (10c and 10d) and 16.6 GHz (10e and 10f).



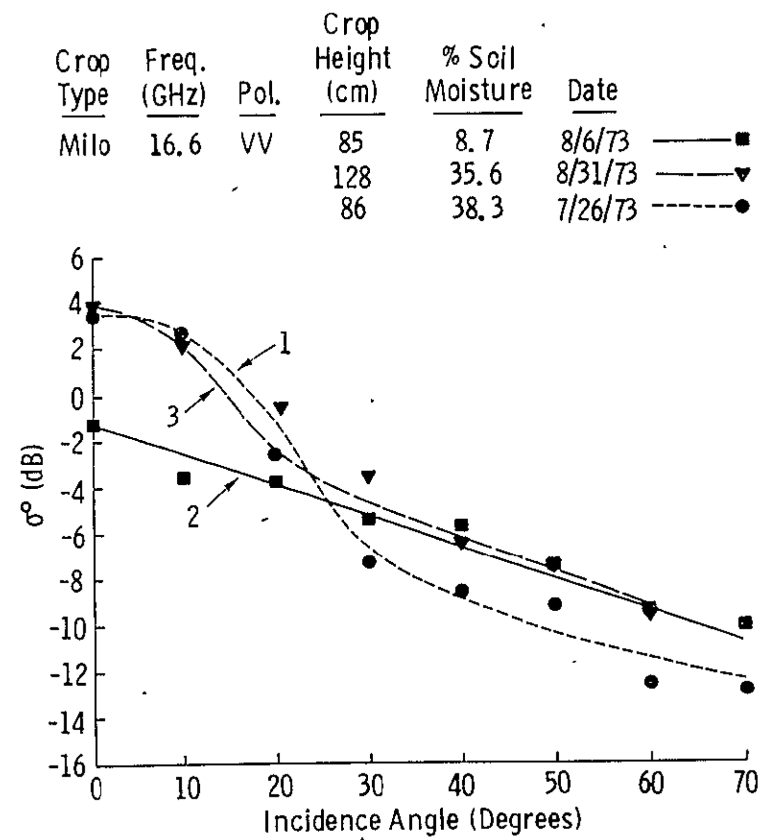
10c. 13 GHz, HH polarization.



10d. 13 GHz, VV polarization.



10e. 16.6 GHz, HH polarization.



16.6 GHz, VV polarization.

soil. This is further supported by the magnitude of σ^o of curve 3 which at 9 GHz (Figure 10a) is slightly lower than σ^o of curve 1 and also slightly lower in soil moisture content. As θ is increased, curves 1 and 2 cross at about 35^o at 9 GHz decreasing to about 25^o at 16.6 GHz. Furthermore, the difference in σ^o increases with θ and frequency. Since the plant heights associated with curves 1 and 2 are about the same, we believe that the heavy rain is responsible for the change in the plant morphology, which in turn is observed as a change in the backscatter response.

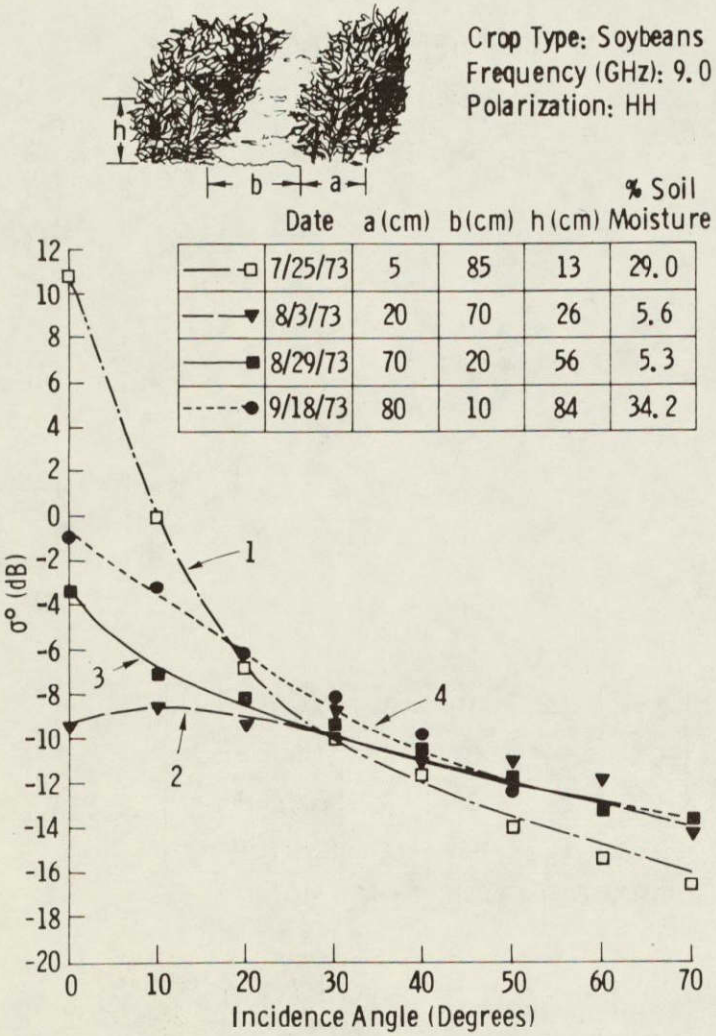
The fact that curves 1 and 2 cross at about 25^o-35^o, indicates that no appreciable penetration has occurred past these angles. Hence the small difference in σ^o between curves 2 and 3, with corresponding plant heights of 85 cm and 128 cm respectively, at angles past 35^o is an indicator of the state of growth of the milo plants.

3.3.3 Soybeans

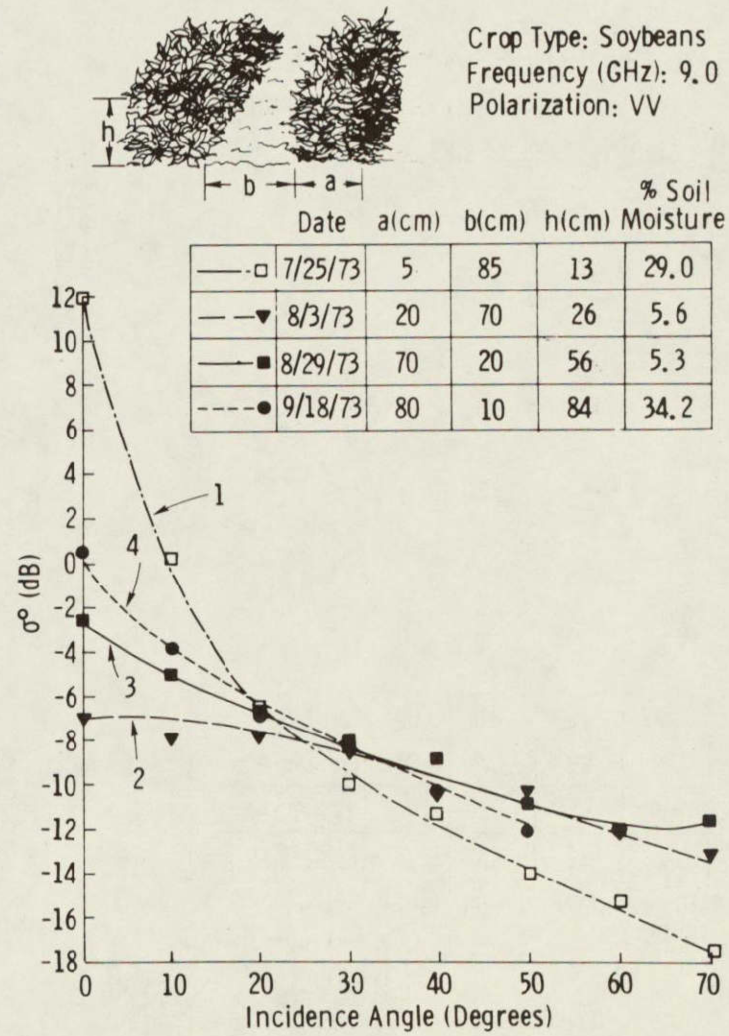
Figures 11a through 11f present the measured angular response of σ^o for soybeans. Each figure contains four curves representing four different growth stages. The soybean field was planted in parallel rows having a period (spacing between the centers of two adjacent rows) of about 90 cm. The radar antennas were pointed in the direction of the rows (parallel). Between the dates of the first data set, July 25, and the last data set, September 18, the soybean plants grew in height from 13 cm to 84 cm. The 90 cm row spacing is divided into two segments, a segment covered by the soybean plants (designated "a"in Figure 11) and a segment "b" for which the soil is bare. Corresponding to the dates noted earlier, the plant-row width "a" increased from 5 cm to 85 cm and the open-row width "b" decreased from 85 cm to 10 cm.

In addition to the geometrical and morphological changes mentioned above, soil moisture should also be considered. For the two extreme growth stages (13 cm and 75 cm heights) the soil moisture was very high whereas for the two intermediate stages the soil moisture was very low.

The objective now is to attempt to separate the influence of soil moisture from the influence of growth stage on the backscattering coefficient σ^o. First let us consider the 13 cm height case (labeled as curve 1 in Figure 11). Since the soybeans covered only about 5.5% of the total area, then for all practical purposes the radar return shown was from the bare soil, particularly at the low angles of incidence. The strong return at nadir is due to the high soil moisture content of 29%. Note that as

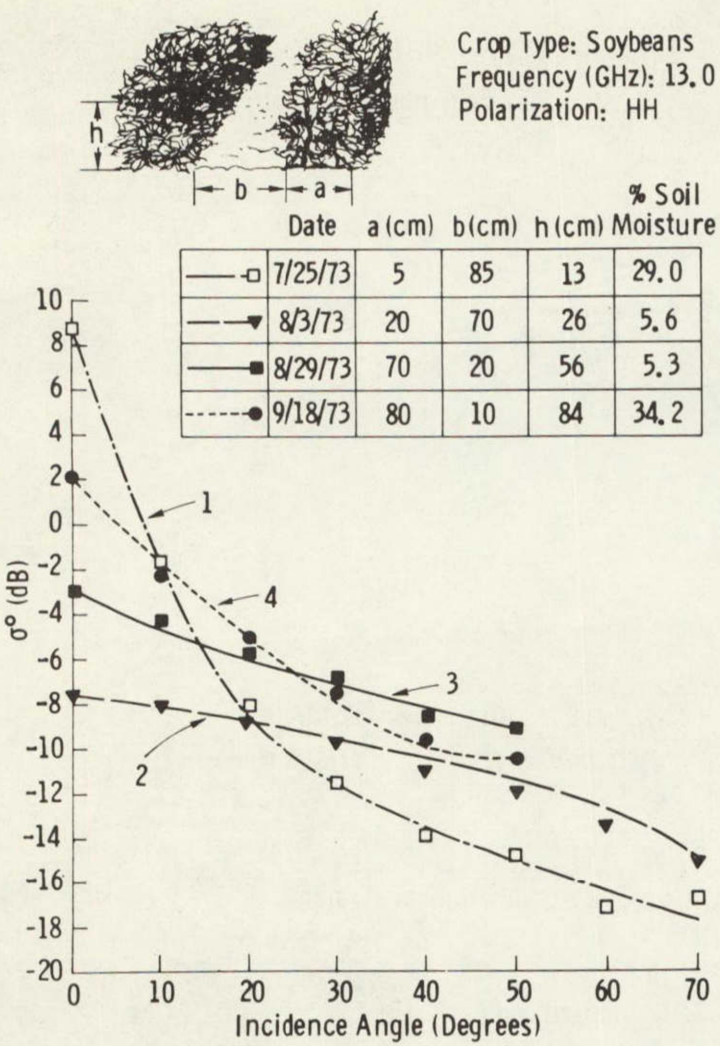


11a. 9 GHz, HH polarization.



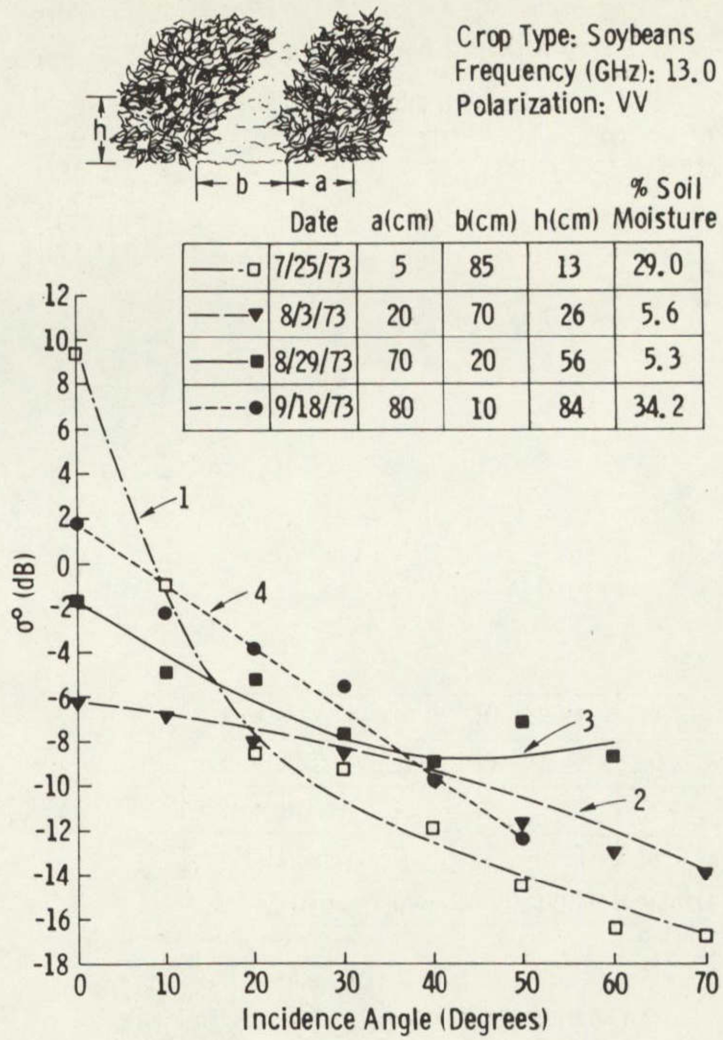
11 b. 9 GHz, VV polarization.

Figure 11. Angular response of σ^{o} of soybeans for various soil moisture contents and growth stages at 9 GHz (11a and 11b), 13 GHz (11c and 11d), and 16.6 GHz (11e and 11f).



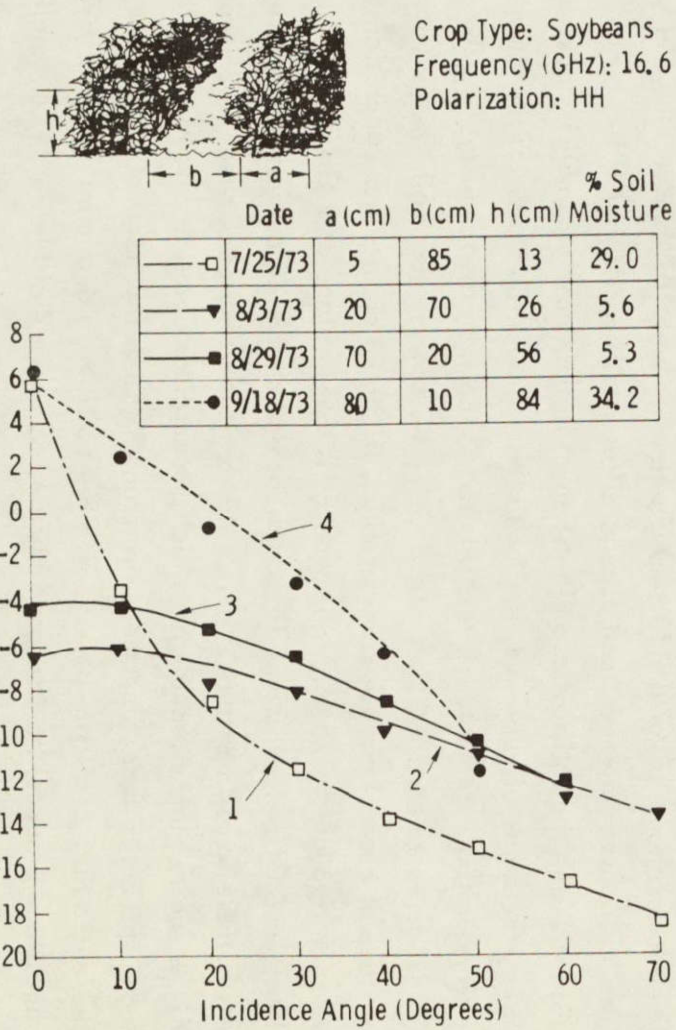
	Date	a (cm)	b (cm)	h (cm)	% Soil Moisture
—·□	7/25/73	5	85	13	29.0
— —▼	8/3/73	20	70	26	5.6
——■	8/29/73	70	20	56	5.3
- - - -●	9/18/73	80	10	84	34.2

11c. 13 GHz, HH polarization.



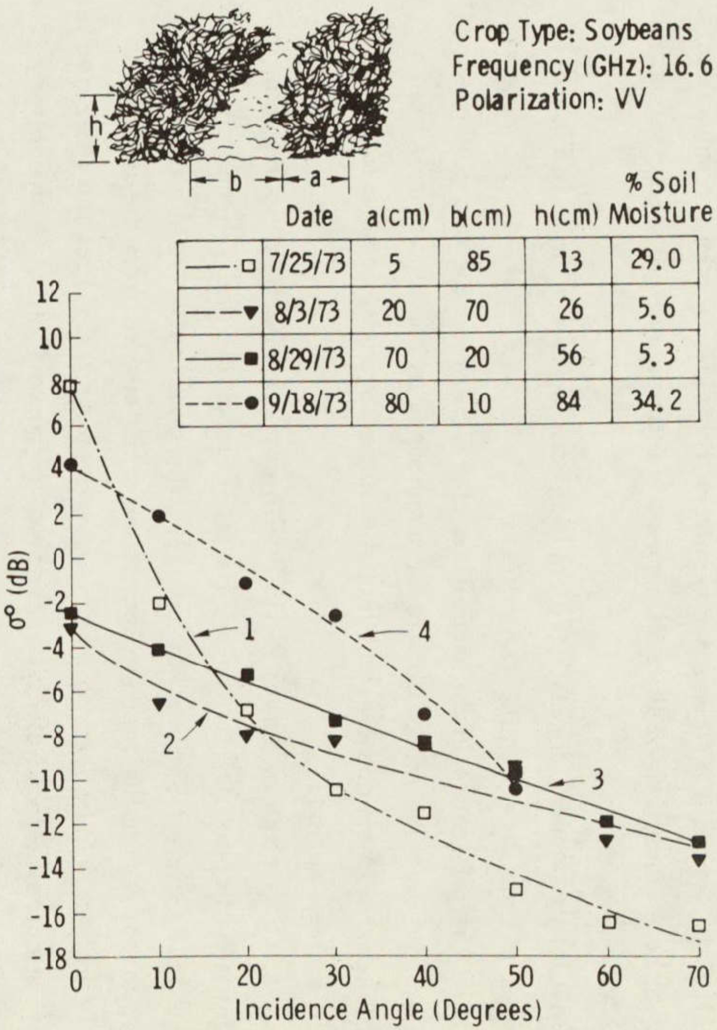
	Date	a(cm)	b(cm)	h(cm)	% Soil Moisture
—·□	7/25/73	5	85	13	29.0
— —▼	8/3/73	20	70	26	5.6
——■	8/29/73	70	20	56	5.3
- - - -●	9/18/73	80	10	84	34.2

11d. 13 GHz, VV polarization.



	Date	a (cm)	b (cm)	h (cm)	% Soil Moisture
□	7/25/73	5	85	13	29.0
▼	8/3/73	20	70	26	5.6
■	8/29/73	70	20	56	5.3
●	9/18/73	80	10	84	34.2

11e. 16.6 GHz, HH polarization.



	Date	a (cm)	b (cm)	h (cm)	% Soil Moisture
□	7/25/73	5	85	13	29.0
▼	8/3/73	20	70	26	5.6
■	8/29/73	70	20	56	5.3
●	9/18/73	80	10	84	34.2

11f. 16.6 GHz, VV polarization.

3.3.4 Alfalfa

Figure 12 presents the scattering response of alfalfa for two extreme growth stages, mature 50 cm tall alfalfa and 5 cm tall "cut" alfalfa. As was mentioned earlier in section 3.1, the soil surface of the cut alfalfa field was very smooth, which explains the large magnitude of σ^o at normal incidence and the sharp decay with incidence angle close to nadir. The decay rate is smaller for VV than for HH polarization, and in both cases the decay rate decreases with frequency.

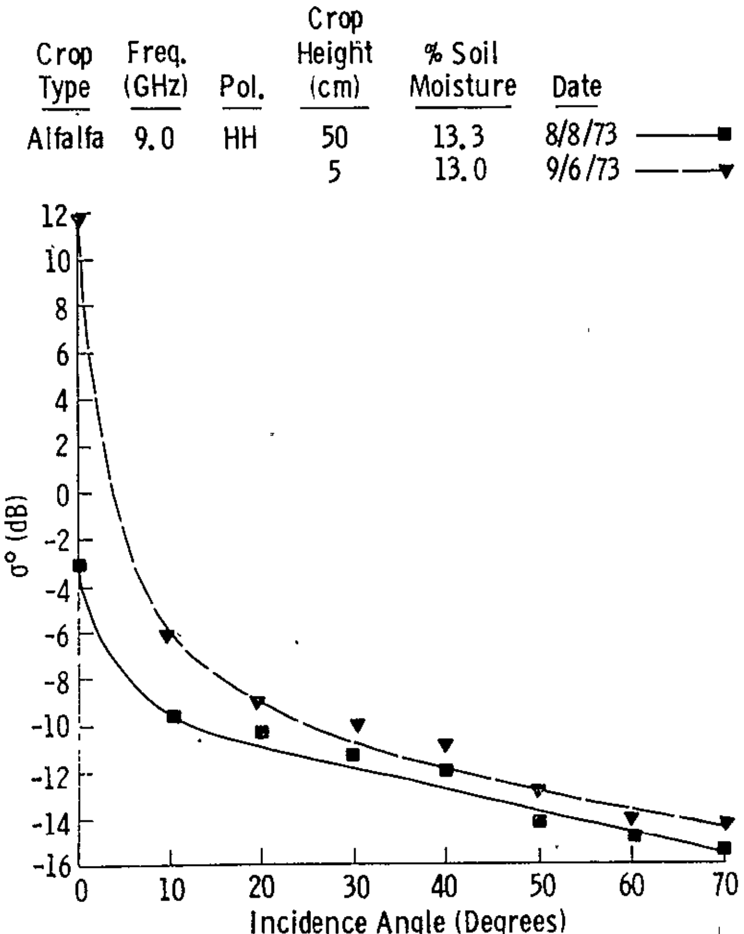
Based on previous 4-8 GHz measurements of σ^o of mature alfalfa under varying conditions of soil moisture [1], it was proposed that alfalfa appears electromagnetically as a relatively smooth surface. This description was supported by the observation that at normal incidence σ^o of mature alfalfa exhibited no positive response to soil moisture increase and by the relatively sharp angular decay of σ^o close to normal. Hence, we propose that the angular response curves of the 50 cm tall alfalfa (Figure 12) are primarily due to contributions from the alfalfa itself, with insignificant contribution from the underlying soil. As the frequency is increased from 9 GHz to 16.6 GHz, the alfalfa appears increasingly rougher, thereby producing a gentler slope close to normal incidence.

3.4 Crop Discrimination Using Frequency Agility and Dual Polarization Capabilities

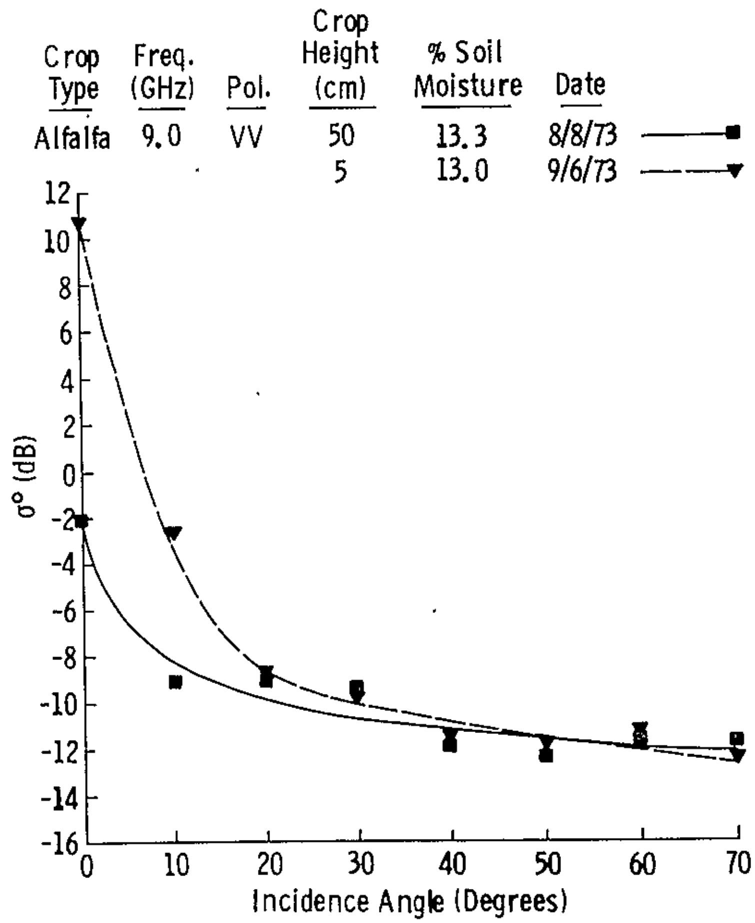
As seen earlier in this report, radar backscatter from vegetation is a function of a variety of variables such as crop type, stage of growth, soil moisture and others. Thus it would be quite naive to assume that a single frequency, singly polarized system would provide optimum results in terms of crop discrimination capabilties.

Figures 13a through 13f indicate this point. For all the data shown, an attempt was made to depict relatively mature crops with low soil moisture contents so as to reduce the effects of this added variable. As we have seen, however, even low soil moisture content affects backscatter near nadir so that discriminations should probably be made at incidence angles away from nadir. Obviously these four crop types under discussion are not the only vegetation types of interest but they will serve to make certain observations.

If only one frequency and polarization were available it seems as if 13.0 GHz and vertical polarization would provide a good deal of information as shown in Figure 13d. At angles larger than 30° the dynamic range of these targets is approximately

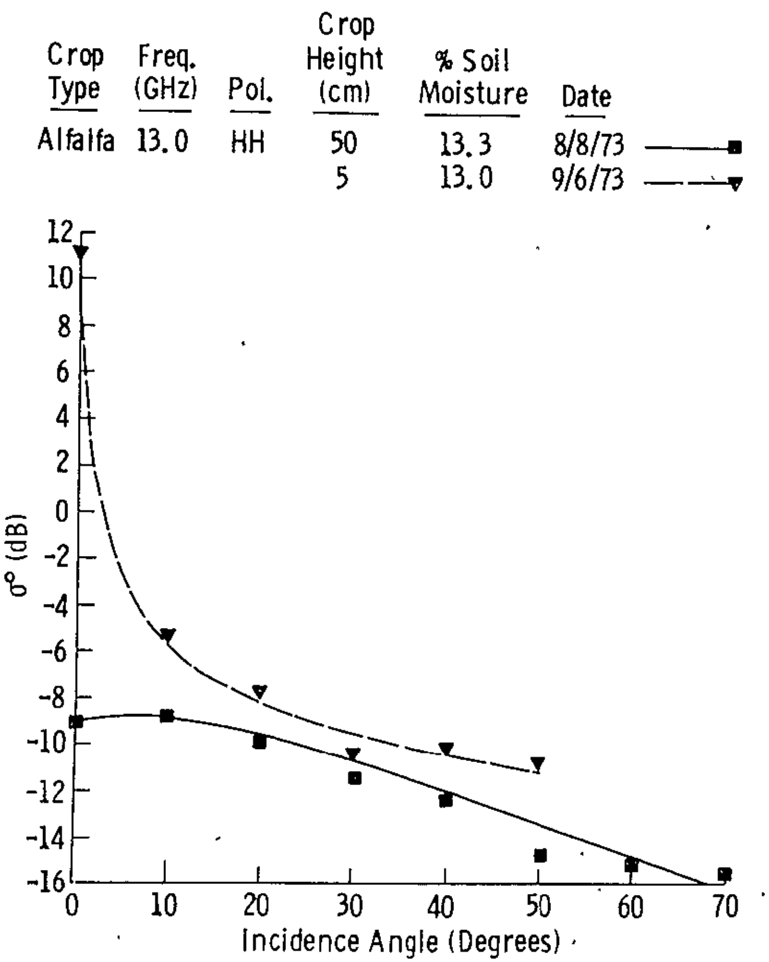


12a. 9 GHz, HH polarization.

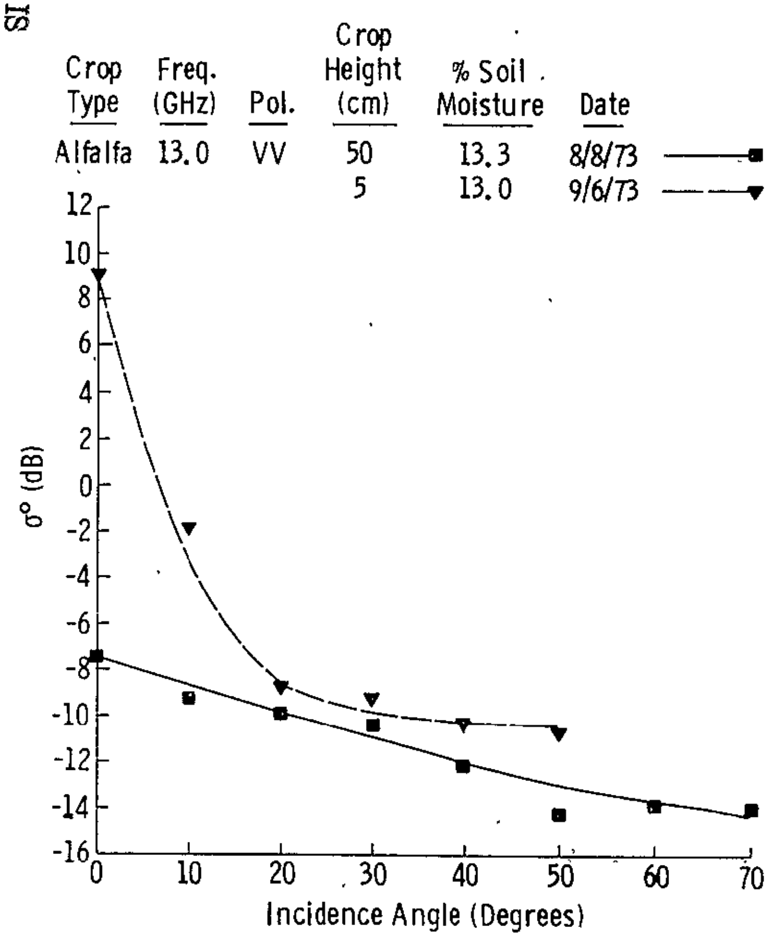


12b. 9 GHz, VV polarization.

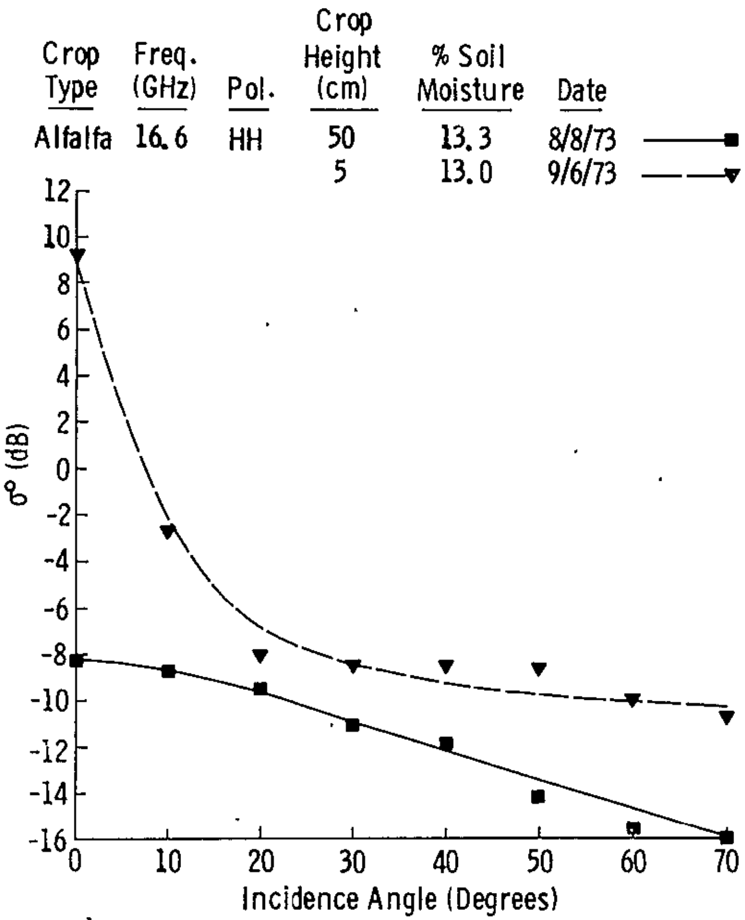
Figure 12. Angular response of σ^o of mature and cut alfalfa at 9 GHz (12a and 12b), 13 GHz (12c and 12d), and 16.6 GHz (12e and 12f).



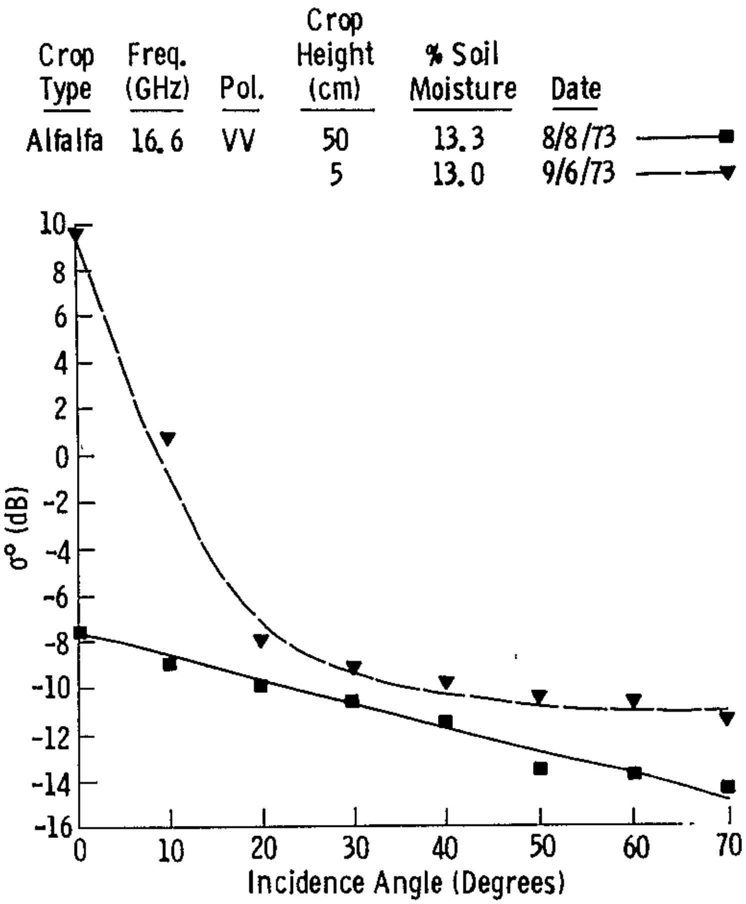
12c. 13 GHz, HH polarization.



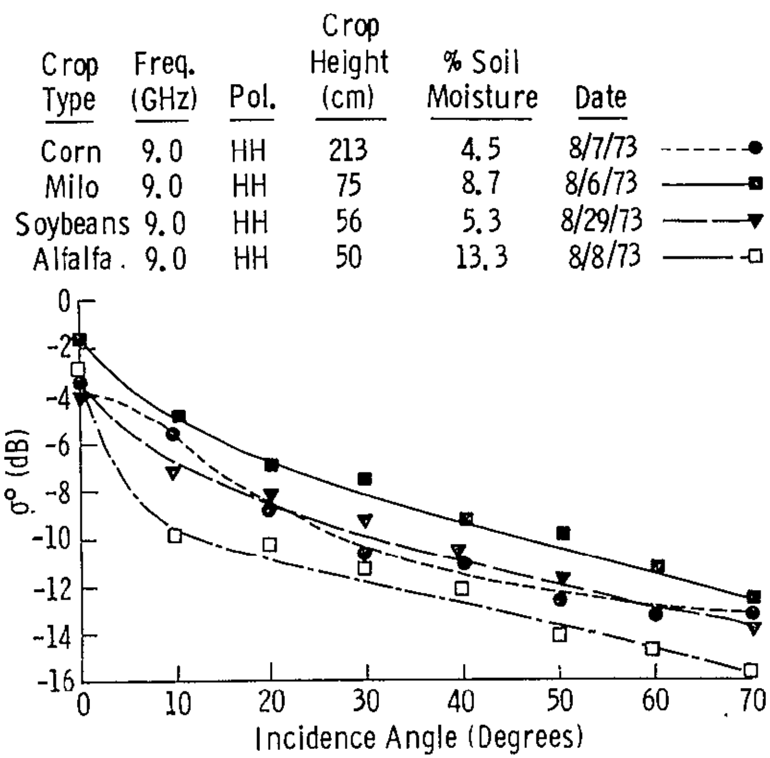
12d. 13 GHz, VV polarization.



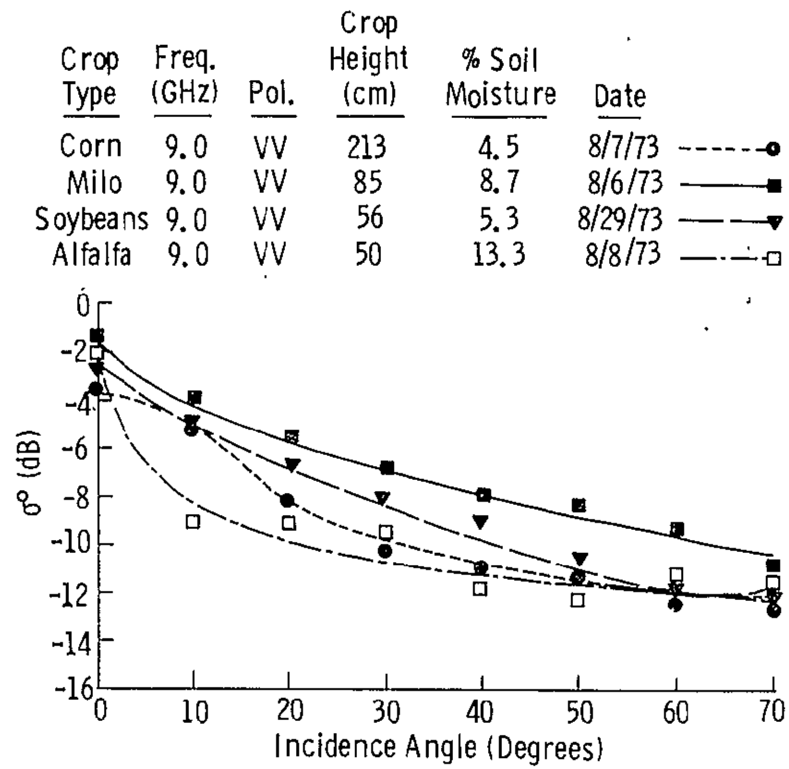
12e. 16.6 GHz, HH polarization.



12f. 16.6 GHz, VV polarization.



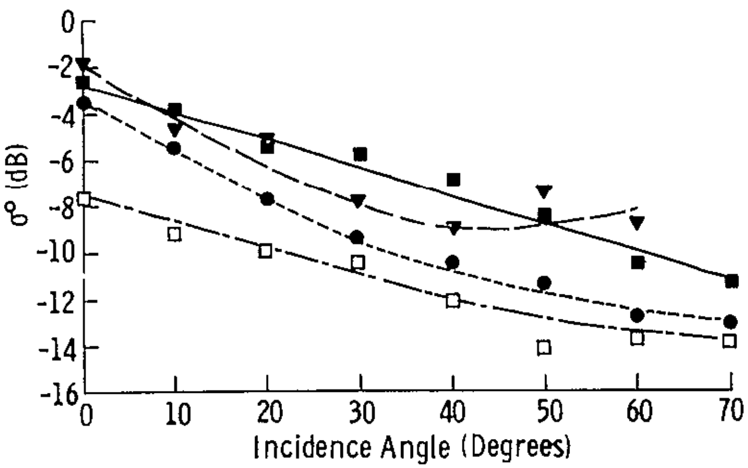
13a. 9 GHz, HH polarization.



13b. 9 GHz, VV polarization.

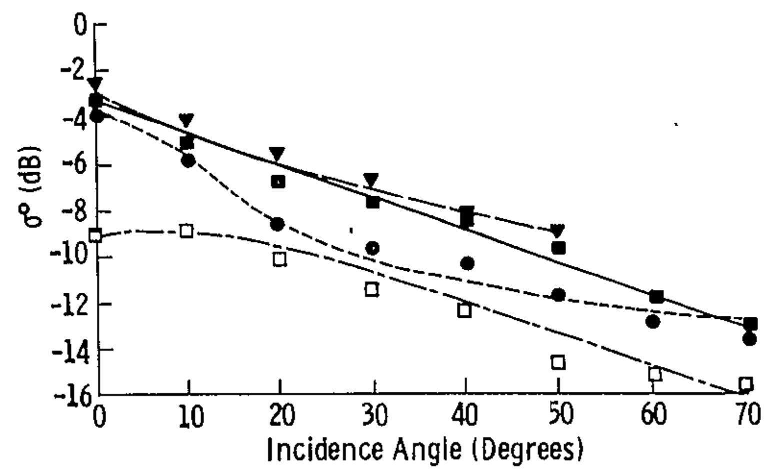
Figure 13. Angular variations of σ^o for all four crops at 9 GHz (13a and 13b), 13 GHz (13c and 13d), and 16.6 GHz (13e and 13f). Note that an attempt was made to depict relatively mature with low soil moisture contents.

Crop Type	Freq. (GHz)	Pol.	Crop Height (cm)	% Soil Moisture	Date
Corn	13.0	VV	213	4.5	8/7/73
Milo	13.0	VV	75	8.7	8/6/73
Soybeans	13.0	VV	56	5.3	8/29/73
Alfalfa	13.0	VV	50	13.3	8/8/73

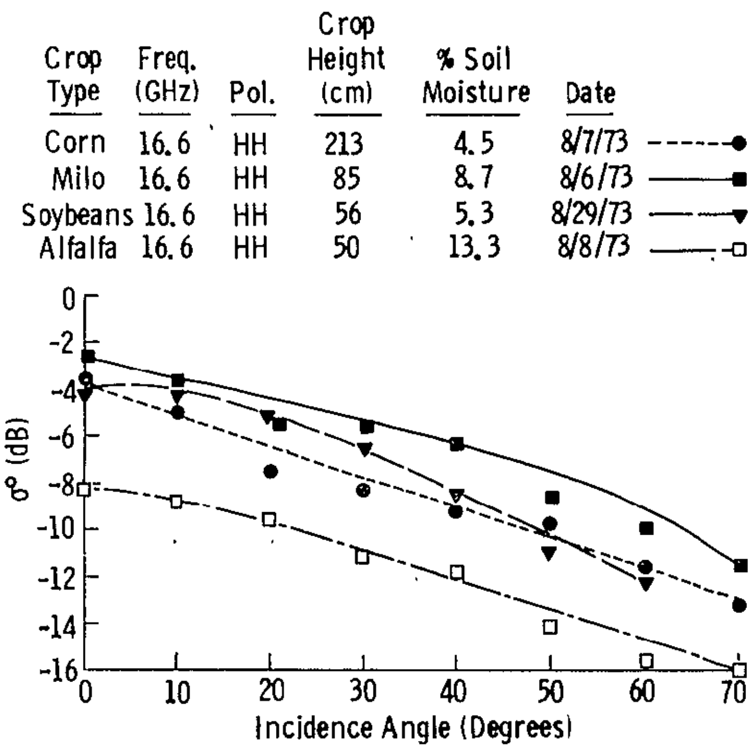


13c. 13 GHz, HH polarization.

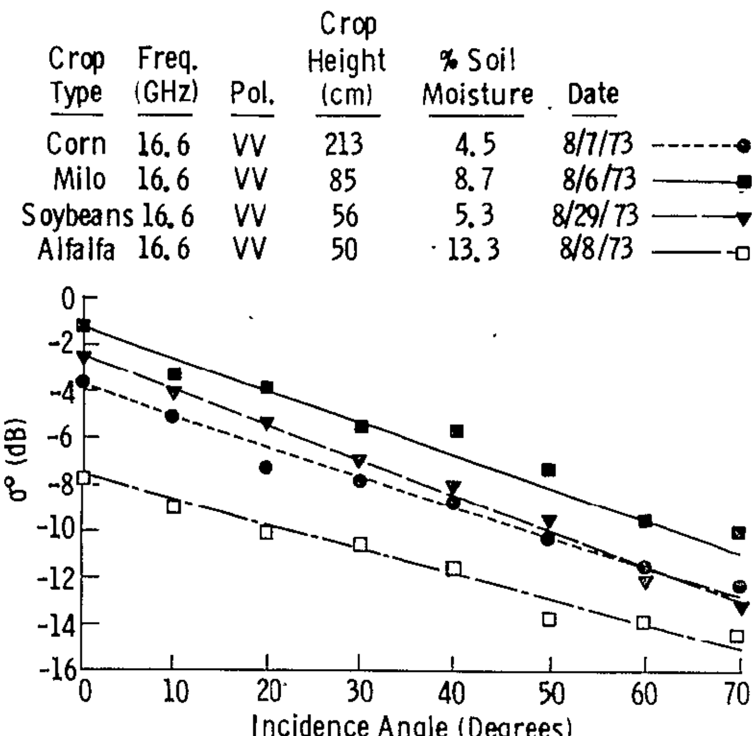
Crop Type	Freq. (GHz)	Pol.	Crop Height (cm)	% Soil Moisture	Date
Corn	13.0	HH	213	4.5	8/7/73
Milo	13.0	HH	85	8.7	8/6/73
Soybeans	13.0	HH	56	5.3	8/29/73
Alfalfa	13.0	HH	50	13.3	8/8/73



13d. 13 GHz, VV polarization.



13e. 16.6 GHz, HH polarization.



13f. 16.6 GHz, VV polarization.

5.0 dB. Milo and soybeans may be difficult to separate however with only about 1.0 dB difference in σ^o. Difficulties might also occur in the separation of corn and alfalfa.

A choice of two frequencies seems to make separation somewhat easier. At 9.0 GHz, with vertical polarization milo and soybeans are separated by about 2.0 dB at angles between 30° and 65° although corn and alfalfa are indistinguishable beyond 50°. Making use of the 16.6 GHz vertically polarized data, corn and alfalfa separate by 3.0 dB. Thus although the use of these two frequencies does not increase the effective dynamic range of σ^o for these targets it does help in separating targets in a pairwise fashion within the 30°-65° range. These are similar to the observations of Shuchman and Drake [12] who studied the feasibility of using multiplexed SLAR imagery for mapping vegetation communities. They noted that "significantly more information for mapping vegetation communities and for water resource management was obtained from the multiplexed X- and L-band SLAR imagery than could have been obtained from the imagery of either wavelength alone."

4.0 CONCLUDING REMARKS

The results of the experiment reported have lead to a number of observations.

a) Although soil moisture can be sensed through vegetation the sensitivity of radar backscatter to soil moisture is quite dependent on vegetation characteristics and sensor parameters.

b) Spectral response curves indicate that lower frequencies provide more information on soil moisture content due to their inherently better penetrating ability. Angles near nadir are a necessity to accurately estimate soil moisture.

c) Temporal plant morphology variations play a large part in determining the response of radar to vegetation and needs to be emphasized in further studies, particularly if radar is to be used in the estimation of crop growth stage.

d) Crop discrimination is best accomplished with multifrequency vertically polarized data. To reduce the effect of the added variable of soil moisture in making discriminations,an incidence angle range between 30° and 65° seems to provide adequate results.

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[4] Ulaby, F. T., "Radar Measurement of Soil Moisture Content," IEEE Transactions on Antennas and Propagation, vol. AP-22, no. 2, pp. 257-265, March, 1974.

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[9] Cosgriff, R. L., W. H. Peake and R. C. Taylor, "Terrain Scattering Properties for Sensor System Design," Terrain Handbook II, Antenna Lab, Engineering Experiment Station, Ohio State University, 1959.

[10] Kanemasu, E., Evapotranspiration Laboratory, Kansas State University, Manhattan, Kansas, Private Communication.

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[12] Schuchman, R. A. and B. Drake, "Feasiblity of Using Multiplex SLAR Imagery for Water Resource Management and Mapping Vegetation Communities," Proc. 9th International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, April, 1974.

APPENDIX A

Ground Data Acquisition for 1973 Microwave (MAPS) Measurements: Results

Josef Cihlar

INTRODUCTION

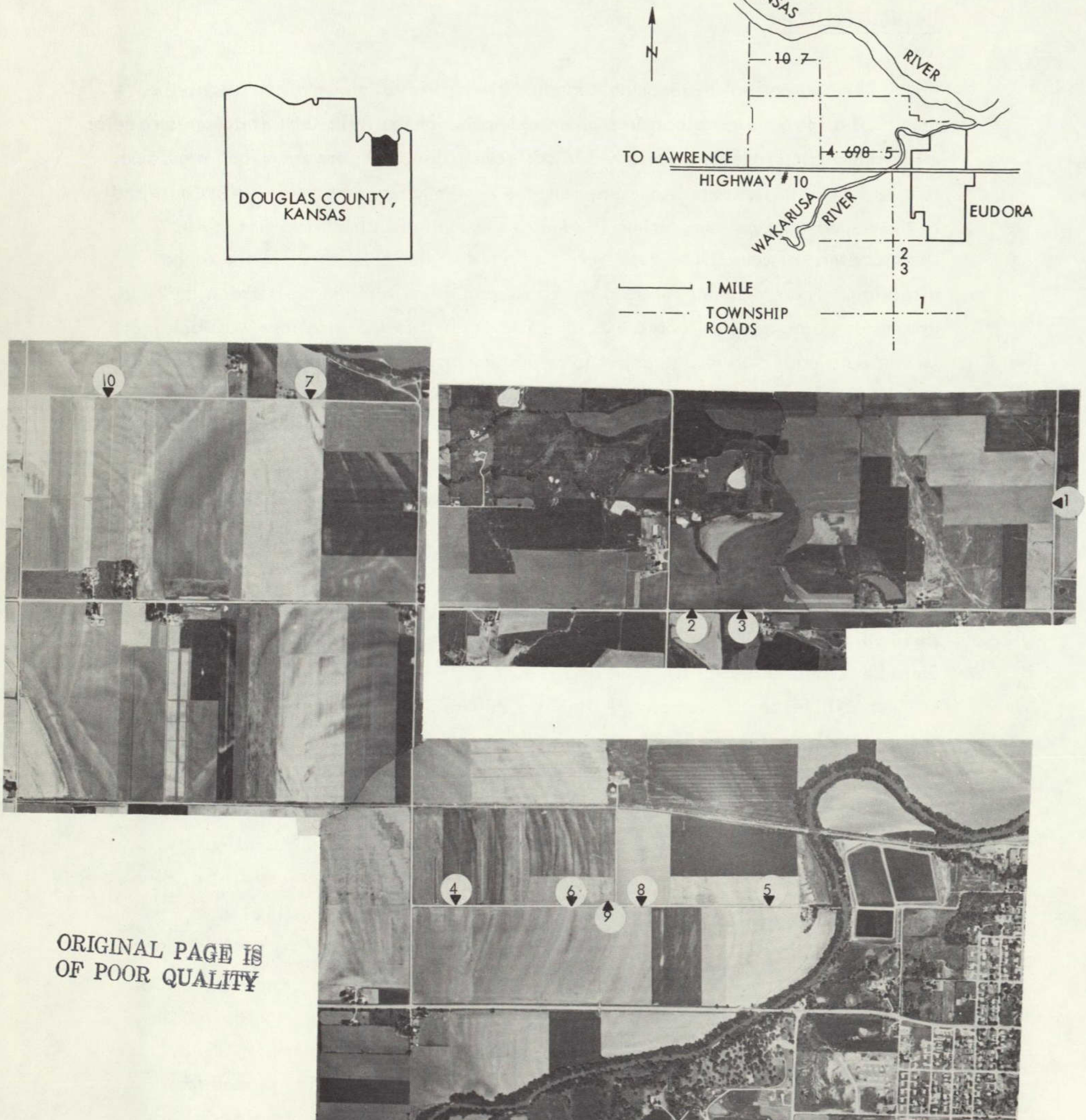
The purpose of this memorandum is to summarize, in one publication, the results of all ground measurements taken in support of the 8-18 GHz radar spectrometer measurements. Procedures followed in collecting the data were described previously (Cihlar, 1973). The extent of measurements was in some cases smaller than outlined in the above memorandum, primarily due to the lack of either facilities (ovens, thermometers) or time. The data were collected at three distances in the range direction. These distances were 3 m, 20 m, and 43 m from the position on the ground at which the look angle was 0°. The spacing of the locations was such that (i) the data collected at 3 m apply to measurements at 0°, 10°, and 20° look angle; (ii) data collected at 20 m corresponded to 30°, 40°, and 50° look angle measurements; (iii) and measurements at 60° and 70° may be related to samples from 43 m (Cihlar, 1973). These different positions are indicated in Table A-2 and A-3 in the column "Range".

Ground truth sampling was most often made at approximately the same time as the radar measurements. In addition, samples were collected after appreciable rainfalls in order to provide basis for moisture extrapolations in time and for other purposes concerned with data analysis. These two types of ground data can be distinguished since in the latter case, no identifying numbers are present in the column Data Set (Table A-2, A-3).

With respect to accuracy, the data fall into three categories. First, values actually measured in the field or in the laboratory are indicated by a number or a letter. Second, estimated values are marked by a star (*). In these cases, measurements either were not taken or samples were lost during processing. Since some ground data are indispensable for radar return analysis, estimates were made using all available information (rainfall, temporal changes of moisture, etc.). Third, blank spaces indicate that measurements were not taken and were not estimated.

The bulk of the results is included in two tables: Table A-2 contains data about soils and Table A-3 data about the plants. The tables are organized so as to facilitate cross referencing. Table A-4 contains climatological records from the University of Kansas Weather Station for July, August, and September, 1973. Orientation maps for the location of the study area in Douglas County and for the location of individual fields in the area, and aerial photographs of the fields (with the spectrometer's positions indicated by a triangle) taken in July, 1972, are shown in Figure A-1.

Figure A-1. Location of Measurements Sites.



SOILS DATA

The following explanations are provided to permit a full utilization of the information contained in Table A-2.

a) Soil water content is measured on a weight basis (MCW, in %) as well as on a volume basis (MCV, in grams per cm^3). The values of MCW were calculated from (1):

$$MCW = \frac{W_N - D_N}{D_N} \times 100 , \qquad (1)$$

where W_N = net weight of the sample in grams;

D_N = dry weight of the sample in grams.

MCV values were calculated using bulk densities of the soil (BD, in grams per cm^3) and MCW values:

$$MCV = BD \times MCW/100 \qquad (2)$$

Bulk density values (Table A-1) were obtained by repeated sampling of individual fields. Since fields 01, 02, and 03 were measured only once by the radar spectrometer, bulk densities were not determined and therefore MCV values are not given in Table for these fields.

b) The first two columns under the heading "Moisture at Depth" (Table A-2) contain a qualitative, subjective estimate of the moisture state of the surface soil. These estimates were made to provide a measure of the perceived vs. actual moisture contents at every field. The letters d, m, w represent dry, moist, or wet soil at the depth of 0 cm or 0 to 2 cm, respectively.

c) Surface roughness type is a qualitative, subjective description of the nature of the soil surface. The meaning of symbols employed is as follows:

1) Smooth surface.
2) Smooth surface with clods; numbers following this symbol indicate the approximate size (length x width) of an "average" clod in cm.
3) Surface consists of clods only.
4) Cracks are present; the number following this symbol represents the width of an "average" crack in cm.

d) Surface roughness profile is intended to give some idea of the microtopography of row crops. The first (second) number refers to the width (depth) of the recognizable part of the row depression. The upward pointing arrow specifies the location from which soil samples were taken.

PLANTS DATA

The following comments are appropriate regarding the data about plants.

a) Height was calculated as an average of three individual measurements.

b) Density was obtained from the number of plants in a row section 20 feet long.

c) The degree of maturity is described by the following symbols:

I) Vegetative stage
II) Taselling stage
III) Flowering stage
IV) Fruit set stage
V) Early ripening stage
VI) Late ripening stage

d) The presence of diseases was estimated visually. Symbol 0 indicates absence of diseases.

e) Abundance of weeds was described by the following symbols:

n	None
s	Some
c	Common
m	Many

f) Plant sections are abbreviated as follows:

B	Bottom (lower) section
C	Cob
L	Leaves
S	Stem
T	Tassel
Top	Upper part (30 cm long) of a plant.
wp	Whole Plant

g) Net weights are given in two ways. A value designated with a cross (+) applies to the total biomass per 0.0929 m^2 (1 ft^2). The remaining values not so designated refer to individual plants.

REFERENCES

Cihlar, J., "Ground Data Acquisition Procedure for Microwave (MAPS) Measurements," CRES Technical Memorandum 177-42, July, 1973.

TABLE A-1.

SOIL PHASES AND SLOPES

Field Number	Soil Phase	Slope (%)
01	Pawnee Clay Loam	3÷7
02	Sharpsburg Silt Loam	3÷4
03	Woodson Silt Loam	1÷3
04	Eudora—Kimo Complex	0÷1
05	Eudora Silt Loam	0
06	Kimo Silty Clay	0÷1
07	Eudora Silt Loam	1
08	Kimo Silty Clay	0÷1
09	Kimo Silty Clay	0
10	Eudora Silt Loam	0

SOIL BULK DENSITY MEASUREMENTS

	Soil Depth (cm)						
Field Number	0-1	1-2	2-5	5-9	9-15	15-25	25-35
04	1.050	1.050	1.050	1.110	1.250	1.300	1.300
05	1.230	1.230	1.235	1.300	1.440	1.490	1.490
06	1.080	1.080	1.080	1.130	1.270	1.350	1.350
07	1.150	1.150	1.150	1.150	1.220	1.370	1.520
08	1.110	1.110	1.110	1.150	1.300	1.400	1.400
09	0.930	0.970	1.050	1.180	1.350	1.450	1.500
10	1.380	1.390	1.400	1.430	1.460	1.470	1.480

TABLE A-2. SOIL DATA

TABLE A-2. SOIL DATA

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
01	Corn	1,2,3	7/16			%			7 *	8*	13 *	17*	20*	23*				
			7/19	16:00	03	%	w	w	35.2	36.3	37.6	41.9	35.6	25.6		2),3x3	22x4	near saturation
02	Milo	1,2,3,4, 5,6	7/17	16:00	03	%			3.0	4.9	9.7	11.4	12.5					
					20	%			3.0	3.0	9.0	11.3	12.7					
					43	%			2.3	2.9	6.4	9.2	11.7					
		NONE	7/19	15:30	03	%	w	w	33.1	31.5	30.9	25.3	21.5	22.7		2),5x3	15x4	
03	Soybeans	1,2,3	7/17	15:30	03	%			2.2	3.0	5.4	11.7	14.8					
					20	%			2.7	3.9	14.8	15.9	16.4					
					43	%			2.5	4.4	13.0	16.1	16.5					
		4,5	7/18	15:00	03	%	d	d	2.3	3.4	9.4	15.4	16.4				22x5	
					20	%	d	d	2.5	3.6	5.7	13.6	16.9				30x2	
					43	%	d	d	2.8	4.1	7.4	16.4	19.9				30x3	
		NONE	7/19	15:00	03	%	w	w	34.0	30.8	28.9	28.2	25.2	25.0		1)		

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
04	Corn	1,2,3,4, 5,6	7/19	14:30	03	%	w	w	40.4	40.1	36.4	32.5	31.9	32.0		2),5x5	15x3	
						g/cm^3			.425	.421	.382	.361	.400	.416				
					03	%	w	w	38.8	40.0	37.9	32.1	28.5	32.2			10x4	
						g/cm^3			.407	.420	.398	.357	.356	.419				
		NONE	7/25	16:00	03	%	w	w	36.7	35.1	32.8	29.9	27.7			2)	50x3	
						g/cm^3			0.385	.368	0.344	0.331	.346					
A8		7,8,9,10, 11,12	7/27	15:30	03	%	d	m	31.5	30.1	27.2	26.1	26.7	24.2		2),8x4	15x5	
						g/cm^3			.331	.316	.285	.289	.333	.315				
						%			24.8	24.5	24.4	25.3	26.0	22.7			15x5	
						g/cm^3			.261	.257	.257	.281	.324	.294				
						%			26.0	25.4	25.9	26.1	26.2	24.7			15x5	
						g/cm^3			.273	.267	.271	.290	.327	.321				
					20	%	m	m	29.4	29.1	28.5	27.3	25.7	26.0		2),8x4	10x3	
						g/cm^3			.309	.306	.300	.303	.321	.338				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
04 (Continued)	Corn					%			25.9	25.7	25.1	24.4	25.0	25.8				
						g/cm^3			.272	.270	.263	.271	.313	.335				
					43	%	m	m	33.3	31.1	30.1	29.4	29.7	29.4			10x4	
						g/cm^3			.349	.326	.316	.327	.371	.382				
						%			35.4	30.7	30.3	30.3	27.5	30.3			10x4	
						g/cm^3			.371	.322	.318	.336	.344	.393				
		13,14,15 16,17	8/6	15:30	03	%	d	d	7.6	8.6	17.3	21.1	23.2	28.3		2),2x5	30x4	
						g/cm^3			.080	.091	.182	.234	.290	.367				
						%			5.5	13.1	20.0	20.4	22.3	29.1			30x4	
						g/cm^3			.058	.138	.210	.226	.229	.378				
					20	%	d	d	6.5	13.3	21.8	24.4	24.6	25.9		2),5x10	25x5	
						g/cm^3			.068	.139	.229	.270	.307	.337		4),1		
						%			6.3	9.2	19.3	23.9	26.6	28.3			25x5	
						g/cm^3			.066	.097	.203	.265	.332	.368				

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A9

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
					43	%	d	d	7.8	14.1	21.1	25.1	27.2	35.2		2)	30x13	
						g/cm^3			.082	.148	.222	.279	.340	.458		4), 2x5		
						%			5.7	10.9	23.3	25.8	27.2	34.6			30x13	
						g/cm^3			.059	.114	.244	.286	.339	.449				
		NONE	8/12	11:30	03	%	w	w	36.8	35.5	31.8	28.9	25.0	26.2		1)	15x3	
						g/cm^3			.387	.373	.334	.321	.312	.340		2),3x20		
A10		NONE	9/2	15:50	03	%	w	w	38.3	35.9	33.3	30.3	24.6	24.5			20x4	
						g/cm^3			.402	.377	.349	.336	.308	.319				
05	Corn	1,2,3,4, 5,6	7/20	15:00	03	%	w	w	36.4	34.7	29.1	26.2	24.2	23.9		2),5x5	90x4	near saturation
						g/cm^3			.447	.427	.360	.340	.348	.357				
						%			37.5	38.9	39.2	32.5	25.0	24.4			90x4	
						g/cm^3			.461	.479	.484	.423	.359	.364				
		NONE	7/25		03	%	w	w	34.6	34.9	31.9	27.4	23.0	18.4		2),10x3	10x1	
						g/cm^3			.425	.430	.394	.356	.332	.274				
		7,8,9, 10,11	7/30	15:00	03	%	d(m)	m(d)	9.0	14.5	18.6	22.2	22.3	20.1		2),5x5	8x5	
						g/cm^3			.111	.179	.230	.289	.321	.299		4),0.5		

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
A11						%			11.9	17.7	21.2	23.6	21.5	20.7			8x5	
						g/cm^3			.147	.218	.261	.307	.310	.309				
					20	%	m,d	m	22.4	22.2	24.0	24.7	25.9	23.6		1) 2),3x3	5x3	
						g/cm^3			.276	.273	.296	.321	.373	.352		4),0.3		
						%			20.5	19.6	20.0	22.1	21.8	21.2				
						g/cm^3			.252	.242	.247	.287	.314	.316				
					43	%	m,d	m(d)	26.3	23.3	23.7	24.6	24.8	25.4		1)	5x3	
						g/cm^3			.323	.287	.293	.320	.357	.378		2),3x3		
						%			17.7	19.6	20.5	22.8	23.9	22.0		4),0x2		
						g/cm^3			.217	.240	.253	.296	.344	.328				
		12,13,14 15,16	8/7	16:15	03	%	d	d	3.2	5.0	13.6	19.3	23.6	23.3		1)	61x1	
						g/cm^3			.039	.061	.168	.250	.340	.346		2),1.0x1.0		
						%			2.7	4.6	14.1	18.8	21.0	21.0			90x0	
						g/cm^3			.033	.056	.174	.244	.302	.313				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Surface Roughness Profile	Note
					20	%	d	d	3.6	5.4	11.3	19.0	21.9	21.7		1)	15x8	
						g/cm^3			.045	.066	.139	.246	.315	.324		2),1.5x 1.5		
						%			4.4	6.4	13.4	19.9	21.4	21.5			15x8	
						g/cm^3			.054	.078	.166	.259	.308	.321				
					43	%	d	d	3.2	4.4	15.5	20.3	20.0	19.2			20x3	
						g/cm^3			.040	.054	.192	.264	.288	.286		2)1.5x 1.5		
						%			4.5	6.4	12.2	15.9	17.0	17.0			10x5	
A12						g/cm^3			.055	.078	.151	.207	.244	.253				
		NONE	8/12	10:45	03	%	w	w	31.0	29.0	27.0	24.6	21.6	25.4		1)	8x3	
						g/cm^3			.381	.357	.333	.319	.311	.378		2),2.5x5		
			8/14	16:20	03	%	m	m	26.4	23.0	21.8	20.9	16.7	14.7		1)	90x0	
						g/cm^3			.325	.283	.269	.272	.240	.219				
					20	%	m	m	26.1	14.1	23.6	24.7	24.6	21.2		1)	5x3	
						g/cm^3			.321	.173	.291	.321	.354	.316		2),5x5		
					43	%	m	m	27.3	25.7	24.3	24.9	22.8	18.8		2),5x5	5x3	
						g/cm^3			.336	.316	.300	.324	.328	.280				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
		NONE	8/28	14:30	03	%	d	d	2.2	4.6	9.7	13.1	13.1			1)	20 x5	
						g/cm^3			.027	.057	.120	.170	.189					
					20	%	d	d	2.1	3.9	16.0	18.0	18.0			1)		
						g/cm^3			.025	.048	.198	.234	.259					
					43	%	d	d	2.9	10.4	13.1	17.0	18.0			1)		
						g/cm^3			.036	.128	.162	.221	.259					
		NONE	9/2	14:15	03	%	w	w	32.9	28.5	25.9	18.1	15.0	15.6		1)	90x0	
						g/cm^3			.404	.351	.320	.236	.216	.233				
					20	%	w	w	31.2	30.8	29.3	26.5	22.3	19.3		1),3x3	15x6	
						g/cm^3			.384	.379	.363	.345	.321	.288				
		17,18,19	9/15	12:20	03	%	w	w	33.0	29.3	27.3	25.3	21.8	21.7	22.5	1)	90x0	
						g/cm^3			.406	.360	.337	.328	.314	.323	.338			
						%			32.1	29.6	26.7	24.6	24.0	21.0	22.8			
						g/cm^3			.395	.364	.330	.320	.345	.312	.342			
					20	%	w	w	27.7	26.7	26.1	26.1	24.7	23.1	18.5	1)		
						g/cm^3			.340	.328	.322	.340	.355	.343	.278			

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
					43	%	w	w	28.6	27.5	25.6	26.0	24.4	23.9		1)		
						g/cm^3			.351	.338	.316	.337	.352	.356				
06	Corn	1,2,3, 4,5	7/22			%			43.0*	41.0*	37.0*	37.0*	33.0*	32.0*				
						g/cm^3			.464*	.445*	.400*	.420*	.420*	.432*				
		NONE	7/25	16:15	03	%	w	w	41.4	40.7	36.8	36.6	30.5	31.4		2),10x5		
						g/cm^3			.447	.439	.398	.414	.387	.423				
		NONE	7/30		03	%	d	m	10.0	20.4	25.4	26.5	27.6	27.9		2),5x5	20x8	
						g/cm^3			.108	.220	.274	.299	.350	.376		4),1.0		
					20	%	d	m	28.9	27.1	28.6	28.8	29.9	36.0		2),5x5	30x9	
						g/cm^3			.313	.293	.309	.326	.380	.486		4),0.6		
					43	%	m	m	34.3	33.3	34.1	31.8	30.5	30.0		1)	30x8	
						g/cm^3			.370	.360	.368	.359	.387	.405				
		6,7,8, 9,10	8/2	16:00	03	%	d	d(m)	8.4	11.7	24.0	27.4	28.1	28.3		2),3x5	15x10	Photo Taken
						g/cm^3			.090	.126	.260	.309	.357	.382		4),0.7		
						%			8.2	11.7	13.9	19.2	22.5	25.4				
						g/cm^3			.089	.127	.151	.217	.285	.343				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
A15					20	%	d	d(m)	5.7	12.6	21.5	27.1	26.4	30.4		2),3x5	30x15	
						g/cm^3			.061	.136	.233	.306	.336	.411				
						%			10.3	18.9	22.6	25.6	26.8	25.6		4),0.7	30x15	
						g/cm^3			.111	.204	.244	.289	.340	.345				
					43	%	d(m)	d(m)	9.3	14.6	20.7	22.4	25.0	26.3		2),3x5	30x10	
						g/cm^3			.100	.157	.224	.253	.317	.354				
						%			8.8	19.7	24.9	25.9	20.2	31,0		4), 0.7	30x10	
						g/cm^3			.095	.212	.268	.293	.256	.419				
		11,12,13, 14,15	8/7	15:15	03	%	d	d	6.1	8.9	16.1	24.9	27.2	32.5		2),1.5x8	38 x 3	Photo T
						g/cm^3			.066	.096	.174	.282	.345	.439				
						%			6.2	8.3	14.0	22.0	27.8	33.3		4),1.5	25x5	
						g/cm^3			.067	.089	.151	.249	.353	.450				
					20	%	d	d	5.9	9.0	16.8	20.7	24.1	27.7		2),1.5x5	15x5	
						g/cm^3			.064	.097	.181	.233	.306	.374				
						%			6.1	7.5	17.0	27.1	28.6	30.2		4),1.0	10x8	
						g/cm^3			.066	.081	.183	.307	.363	.407				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
					43	%	d	d	6.9	9.4	13.9	21.5	23.9	26.2		2),1.5x5	15x10	
						g/cm^3			.074	.101	.150	.242	.303	.354		4),1.0		
		NONE	8/12	11:45	03	%			32.3	30.1	28.8	28.4	27.1	24.1				
						g/cm^3			.348	.325	.311	.321	.344	.325				
		16	8/28	·		%			8.0*	12.0*	17.0*	20.0*	24.0*	24.0*				
						g/cm^3			.086*	.130*	.184*	.266*	.305*	.324*				
		NONE	9/2	16:10	03	%	w(m)	w(m)	34.2	30.6	28.8	25.3	20.8	23.0			10x5	
A16						g/cm^3			.369	.330	.311	.285	.264	.311				
07	Bare Ground	NONE	7/20	15:45	03	%			26.3	24.6	24.8	23.9	26.0	26.3				Photo Tal
						g/cm^3			.302	.283	.285	.274	.317	.360				
		1,2,3, 4,5	7/23	15:00	03	%	m	m	18.8	19.1	20.6	22.5	22.8	23.1	20.7	2),8x8		
						g/cm^3			.217	.220	.237	.259	.278	.317	.300		x615	
					20	%	m	m	23.4	22.1	20.7	21.1	21.5	21.9	21.6	2),5x5		
						g/cm^3			.269	.254	.238	.242	.262	.300	.313			
					43	%	m	m	21.9	21.3	22.1	22.5	23.4	23.2	21.6	2),8x8		
						g/cm^3	m	m	.251	.245	.255	.259	.286	.317	.312			

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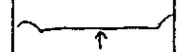
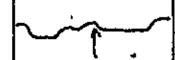
Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
		NONE	7/25	16:45	43	%	d	m	17.9	17.8	19.3	19.2	20.4	21.6	22.2	2),9x5		Straw at 10 to 12 c
						g/cm^3			.205	.205	.222	.220	.249	.296	.322			
		6,7,8, 9,10	8/1	13:20	03	%	d	d	2.4	5.2	14.2	16.5	18.3	20.2	16.5	2),15x10		Photo Taken
						g/cm^3			.028	.060	.163	.190	.223	.277	.239			
						%			3.5	7.0	16.5	19.2	20.0	20.7	22.9	4),0.2		
						g/cm^3			.040	.080	.190	.221	.244	.283	.332			
					20	%	d	d	1.8	3.3	11.2	15.4	17.1	18.8	22.4			
						g/cm^3			.021	.038	.129	.178	.209	.257	.325			
						%			3.6	10.4	15.9	17.5	21.5	18.6	24.6			
						g/cm^3			.042	.120	.182	.202	.263	.254	.356			
					43	%	d	d	3.5	11.0	14.2	16.0	17.5	17.8	19.0			
						g/cm^3			.040	.126	.164	.184	.214	.244	.276			
						%			5.5	12.8	14.9	18.1	19.3	18.9	22.2			
						g/cm^3			.063	.147	.172	.208	.235	.259	.322			

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
A18		11,12,13 14,15	8/8	16:15	03	%	d	d(m)	4.2	7.0	8.4	10.0	20.0	20.1	21.7	2),12x15		Photo Take
						g/cm^3			.048	.080	.096	.115	.242	.275	.314			
						%			5.6	12.0	15.7	17.4	19.0	20.0	23.4	4),0.7		
						g/cm^3			.064	.138	.180	.200	.232	.272	.340			
					20	%	d	d(m)	5.0	12.3	15.5	18.3	19.9	22.0	21.5	1)		
						g/cm^3			.057	.141	.178	.210	.242	.301	.312	4),0.7		
						%			4.9	13.7	17.3	18.4	20.1	22.7	21.7			
						g/cm^3			.056	.158	.199	.212	.245	.311	.315			
					43	%	d	m	7.6	16.2	18.5	19.9	21.9	23.8	22.9	2)		
						g/cm^3			.087	.186	.213	.229	.267	.327	.332	4),2.0		
		NONE	8/12	12:00	03	%	m	m	24.0	22.7	22.8	22.9	24.4	21.7	20.3	2),13x10		Straw at 14 to 15 cm
						g/cm^3			.276	.261	.262	.264	.297	.297	.294			
						%			23.9	22.7	23.7	24.7	23.2	23.1	21.4			
						g/cm^3			.275	.261	.273	.283	.283	.316	.310			

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
A19		Fading Experiment	8/14		03	%	m	m	19.3	19.0	20.5	22.4	24.6	22.5	21.1	2),25x20		Photo Taken Many weeds 3 to 15 cm
						g/cm^3			.222	.219	.236	.258	.300	.308	.306			
						%			19.9	19.6	21.5	22.0	23.3	23.7	22.3			
						g/cm^3			.229	.225	.247	.253	.284	.325	.323			
					20	%	m	m	20.0	19.6	21.0	22.3	22.7	23.4	21.4	2),20x10		Many weeds 3 to 15 cm
						g/cm^3			.23	.225	.242	.256	.277	.321	.310			
						%			19.1	19.5	21.0	21.2	22.4	22.5	21.8			
						g/cm^3			.220	.224	.242	.244	.273	.308	.316			
					43	%	m	m	18.0	20.3	21.5	23.7	24.6	25.9	25.5	2),10x13		Many weeds 3 to 15 cm
						g/cm^3			.207	.233	.247	.273	.300	.355	.370			
						%			18.6	19.3	21.7	22.9	25.6	25.5	24.6			
						g/cm^3			.214	.222	.250	.263	.312	.349	.357			
		NONE	8/31	13:30	03	%	m	m	25.7	23.4	21.5	23.0	23.9	23.5	20.8	2),3x8		Field disked
						g/cm^3			.296	.269	.247	.265	.292	.322	.302			

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
A20		NONE	9/1	8:45	03	%			23.8	20.9	21.0	20.8	21.5	21.4	19.2	2),2x2		
						g/cm^3			.274	.240	.242	.239	.262	.293	.278	4),0.4		
		16,17	9/4	16:15	03	%	m(d)	m	19.8	19.8	19.3	20.0	22.3	20.6	17.2	1)		Photos Taken Roughness Measured
						g/cm^3			.228	.228	.222	.230	.272	.282	.249	2),3x3		
						%			17.3	17.8	19.6	20.2	21.2	22.3	19.7			Soil Drying During Measurements
						g/cm^3			.199	.205	.222	.232	.259	.306	.286			
					20	%	m(d)	m	16.3	18.7	18.8	18.8	20.6	21.4	24.3	1)		
						g/cm^3			.188	.215	.216	.216	.252	.300	.305	2),3x3		
					43	%	m(d)	m	19.9	17.4	17.9	19.3	20.3	21.7	20.7	1)		
						g/cm^3			.229	.200	.206	.222	.248	.298	.300	2),3x3		
		18,19,20 21	9/5	13:30	03	%			26.0	22.9	24.3	23.8	26.1	24.2	21.8			
						g/cm^3			.299	.263	.279	.273	.318	.331	.316			
					06	%			15.6									
						g/cm^3			.179									

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
A21					09	%			10.7									
						g/cm^3			.123									
					12	%			10.8									
						g/cm^3			.124									
					15	%			12.5									
						g/cm^3			.144									
					18	%			10.4									
						g/cm^3			.120									
					20	%			10.0	14.8	16.8	18.5	18.4	20.4	17.7			
						g/cm^3			.115	.170	.193	.213	.225	.279	.257			
					22	%			11.1									
						g/cm^3			.128									
					24	%			9.8									
						g/cm^3			.113									

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
					26	%			12.2									
						g/cm^3			.140									
					28	%			13.8									
						g/cm^3			.159									
					43	%			12.8	14.9	16.9	17.5	18.7	20.2	21.6			
						g/cm^3			.147	.172	.194	.201	.229	.278	.291			
08	Soybeans	1,2,3, 4,5	7/25	14:30	03	%	m(d)	m	31.1	33.8	37.9	33.6	35.1	35.7		2),5x2	60x1	
						g/cm^3			.345	.375	.421	.386	.456	.500				
						%			26.0	35.1	38.7	37.2	34.1	37.2		4),3		
						g/cm^3			.288	.389	.430	.428	.444	.521				
					20	%			25.8	32.8	35.8	36.3	35.5	34.7		2),5x2	60x4	
						g/cm^3			.286	.364	.397	.418	.461	.485				
						%			26.0	31.9	38.4	35.0	35.2	34.0		4),2		
						g/cm^3			.289	.354	.426	.403	.457	.476				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
A23 SSA				--	43	%			21.3	31.7	36.2	35.4	33.9	34.6		2),5x2	60x3	
						g/cm^3			.236	.351	.402	.407	.441	.485				
						%			20.7	31.5	35.6	35.4	34.8	35.8		4),2		
						g/cm^3			.230	.350	.395	.407	.452	.501				
		NONE	7/26	14:10	03	%	m	w	30.5	31.5	34.5	35.7	34.8	38.5				
						g/cm^3			.339	.350	.383	.411	.452	.539				
					20	%	m	w	29.2	30.6	33.5	36.6	37.8	41.3				
						g/cm^3			.324	.340	.372	.421	.491	.578				
		6,7,8, 9,10	8/3	14:35	03	%	d	d	2.8	6.6	8.1	28.5	29.6	25.9		2),10x10 to 2 x 2		Soybeans Cultivated on 7/29
						g/cm^3			.031	.073	.090	.327	.385	.362				
					20	%	d	d	2.4	5.0	17.7	23.1	23.9	22.8				
						g/cm^3			.027	.055	.197	.265	.311	.319				
					43	%	d	d	2.7	8.2	24.7	26.5	27.9	29.8				
						g/cm^3			.029	.091	.274	.305	.363	.417				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Surface Roughness Profile	Note
						%			2.5	6.5	16.9	21.7	21.7	23.0				
				--		g/cm^3			.027	.072	.187	.249	.282	.321				
		NONE	8/12	11:00	03	%			37.6	38.8	37.5	32.4	33.1	32.4		2),10x10	x4	
						g/cm^3			.417	.430	.416	.373	.430	.453				
						%			35.8	35.1	37.3	35.7	30.9	30.1			x4	
						g/cm^3			.397	.390	.414	.410	.401	.421				
A24		Fading Experiment	8/17	15:15	03	%	d	d	6.3	10.8	26.8	28.9	31.2	31.3		3),5x3	90x0	Photo Taken
						g/cm^3			.070	.120	.297	.332	.406	.438				
						%			5.1	13.1	25.8	32.1	32.1	28.9		4),0.3	90x0	
						g/cm^3			.057	.145	.286	.369	.417	.405				
					20	%	d	d	5.9	14.6	28.4	32.3	35.1	34.0		3),5x3	80x2	
						g/cm^3			.065	.162	.315	.371	.456	.476				
						%			4.7	10.3	28.2	30.4	33.0	35.1		4),0.3	80x2	
						g/cm^3			.052	.114	.313	.350	.429	.491				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
					43	%	d	d	5.1	11.7	28.7	31.9	31.3	31.7		3),5x3		
				--		g/cm^3			.057	.130	.319	.367	.407	.444				
						%			4.7	9.3	24.9	29.3	28.9	30.5		4),0.3		
						g/cm^3			.052	.103	.276	.337	.376	.427				
		11,12,13, 14,15	8/29	13:00	03	%	d	d	3.5	5.1	7.3	20.2	21.1	20.6		2),4x4	40x0	03,20,43: Soil Very Hard Below 4 cm Depth
						g/cm^3			.039	.057	.081	.232	.274	.288				
					20	%	d	d	5.2	7.0	10.6	17.5	20.5	19.2		2),4x4	40x0	
						g/cm^3			.058	.078	.150	.201	.267	.269				
					43	%	d	d	4.4	6.4	12.5	19.5	20.9	19.8		2),4x4	10x4	
						g/cm^3			.049	.071	.139	.224	.272	.277				
						%			3.9	6.7	10.8	16.8	18.9	22.4			10x4	
						g/cm^3			.043	.074	.120	.193	.246	.314				
		NONE	8/31	13:20	03	%	w	w	38.7	35.9	34.6	28.1	25.5	28.3		2),10x2		
						g/cm^3			.430	.398	.384	.323	.332	.396				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
A26		NONE	9/2	14:50	20	%	w	w	40.4	38.1	36.4	29.6	25.2	22.0		2),5x5		
						g/cm^3			.449	.422	.404	.340	.327	.313				
		16,17	9/18	15:00	03	%			29.5	31.0	33.6	29.5	25.3	23.0				03,20,43: Radar Measurements and Soil Samples Taken on NS Slope; Some Eudora Silt Loam
						g/cm^3			.328	.344	.374	.339	.329	.322				
						%			34.0	33.7	34.4	30.3	27.6	26.7				
						g/cm^3			.377	.374	.382	.348	.359	.374				
					20	%			34.5	34.6	33.2	28.5	27.3	30.1		2),3x3		
						g/cm^3			.383	.384	.368	.328	.355	.422				
						%			36.8	36.1	35.2	33.6	32.9	28.8				
						g/cm^3			.408	.401	.391	.387	.427	.404				
					43	%			34.7	34.2	33.1	29.3	27.5	25.7				
						g/cm^3			.385	.380	.368	.337	.357	.359				
						%			36.3	34.6	33.1	30.9	29.7	27.2				
						g/cm^3			.402	.384	.368	.355	.386	.381				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
09	Milo	1,2,3, 4,5	7/26	13:30	03	%	w	w	39.4	37.6	35.8	35.8	37.6	30.4		2),7x3	10×5	
						g/cm^3			.366	.365	.376	.376	.443	.410				
						%			39.9	38.9	36.5	35.2	31.7	30.6				
						g/cm^3			.371	.377	.383	.415	.428	.444				
					20	%	w	w	36.7	35.9	35.2	34.1	32.6	30.9		1)	30×5	
						g/cm^3			.341	.348	.370	.403	.440	.449		2),3x1		
						%			40.2	37.9	36.7	35.8	34.1	32.4				
						g/cm^3			.374	.368	.385	.422	.461	.470				
					43	%	w	w	36.7	35.1	33.7	29.2	26.9	32.4		1)	30×3	
						g/cm^3			.341	.340	.354	.345	.363	.470		2),1x1		
						%			36.1	34.9	34.1	31.1	29.1	27.8				
						g/cm^3			.335	.339	.358	.367	.393	.403				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
A28		6,7,8 9,10	8/6	14:00	03	%	d	d	6.5	11.2	17.0	22.9	24.4	25.5		1)		
						g/cm^3			.060	.109	.178	.270	.329	.370		4),1.5		
						%			6.1	9.7	18.9	22.8	24.1	25.9				
						g/cm^3			.057	.094	.199	.269	.326	.375				
					20	%	d	d	7.8	11.5	16.0	23.4	22.3	26.5		1)		
						g/cm^3			.073	.112	.168	.276	.301	.384		4),1.5		
						%			7.6	12.6	19.8	22.4	24.2	27.9				
						g/cm^3			.071	.122	.208	.264	.326	.404				
					43	%	d	d	5.9	9.4	17.9	20.8	28.3	24.5		1)		
						g/cm^3			.055	.091	.188	.246	.381	.355		4), 2.0		
						%			6.0	9.6	19.6	21.5	22.2	28.6				
						g/cm^3			.056	.093	.206	.254	.300	.414				
		NONE	8/12	11:15	03	%	w	w	37.2	36.4	33.1	29.5	23.5	23.1	24.1	2),5x5	2.5x4	
						g/cm^3			.346	.353	.348	.348	.317	.334	.349			

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
A29		11,12	8/30			%			7.0*	9.0*	17.0*	22.0*	24.0*	26.0*				
						g/cm^3			.065*	.087*	.179*	.260*	.324*	.377*				
		13,14,15	8/31	12:45	03	%	w	w	35.3	36.3	33.3	31.7	25.0	25.1		2)	x5	
						g/cm^3			.329	.352	.350	.374	.337	.364				
					20	%	w	w	37.3	34.4	33.0	30.5	22.3	23.4		2)		
						g/cm^3			.346	.334	.346	.360	.301	.339				
					43	%	w	w	36.4	34.0	32.3	24.8	21.8	23.8		2)		
						g/cm^3			.339	.329	.339	.293	.294	.344				
		NONE	9/2	15:20	03	%	m	m,w	38.8	37.2	34.3	32.9	27.7	23.2			20x6	
						g/cm^3			.361	.361	.361	.388	.374	.336				
					20	%	m	m,w	37.1	36.1	33.9	29.2	22.8	24.3				
						g/cm^3			.345	.351	.356	.345	.308	.352				
		16,17,18	9/19			%			35.0*	34.0*	31.0*	27.0*	25.0*	23.0*				
						g/cm^3			.483*	.473*	.434*	.386*	.365*	.338*				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
10	Alfalfa	1,2,3,4	8/1	15:30	03	%	d	m	5.1	9.2	13.7	15.2	16.6	17.4		1)		Photo Taken
						g/cm^3			.071	.128	.191	.217	.242	.256				
						%			6.9	10.6	13.0	14.0	16.0	16.6				
						g/cm^3			.095	.148	.181	.200	.233	.243				
					20	%	m	m	17.4	14.3	15.8	16.6	17.6	18.9		1)		
						g/cm^3			.240	.199	.221	.238	.257	.278				
						%			17.2	16.2	15.4	16.2	17.0	17.8				
						g/cm^3			.238	.225	.216	.232	.248	.261				
					43	%	m	m	19.7	24.4	16.8	17.6	18.7	20.1		1)		
						g/cm^3			.272	.339	.235	.251	.273	.295				
	-	5,6,7,8,9	8/8	15:30	03	%	m	m	11.7	10.9	10.5	11.1	12.0	13.9		1)		
						g/cm^3			.161	.151	.147	.158	.175	.204				
						%			13.7	14.0	11.3	10.5	10.6	13.4				
						g/cm^3			.189	.195	.159	.150	.154	.196				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm) 0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Surface Roughness Type	Profile	Note
					20	%	m	m	15.1	15.0	14.9	14.7	14.5	14.6		1)		
						g/cm^3			.208	.209	.209	.210	.212	.215				
						%			15.6	15.4	14.9	13.9	14.2	14.5				
						g/cm^3			.215	.214	.209	.199	.207	.213				
					43	%	m	m	13.0	11.5	11.3	12.0	12.3	12.5		1)		
						g/cm^3			.179	.160	.159	.172	.179	.184				
		NONE	8/12	12:15	03	%			28.6	25.4	23.4	24.9	20.9	20.9		1)		
						g/cm^3			.395	.353	.328	.356	.305	.308				
		Fading Experiment	8/16	15:20	03	%			16.4	30.1	16.8	16.7	17.4	17.0		1)		Photo Taken
						g/cm^3			.226	.419	.235	.239	.254	.250				
					20	%			23.4	21.0	20.2	20.1	19.9	19.7		1)		
						g/cm^3			.323	.291	.283	.288	.290	.290				
					43	%			16.0	14.2	19.6	19.2	17.2	17.0		1)		
						g/cm^3			.220	.198	.275	.274	.251	.250				

Field	Crop	Data Set	Date	Time	Range (m)	Moisture Units	Moisture at Depth (cm)									Surface Roughness		Note
							0	0-2	0-1	1-2	2-5	5-9	9-15	15-25	25-35	Type	Profile	
A32		NONE	9/2	16:00	03	%			21.5	20.4	19.6	19.4	18.1	15.6	15.7	1)		
						g/cm^3			.297	.284	.274	.277	.264	.229	.231			
						%			26.5	22.7	21.4	20.7	17.2	18.2				
						g/cm^3			.366	.316	.300	.296	.251	.267				
		10, 11, 12	9/6	16:00	03	%			7.0	12.8	14.7	16.2	17.5	15.8	16.3	1)		03, 20, 43" Most of the Soil Surface Covered with Dry Organic Matter
						g/cm^3			.097	.179	.205	.232	.256	.232	.240			
						%			6.2	13.0	15.4	16.7	17.1	16.1	13.5			
						g/cm^3			.085	.181	.216	.239	.250	.237	.198			
					20	%			18.7	15.3	15.6	17.3	17.9	18.4		1)		
						g/cm^3			.258	.212	.218	.248	.261	.270				
					43	%			12.8	12.1	13.8	16.0	16.4	15.9		1)		
						g/cm^3			.177	.168	.193	.229	.239	.234				

TABLE A-3. PLANT DATA

TABLE A-3. PLANT DATA

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams) Wet	Net Weight (grams) Dry	Moisture by (% weight) Wet Basis	Moisture by (% weight) Dry Basis	Note
01	Corn	1,2,3	7/16			------------Measurements Not Taken------------							T				300*	
													L				450*	
													S				900*	
02	Milo	1,2,3, 4,5,6	7/17			------------Measurements Not Taken------------												
03	Soy-beans	1,2,3	7/17			------------Measurements Not Taken------------												
		4,5	7/19					91	II start	green 100	0	0						
04	Corn	1,2,3, 4,5,6	7/19	14:30	03	170		91	II start	green 100	0	n	L	201.20	36.59		450	
													S	373.68	36.28		930	
						160			II start	green 100	0	n	L	185.92	37.07		402	
													S	465.96	46.49		902	
		NONE	7/25	16:05	03			91	III	green 100	0	n	T		5.50		170*	
													L	112.25	28.90		288	
													C	164.15	15.70		946	
													S	375.9	53.9		597	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
		7,8,9, 10,11,12	7/27	15:30	03	252	4.6	91	III	green 100	0	n	T	26.07	9.2		183	
													L	151.98	33.70		351	
													C	81.24	9.65		742	
													S	487.10	61.60		691	
					43	241	5.1	91	III	green 100	0	n	T	13.71	5.75		138	
													L	134.25	33.10		306	
													C	188.62	9.35		1917	
													S	514.71	75.55		581	
		13,14,15 16,17	8/6	15:30	03	230	6.3	91	V	green 100	0	s	T	20.00	7.85		155	
													L	184.50	45.10		309	
													C	314.56	42.10		647	
													S	580.55	95.9		505	
					20	229	5.9	91	V	green 100	0	s						
					43	212	5.7	91	V	green	0	c	T		5.40		100*	
													L	148.02	38.70		283	
													C	388.45	71.60		443	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/ m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
													S	458.45	80.40		470	
		NONE	8/12		-----No Samples Taken-----													
			9/3		03								T		3.17		50*	
													L	139.12	35.90		288	
													C	473.55	159.10		198	
													S	516.18	82.15		528	
05	Corn	1,2,3, 4,5,6	7/20	15:00					II		0	n	T				250*	
													L				275*	
													S				540*	
		NONE	7/25	15:30	03	228	5.2	91	II finished	green 100	0	s	T		4.25		220*	
													L	134.00	36.20		270	
													C	541.15	51.80		945	
													S	426.27	74.10		475	

C2

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
A36		7,8,9, 10,11	7/30	12:00	03	227	4.4	91	III 50%	green 100	0	s	T	-	6.50		181*	
													L	142.3	38.90		266	
													C	19.78	3.35		491	
													S	567.95	114.80		395	
					43				V				T		2.20		150*	
													L	91.20	24.90		266	
													C	108.30	12.90		739	
													S	287.50	59.90		380	
		12,13,14 15,16	8/7	16:15	03	213	3.4	91	V	green 85	0	n	T	9.80	4.05		142	
													L	109.6	30.1		264	
													C	236.8	37.9		525	
													S	299.9	76.6		292	
					43	254	6.7	91	V	green 85	0	n	T	7.90	4.25		86	
													L	191.40	46.00		316	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams) Wet	Net Weight (grams) Dry	Moisture by (% weight) Wet Basis	Moisture by (% weight) Dry Basis	Note
A37													C	492.40	180.30		173	
													S	554.70	98.05		466	
		NONE	8/12	No Samples Taken														
		Fading Experiment	8/14	16:20	03	243	4.1	91	V	green	0	n	T		2.70		50*	
													L	107.78	28.00		285	
													C	341.52	131.00		161	
													S	293.60	51.00		476	
					43	248	4.4	91	V	green	s	s	T		3.90		70*	
													L	170.33	40.3		323	
													C	414.67	170.80		143	
													S	421.1	82.20		412	
			8/28	14:30	03	237		91	VI	brown	corn borer		T		8.04		18*	
													L	135.84	57.1		138	
													C	564.6	341.23		66	
													S	553.5	101.9		443	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
A38			9/3		03			91		brown			T		3.12		15*	
													L	122.41	46.85		161	
													C	420.05	233.20		80	
													S	284.48	61.75		361	
		17,18,19	9/15	12:30	03			91	VI	brown		s	T		4.77		9*	
													L	49.62	42.30		17	
													C	374.41	244.13		53	
													S	336.57	84.5		298	
					43			91	VI	brown		s	T		1.97		10*	
													L	23.57	22.96		3	
													C	221.60	138.15		60	
													S	174.91	44.12		296	
06	Corn	1,2,3,4,5	7/22										T				400*	
													L				350*	
													S				800*	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
A39		NONE	7/25	16:15	03	218		91	III start	green 100	0	n	T		6.00		300*	
													L	164.42	39.20		319	
													C	97.35	9.20		958	
													S	611.35	69.80		776	
			7/30		03	243	3.6	91	III	green 100	0	n	T	16.28	6.00		171	
													L	111.53	25.70		334	
													C	87.77	11.20		684	
													S	378.62	59.00		542	
					43	217	3.6	91	III	green 100	0	s(c)	T		3.10		150*	
													L	125.91	27.00		366	
													C	69.31	6.15		1027	
													S	371.10	51.11		626	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
A40		6,7,8, 9,10	8/2	16:00	03	239	3.6	91	III	green 100	0	n	T		2.70		100*	Photo Taken
													L	105.91	22.60		369	
													C	108.81	13.40		712	
													S	350.23	44.00		696	
					43	228	3.6	91	III < 50%	green 100	0	s	T		3.45		110*	
													L	163.14	37.50		335	
													C	352.62	47.80		638	
													S	606.35	87.20		595	
		11,12,13, 14,15	8/7	15:15	03	232	3.6	91	V	green 100	0	n	T	9.60	4.50		113	Photo Taken
													L	168.70	39.40		325	
													C	298.00	34.10		774	
													S	586.60	84.40		595	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/ m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
					43	225		91	V	green 100	0	s	T	7.8	3.30		136	
													L	151.3	36.50		315	
													C	276.50	48.30		473	
													S	483.70	79.50		508	
		NONE	8/12	No Samples Taken														
A41		16	8/28										T				70*	
													L				260*	
													C				250*	
													S				500*	
		NONE	9/3		03								T	6.29	4.22		49	
													L	129.56	36.80		252	
													C	446.82	170.80		162	
													S	429.54	73.75		482	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
08	Soy-beans	1,2,3, 4,5	7/25	14:30	03	12	15.9	91	I	green 100	0	s	wp	4.278	0.738		480	Photo Taken
					43	13.5	11.8	91	I	green 100	0	s	wp	3.328	0.650		412	
			7/26	No Samples Taken														
		6,7,8, 9,10	8/3	14:35	03	26.2		91	I	green 100	0	n	wp	13.32	2.40		455	
					43	23.7		91	I	green 100	0	n	wp	7.85	1.38		467	
			8/12	No Samples Taken														
		Fading Experiment	8/17	15:15	03	38	11.1	91	III start	green 100	0	n	wp	15.25	3.46		341	Photo Taken
					43	35	12.1	91	III start	green 100	0	n	wp	22.10	5.36		311	
		11,12,13, 14,15	8/29	13:00	03	56	18	91	IV	green 100	0	n	wp	49.5	10.6		367	
					43	56	20	91	IV	green 100	0	n	wp	42.27	9.26		356	
		NONE	8/31			50			V	green 100		n						
		NONE	9/3		03			91		green 100			wp	127.70	23.38		446	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/ m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
		16,17	9/18	15:00	03	68		91		green 100	0	n	Top	77.32	19.21		302	
													B	174.92	39.66		341	
					43	84		91		green 100	0	n	Top	58.93	15.11		290	
													B	140.91	29.0		386	
09	Milo	NONE	7/25		03	83		91		green 100			wp	175.45	25.60		585	
		1,2,3, 4,5	7/26	13:30	03	86	15.1	91	I	green 100			wp	274.08	39.70		590	
					20			91	I	green 100	0	n						
					43	92	13.0	91	I	green 100	0	n	wp	99.84	12.0		732	
		6,7,8, 9,10	8/6	14:00	03	73	12.5	91		green 100	0	n	L	163.90	28.90		467	
													S	215.80	32.70		560	
					43	97	10.8	91		green 100	0	n	L	123.33	24.90		395	
													S	199.32	28.65		596	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
A44		13,14,15	8/31	12:45	03	128		91	V	green 80	0	n	T	79.81	34.09		134	
													L	59.55	16.94		252	
													S	137.20	23.20		492	
					43	125	13.1	91	V	green 80	0	n						
		NONE	9/3		03								T	129.36	64.20		102	
													L	73.44	17.90		310	
													S	164.28	56.10		193	
			9/19		03								T	150.92	83.87		80	
													L	84.24	22.58		273	
													S				150*	
10	Alfalfa	1,2,3,4	8/1	15:30	03	41	1000	N.A.	I	green 100	0	N.A.	wp	147.46+	23.60+		525	Photo Taken
					43	46	1500	N.A.	I	green 100	0	N.A.	wp	285.92+	45.40+		530	

Field	Crop	Data Set	Date	Time	Range (m)	Height (cm)	Density (plants/m)	Row Width (cm)	Maturity	Color (%)	Diseases	Weeds	Section	Net Weight (grams)		Moisture by (% weight)		Note
														Wet	Dry	Wet Basis	Dry Basis	
		5,6,7,8	8/8	15:30	03	50		N.A.	I	green 100	0	N.A.	wp	125.50+	24.00+		423	
		NONE	8/12	-----	-----	-----	-----	-----No Samples Taken-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
		Fading Experiment	8/16	15:20	03	63		N.A.	III 5%	green 100		N.A.	wp	164.66+	35.10+		369	Photo Taken
					43	63		N.A.	III	green		N.A.	wp	176.53+	39.60+		346	03,43: Some Plants Tilted
		NONE	9/3		03				I				wp				683	
		10,11,12	9/6	16:00	03				I				wp				498	

TABLE A-4. CLIMATOLOGICAL RECORDS FROM THE UNIVERSITY OF KANSAS WEATHER STATION FOR JULY, AUGUST AND SEPTEMBER, 1973.

TABLE A-4.

WS FORM E-15
(4-72)

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

RECORD OF RIVER AND CLIMATOLOGICAL OBSERVATIONS

MONTH JULY 19 73

STATION Lawrence (Climatological) (River Station, if different) RIVER (Name) TYPE OF RIVER GAGE

COUNTY Douglas TIME (local) OF OBSERVATION RIVER, PRECIPITATION 5 pm TEMPERATURE 5pm STANDARD TIME IN USE CDT

STATE Kansas ELEVATION OF RIVER GAGE ZERO Ft. FLOOD STAGE Ft. NORMAL POOL STAGE Ft.

Date	River Stage (Feet and hundredths): Condition	Gage Reading at ___ A.M.	Tendency	Adjusted Gage Readings, etc.	Temperature °F.: 24 Hrs. Ending at Observation Max.	Min.	At Obsn.	Precipitation: Time of Beginning	Time of Ending	Time of Beginning	Time of Ending	24-Hr. Amounts: Rain, Melted Snow, etc. (Ins. and hund'ths)	Snow, Ice Pellets, Hail (Ins. and tenths)	At Obsn. Snow, Ice Pellets, Hail, Ice on Gnd. (Inches)
1					96	73	96					--	--	--
2	12	HRMAX		94	96	68	93	7:15a	9:10a	9:45p	10:45p	.49	--	--
3					94	67	94	12:10p	12:20p			1.41	--	--
4	12	HRMAX		92	94	69	92	1:25a	2:40a			.76	--	--
5	12	HRMAX		82	92	69	70	1:10p	8:10p	11:30p	MNT	.05	--	--
6					91	68	90	MNT	1:35a			.04	--	--
7					93	70	92					--	--	--
8					95	71	93					--	--	--
9	12	HRMAX		92	93	73	92					--	--	--
10	12	HRMAX		90	92	72	88					--	--	--
11					94	69	92					--	--	--
12					96	70	95					--	--	--
13	12	HRMAX		94	95	69	93					--	--	--
14	12	HRMAX		75	93	67	74	4:15a	3:20a	1:45p	2:50p	.17	--	--
15					84	61	82					--	--	--
16					87	61	86					--	--	--
17					89	67	85					--	--	--
18					97	71	95	4:50p	5:25p	11:25p	MNT	--	--	--
19	12	HRMAX		88	95	69	86	MNT	8:15a	7:45p	9:20p	4.28	--	--
20					93	69	92	0:40a	6:00a	6:15p	7:00p	1.23	--	--
21	12	HRMAX		74	92	65	72	2:00a	3:20a	8:50a	9:30a	.26	--	--
22					79	65	78	2:55p	8:20p	7:50p	10:00p	.02	--	--
23					88	69	87	5:30a	6:45a	5:55p	6:15p	.39	--	--
24	12	HRMAX		83	87	69	81	10:10a	10:45a	11:25p	MNT	.32	--	--
25					85	68	84	MNT	1:30a	4:35a	6:15a	.07	--	--
26					87	63	86					--	--	--
27					93	67	93					--	--	--
28	12	HRMAX		91	93	70	90	3:45a	4:20a			.01	--	--
29	12	HRMAX		87	90	67	84					--	--	--
30					91	71	90					--	--	--
31	12	HRMAX		82	90	64	80					--	--	--
Sum												9.50	0	
Greatest												4.28	0	0

Check Bar (For wire-weight gage only) — Reading | Date

Normal Check Bar

CONDITION OF RIVER AT GAGE
A. Obstructed by Rough Ice.
B. Frozen, But Open at Gage.
C. Upper Surface of Smooth Ice.
D. Ice Gorge Above Gage.
E. Ice Gorge Below Gage.
F. Shore Ice.
G. Floating Ice.
H. Pool Stage.

Special Observations of Precipitation and River Stages

Date	Time of Observation	Precipitation Since 7 A.M.	River Stage	Tendency	Crest Stage, Date and Time, Depth of Snow or Ice, State of Weather at Time of Observation
1	5:00p				Wind Gust 20 mph
2	8:00a				Wind Gust 20 mph
3	5:00p				Wind Gust 19 mph
4	2:24a				Wind Gust 37 mph
7	5:00p				Wind Gust 15 mph
10	5:00p				Wind Gust 16 mph
12	5:00p				Wind Gust 15 mph
18	8:00a				Vsby. 3mi.until 9:00a
20	0:35a	Squall	line Winds		Max. 22 mph
21	5:00p				Wind Gust 15 mph
22	8:00p				Vsby. 21/2mi. until 9:15a
31	5:00p				Wind Gust 14 mph

IF MORE SPACE IS NEEDED, USE ADDITIONAL FORM

Remarks:
2nd tornado warning issued--none sighted here--max. wind recorded 47 mph--estimated up to 80mph due to damage--5"limbs down &power outtage--worst of storm from 9:55 to 10:15pm.

19th severe lightning & torrential rains fell from 2:00a to about 4:00a--vsby. often reduced to less than 100 ft.--very little damage to city.

Observer Ted Stimach Station Lawrence

River District Office Month July 1973

ORIGINAL PAGE IS OF POOR QUALITY

WS FORM E-15
(4-72)

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

RECORD OF RIVER AND CLIMATOLOGICAL OBSERVATIONS

MONTH August 19 73

STATION Lawrence (Climatological) (River Station, if different) RIVER (Name) TYPE OF RIVER GAGE

COUNTY Douglas TIME (local) OF OBSERVATION RIVER, PRECIPITATION 5 pm TEMPERATURE 5 pm STANDARD TIME IN USE CDT

STATE Kansas ELEVATION OF RIVER GAGE ZERO Ft. FLOOD STAGE Ft. NORMAL POOL STAGE Ft.

A47

Date	River Stage (Feet and hundredths): Condition	Gage Reading at __A.M.	Tendency	Adjusted Gage Readings, etc.	Temperature °F. 24 Hrs. Ending at Observation: Max.	Min.	At Obsn.	Precipitation: Time of Beginning	Time of Ending	Time of Beginning	Time of Ending	24-Hr. Amounts: Rain, Melted Snow, etc. (Ins. and hund'ths)	Snow, Ice Pellets, Hail (Ins. and tenths)	At Obsn. Snow, Ice Pellets, Hail, Ice on Gnd. (Inches)
1					80	60	78	-				--	--	--
2					81	59	80					--	--	--
3					86	60	85					--	--	--
4					87	64	85					--	--	--
5					87	65	86					--	--	--
6					90	67	88					--	--	--
7					94	71	93					--	--	--
8	12	HRMAX	X	89	93	68	89	1:25a	4:15a			.42	--	--
9	12	HRMAX	X	87	90	67	86	7:15a	9:00a			.89	--	--
10					90	71	78	3:25p	3:40p	4:30p	4:50p	T	--	--
11					92	68	91					--	--	--
12	12	HRMAX	X	85	91	66	84	3:30a	5:10a			.32	--	--
13					86	69	85	8:20a	10:00a			.07	--	--
14					85	65	83					--	--	--
15					84	64	83	10:40a	11:45a			.01	--	--
16					89	65	87					--	--	--
17					91	69	89					--	--	--
18					92	69	91					--	--	--
19					93	70	92					--	--	--
20					94	70	93					--	--	--
21					93	70	92					--	--	--
22					93	67	92					--	--	--
23					93	72	90	2:15a	3:10a			.07	--	--
24	12	HRMAX	X	85	90	70	84					--	--	--
25					100	72	100					--	--	--
26	12	HRMAX	X	98	100	74	98					--	--	--
27	12	HRMAX	X	95	98.	73	95					--	--	--
28	12	HRMAX	X	94	95	70	93					--	--	--
29	12	HRMAX	X	91	93	69	89					--	--	--
30					92	69	69	3:15p	6:00p			.37	--	--
31					91	70	90					.15	--	--
Sum			X				X				Sum	2.30	0	X
											Greatest	.89	--	--

Check Bar (For wire-weight gage only)

Reading	Date	Normal Check Bar

CONDITION OF RIVER AT GAGE
A. Obstructed by Rough Ice.
B. Frozen, But Open at Gage.
C. Upper Surface of Smooth Ice.
D. Ice Gorge Above Gage.
E. Ice Gorge Below Gage.
F. Shore Ice.
G. Floating Ice.
H. Pool Stage.

Special Observations of Precipitation and River Stages

Date	Time of Observation	Precipitation Since 7 A.M.	River: Stage	Tendency	Crest Stage, Date and Time, Depth of Snow or Ice, State of Weather at Time of Observation
5	5:00p				Wind Gust 24 mph
6	5:00p				Wind Gust 24 mph
7	5:00p				Wind Gust 23 mph
7	8:00a		Smog		Vsby. 6 mi. until 9:00a
8	8:00p				Wind Gust 17 mph
10	3:25p				Wind Gust 22 mph
11	5:00p				Wind Gust 16 mph
12	8:00a		Fog		Vsby. 2-1/4 mi. until 9:15a
13	8:00a		Fog		Vsby. 2mi. until 8:15a
16	8:00a		Fog		Vsby. 3-1/2mi. until 8:45a
17	8:00a		Fog		Vsby. 5 mi. until 8:45a
18	5:00p				Wind Gust 14 mph
19	5:00p				Wind Gust 16 mph
22	5:00p				Wind Gust 19 mph
24	8:00a		Fog		Vsby. 2mi. until 4:30p
25	5:00p				Wind Gust 18 mph
26	5:00p				Wind Gust 17 mph
27	5:00p				Wind Gust 15 mph
28	5:00p				Wind Gust 17 mph
30	3:40p		Squalline		Wind Gust 22 mph
31	5:00p				Wind Gust 29 mph

IF MORE SPACE IS NEEDED, USE ADDITIONAL FORM

Remarks:
30th Temperature dropped 19° in 5 minutes with squalline.

Observer Ted Stimach Station Lawrence

River District Office Month August 1973

ORIGINAL PAGE IS OF POOR QUALITY

A48

WS FORM E-15 (4-72)

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

RECORD OF RIVER AND CLIMATOLOGICAL OBSERVATIONS

MONTH September 19 73

STATION Lawrence (Climatological) RIVER ______ (River Station, if different) (Name) TYPE OF RIVER GAGE ______

COUNTY Douglas TIME (local) OF OBSERVATION RIVER, PRECIPITATION 5 pm TEMPERATURE 5 pm STANDARD TIME IN USE ______

STATE Kansas ELEVATION OF RIVER GAGE ZERO ______ Ft. FLOOD STAGE ______ Ft. NORMAL POOL STAGE ______ Ft.

Date	River Stage (Feet and hundredths): Condition	Gage Reading at ___ A.M.	Tendency	Adjusted Gage Readings, etc.	Temperature °F. 24 Hrs. Ending at Observation: Max.	Min.	At Obsn.	Precipitation: Time of Beginning	Time of Ending	Time of Beginning	Time of Ending	24-Hr. Amounts: Rain, Melted Snow, etc. (Ins. and hund'ths)	Snow, Ice Pellets, Hail (Ins and tenths)	At Obsn. Snow, Ice Pellets, Hail, Ice on Gnd. (Inches)
1	12	HRMAX		77	90	72	74	9:00a	4:30p			.47	--	
2					82	69	79	5:25a	5:35p			.01	--	
3					79	67	73	1:45p	2:50p	3:50p	4:35p	.12	--	--
4					85	67	84					---	--	--
5	12	HRMAX		81	84	63	79					---	--	--
6					83	55	82					---	--	--
7	12	HRMAX		71	82	67	65	11:15a	4:30p	5:55p	8:30p	.49	--	--
8					75	66	70	8:10a	9:00p			.31	--	--
9					84	68	83	8:15a	8:50a	5:00p	5:05p	.15	--	--
10	12	HRMAX		77	85	65	76					T	--	--
11					83	61	81					---	--	--
12	12	HRMAX		68	81	58	62	12:00p	4:40p	10:45p	10:55p	.23	--	--
13					67	62	65	8:45a	9:10a			.03	--	--
14					70	58	69					---	--	--
15					77	54	76					---	--	--
16	12	HRMAX		55	76	50	52	6:30a	10:25a	3:50p	9:15p	.48	--	--
17					55	48	54	5:20a	6:00a	7:50a	9:15p	.31	--	--
18					66	40	64					---	--	--
19					74	52	71					---	--	--
20					72	62	70					T	--	--
21					89	64	88	8:55p	9:35p	9:50p	11:00p	---	--	--
22	12	HRMAX		79	88	64	77	1:10a	3:40a	11:45p	MNT	.44	--	--
23					82	64	81	MNT	6:50a	10:15a	10:45p	1.04	--	--
24	12	HRMAX		75	81	62	64	12:30p	3:05p	7:30p	9:55p	.83	--	--
25					73	58	72	1:10p	2:10p	4:10p	4:30p	2.82	--	--
26	12	HRMAX		66	72	64	64	5:30a	8:10p			3.00	--	--
27					68	62	67	8:45a	8:15a	8:45a	MNT	.32	--	--
28					75	65	71	MNT	8:55a	11:45a	12:05p	1.74	--	--
29	12	HRMAX		65	71	53	63	3:00p	4:05p			T	--	--
30					66	57	64	2:35a	4:10a	4:50p	6:45p	.06	--	--
31														
Sum											Sum	12.85	0	
											Greatest	3.00	0	0

Check Bar (For wire-weight gage only): Reading | Date

Normal Check Bar

CONDITION OF RIVER AT GAGE
A. Obstructed by Rough Ice.
B. Frozen, But Open at Gage.
C. Upper Surface of Smooth Ice.
D. Ice Gorge Above Gage.
E. Ice Gorge Below Gage.
F. Shore Ice.
G. Floating Ice.
H. Pool Stage.

Special Observations of Precipitation and River Stages

Date	Time of Observation	Precipitation Since 7 A.M.	River: Stage	Tendency	Crest Stage, Date and Time, Depth of Snow or Ice, State of Weather at Time of Observation
1	8:00a				Wind Gust 19 mph
2	5:00p				Wind Gust 15 mph
5	5:00p				Wind Gust 14 mph
7	2:30p		Fog		Vsby. 4mi. until MNT
8	8:00a		Fog		Vsby. 4mi. until 8:30a
10	8:00a		Fog		Vsby.2-1/4mi.until 10:30a
11	8:00a		Fog		Vsby.2-1/16mi.until 10:30a
13	8:00a		Fog		Vsby.1-1/4mi. until 9:00a
12	8:00a				Wind Gust 15 mph
15	8:00a		Fog		Vsby. 1-1/4mi.until 9:00a
14	8:00a				Wind Gust 15 mph
15	8:00a		Fog		Vsby. 3mi. until 8:30a
16	8:00a				Wind Gust 18 mph
/	4:00p		Drizzle		Vsby. 3 mi. until MNT
20	8:00a		Fog		Vsby.3-3/4mi.until 8:20a
21	1:00p				Max. wind 40 mph
23	8:00a		Fog&Rain		Vsby.4-1/2mi.until 11:30a
24	8:00a		Fog		Vsby.5-1/2mi.until 9:00a
/	2:30p				Max. wind 28 mph
/	6:15p		Rain		Vsby. 1 mi.until 6:45p
25	8:00a		Fog		Vsby. 1/8mi.until 10:20p
26	8:00a		Rain		Vsby.2-1/2mi.until 12:00p
27	5:00p		Fog&Rain		Vsby.1 to 4-3/4mi. all day
28					Wind Gust 22 mph

IF MORE SPACE IS NEEDED, USE ADDITIONAL FORM

Remarks:

24th Four hours of thunderstorms dumped 3.48" of precipitation in a little better than 9 hours.

25th Additional rain period 5:55p to 6:05 p.

29th Wind gust 14 mph at 5:00p

Observer Ted Stimach Station Lawrence

River District Office ______ Month September 1973

CRINC LABORATORIES

Chemical Engineering Low Temperature Laboratory

Remote Sensing Laboratory

Flight Research Laboratory

Chemical Engineering Heat Transfer Laboratory

Nuclear Engineering Laboratory

Environmental Health Engineering Laboratory

Information Processing Laboratory

Water Resources Institute

Technical Transfer Laboratory

Air Pollution Laboratory

Satellite Applications Laboratory

CRINC