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SECTION 118

MEASUREMENTS FROM AIRCRAFT TO CHARACTERIZE WATERSHEDS 1/

by

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INTRODUCTION

In 1961 the Southern Plains Watershed Research Center began studying the hydrology of a 1,130-square-mile segment of the Washita River basin located about half way between the river mouth at Lake Texhoma and the headwater area in the panhandle of Texas. The objective of the research program was primarily the evaluation of hydrologic changes in a major river basin brought about by the construction of systems of flood detention reservoirs on tributary watersheds. The complex nature of such a study necessitates an investigation of the planning and design of the systems as well as a thorough study of watershed and climatic conditions before and after the construction period. As a result, instrumentation for measurement of rainfall, runoff, sediment, ground water, water quality, and climatic conditions in the study area is the most comprehensive system available in any one climatic area.

A thorough hydrologic analysis of the data requires the development and use of mathematical models to adequately describe the movement of water from the time it begins to fall as rain until it is absorbed by the soil surface, evaporates, transpires through plants, or is discharged at the mouth of the river. One of the primary elements of any watershed model is the element which separates the quantity of surface runoff from the quantity of water stored in the surface of the drainage basin (1). The surface soil moisture conditions are a good index of this element. However, no good method exists for adequately monitoring soil moisture because of its large spatial variability. In the last 2 or 3 years, various remote sensing techniques have been investigated to see if they might be able to provide the desired index.

1/ Contribution from the Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with the Oklahoma Agricultural Experiment Station. Data for this study have been acquired and furnished by the Earth Resources Division of NASA as part of a study on watershed hydrology.
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Most of the emphasis in remote sensing at this station has been directed toward the measurement of soil moisture, or indirectly, the rainfall-storage capacity of the soil. Other objectives of remote sensing include a search for indicators of pond-water quality, geologic sources of sediment or salt, and rapid methods of mapping seepage.

It should be noted that remote sensing data collected for this study has not been thoroughly analyzed for other applications in hydrologic modeling. Due to limitations on personnel, major emphasis has been placed on the objectives in the order described above.

This report is intended as a summary of the study and observations made in the year 1971 along with the conclusions and concepts developed during this period.

PROCEDURE

DATA COLLECTION

Remote sensing data for this study was first gathered by the NASA NP3A and RB57 aircraft on September 29, 1969. The RB57 aircraft was flown at an altitude of 60,000 feet over the entire study area. Two RC8 cameras with color and color infrared film were the primary sensors. A 12-inch focal length Zeiss mapping camera was used on only part of the area, but five Hasselblad cameras with color, color infrared, and black and white infrared film were operated over the entire block. A detailed account of the sensors used, the film-filter combinations, and the coverage of these flights are available in the Mission Reports, Nos. 105 (4) and 106 (8).

The NP3A aircraft was flown at an altitude of 3,000 feet above the ground. Data from the aircraft consisted of microwave line scans in all five frequencies on the multifrequency microwave radiometers. The microwave radiometers were operated with no deviation from the nadir and only vertical polarization was used. Two RC8 cameras, four KA62 cameras, an RS-14 infrared scanner, and a PRT-5 sensor and recorder were also operated on this flight.

Flight lines for the low altitude mission of the NP3A aircraft with the microwave equipment were planned to enable close control of the nadir track and to sense bare ground sites where soil moisture could be sampled. White plastic panels 50 feet long and 5 feet wide on each end of the sample sites were used to mark the flight line. Excellent control of the nadir track was achieved. Rainfall data is available at close intervals along the lines from recording gages used for the watershed study.

Sampling sites for soil moisture were located such that minor deviation of the aircraft from the flight line would not miss the sampled areas. Large bare ground fields were selected where possible and two lines of sample points perpendicular to the flight line (Fig. 1) were staked 100 feet apart. Samples were gathered at points 50 feet apart along these lines. At each point, two samples were taken; one consisted of a 1-inch core of the top 6 inches and another core from 6 to 12 inches. Thirty-three dual samples were obtained for each site. Each sample was tagged with an appropriate site and location number and sealed. Samples were taken to the station laboratory where they were weighed immediately, dried at 105° C, and reweighed. After the samples were analyzed, the mean and variance of the soil moisture percent (on dry weight basis) was calculated for each site (Table I).

Water quality was sampled at 17 ponds along the flight line for subsequent comparison to infrared response. These were collected at or near the time of the flight to avoid changes in water temperature. Temperature readings near the surface of the water were recorded at the time of sampling. The water quality samples were analyzed for total salts, specific salt constituents, and sediment content.

Preliminary data processing and the development of computer programs to convert the microwave analog data to a digital form was done at NASA-MSC. They furnished the microwave data at .4-second intervals on punched cards showing time and corrected antenna temperature for each radiometer. Photographs and output from the infrared scanner were provided as positive transparencies.

ANALYSIS

A set of photographs in Ektachrome color was used as the base for plotting the ground track. Photo centers were located and transferred to adjoining frames. The radiometer view angles, 16° ± 0.5° for the L band and 5° ± 0.2° for the X through KA bands, were used to calculate the width of track related to the antenna temperatures. Resolution of the microwave data is a function of the integration time of the sensors, the altitude of the sensors, and the speed of the aircraft. On this mission, a 1-second integration time combined with the other factors gave a resolution element approximately 506 feet long by 266 feet wide (Fig. 1) in this instance for the X and KA band radiometers.

A system was developed to synchronize the time of the digital microwave data with points along the ground track. On individual flight lines, it was assumed that the aircraft speed remained constant and therefore the time between the location of all photo centers would also be constant. Computer programs were written to expand or contract the plotted microwave data along the flight line to fit easily detected points associated with lakes and ponds on the photos. A minor change in the length of the time line was necessary and a time shift was required.

A computer plot of the L, X, and KA band microwave data at the same scale as the photos was made such that the transparencies could be positioned over the plot to determine the microwave temperatures associated with the soil moisture data points. The K1 and K2 band radiometers were not functioning properly at the time of the flight and no further attempt was made to use these bands.

The mean of soil moisture at the three depths (0-.5 inch, 0-6 inches, and 0-12 inches) within the resolutional area of each site was plotted against antenna temperature for both the X and KA bands. A similar plot of the soil moisture versus the L band antenna temperatures was also made. Assuming that surface roughness effects might be reflected in antenna temperatures from both the X and KA bands, the difference in temperature between the two bands was plotted versus the soil moisture.

The microwave antenna temperature from data points representing each major land use was averaged for both the X and KA bands (Table II). Land use categories such as roads and farmsteads were not evaluated because the resolution of the radiometers was too poor to adequately represent these spatially compact areas.

The photography and the infrared scanner imagery were studied in an effort to find signatures for any of the common dissolved pollutants found in local ponds and lakes in the area. In addition, data gathered from water samples containing different concentrations of suspended sediments have been analyzed by using visible and infrared spectra. These spectographs were obtained by using the truck-mounted spectrometer at the ARS Remote Sensing Laboratories in Weslaco, Texas. The water samples, beginning with a high concentration of suspended sediments, were repeatedly diluted, sampled, and scanned.

The infrared photographs from the RB57 flight are being used to map eroded soils and gullies. Erosion area in each watershed will be used to test prediction schemes for annual sediment yields.

RESULTS AND DISCUSSION

Temperatures for the X and KA band radiometers appeared to be most sensitive to the presence of free water on the surface, showing sharp drops in temperature over lakes and ponds. From the study of the microwave plots over the entire flight line and a first look at onboard plots in the X and KA bands from the 1971 flights, there are numerous responses that we are unable to logically explain. However, in repeated flights over the same lines, these anomalies appear to recur. The L band radiometer responded to large bodies of water; however, the temperature drop over a lake was less than it was for the X and KA band. The resolution element of the L band radiometer is also much larger than the resolution element for the X or KA bands and probably accounts for some of the lack of sensitivity evident in the data. In addition, there are anomalies present in the L band data that make its validity questionable even though other studies with passive and active microwave systems (3,5) have shown that the L band radiometer measures soil moisture better than the X band.

SOIL MOISTURE

The monitoring of soil moisture, especially in the surface few inches, has been difficult. It is the surface few inches that are most critical in controlling runoff. One factor contributing to the problem is the spatial distribution of soil moisture. A search of the literature on soil moisture offers very little information on its spatial distribution near the surface. The spatial distribution will be a function of the moisture level, soil type, and surface gradients. Preliminary analysis indicates that large numbers of gravimetric samples along a flight line will be necessary to adequately define the variance of the area used as a test site. However, if a small sample is used at each test site, the variance will be so large that little confidence can be placed in the mean value; but because of the narrow width of the resolution element, soil moisture means for the sites were calculated from a limited number of samples. A different sampling pattern was used for the 1971 flights to increase the number of samples per resolutional element at very little increase in the total number of samples.

Plots of antenna temperature versus soil moisture content revealed no apparent relationship between the 0- to 12-inch soil moisture and any of the three (L, S, KA) bands. Soil moisture in the top 6 inches was related reasonably well to the X band antenna temperature (Fig. 2), however, the upland soils had lower soil moisture content and more variable antenna temperatures. Extreme scatter occurs when the KA band antenna temperature is used; therefore there is little evidence that this band would be a good index of soil moisture in the surface 6 inches. Plots using the soil moisture in the surface .5 inch did not indicate any correlation with radiometer temperatures.

The X band antenna temperatures showed some correlation with soil moisture in the top 6 inches of soil, therefore the X band data from this study was compared to averaged data representing extremely wet and dry soils from studies at Texas A & M University (2,7). The combined data is in good agreement and encompasses a broader range of soil moisture than that of this study (Fig. 3). Since this relationship appears to be highly significant, it may be possible that the difference between X band temperatures of the same soil under wet and dry conditions may be related to the soil moisture storage capacity.

When the data points on the plot of KA band antenna temperature minus the X band antenna temperature versus soil moisture (0 to 6 inches) are annotated by site number (Fig. 4) there appears to be a separation of the upland soils and alluvial soils. Analyzing the temperature difference between radiometers of different wave lengths is questioned by most people working with microwave data. However, this technique appears to warrant further study as it may lead to a better understanding of the variation in antenna temperatures recorded over soils with low moisture content.

If the difference in X band microwave temperatures for a soil under two different moisture regimes can be shown to be related to the soil moisture and thus to the rainfall-storage capacity, then it may be possible to use the concept in hydrologic modeling. A test of the concept will be made in 1972 using the instrumented watersheds on the Washita River. Once this is established, improved estimates of runoff for use in flood forecasting and flood control design are possible. The X band scanning radiometer will be used to scan the instrumented watersheds during a dry period and again after a major rainfall event. By maintaining a relatively short time interval between scans, any influence from land use should remain unchanged. The aircraft altitude will be varied to produce approximately the same total number of resolutional elements for each watershed enabling a comparison of watersheds with different drainage areas. The mean antenna temperature for the dry condition subtracted from the mean antenna temperature for the wet condition will produce an index related to the storage capacity of the surface. The index, though a numerical value, would be the mean of a very large number of samples and would not require accurate measurement at each sample point. This index will be used in watershed models to replace values presently estimated by hydrologists or taken from empirical tables based on soils, land use, and crop cover.

Considering that radiometric temperatures have some variation, even at higher temperatures, and that the variance of soil moisture measurements is relatively large, any relation between the two variables is going to be encompassed by fairly broad envelope curves. The width of the envelope curves may make sufficiently accurate quantitative measurement of soil moisture from the air a goal that may not be technically feasible for some time.

The microwave data collected by the NP3A aircraft was analyzed to see if different land use classifications could be detected. The mean antenna temperature for both the X and KA bands for each land use classification is shown in Table II. A comparison of the means does not show any significant difference due to crop cover. However, the data show that the most densely covered areas, alfalfa and bermuda and love grass, have the lowest temperatures; whereas, the open or bare ground have the highest. All the other classifications fall between these two groups. Even though the differences are very small, they are in the order expected. Therefore, data gathered at other times of the year with more luxuriant growth and higher moisture content in the crops might show significant differences in antenna temperatures. It is also possible that the influence of cover is not significant and that the differences shown in the table are contradictory due to the relative roughness of the soil surface associated with planting practices rather than the cover itself. Large numbers of sample points over fields with and without the cover would be necessary to separate the influence of moisture and cover. Economic considerations make such tests with airborne equipment impractical. However, field tests with truck-mounted equipment under well-controlled conditions with measurements taken before and after removal of vegetation could be used satisfactorily to test the influence of cover.

WATER QUALITY

Suspended sediments, particularly clays and fine silts, have been recognized as carriers of other pollutants (6) and as such, they are important in the study of water quality. Analysis of the infrared response from ponds where water quality samples were available did not reveal any means of identifying the common dissolved pollutants found in this area. The response on all film was apparently dominated by the suspended sediment in the water. However, the percent of incident light reflected in the visible and infrared portion of the spectrum was not sensitive to changes in high sediment concentrations similar to that in most streams.

The percent of incident light reflected in the visible light part of the spectrum from water containing suspended sediment does vary with differences in concentration at relatively low sediment loads indicating that reliable estimates of sediment (clays and fine silts) in ponds and lakes can possibly be monitored by aerial photography. Further testing will be necessary to determine effects of other variables such as sediment color on the film response.

SEDIMENT SOURCE AREAS

The study of sediment source areas as indicated on film has not progressed to a point where quantitative estimates of sediment yield for a watershed can be made. Qualitative assessment of sediment yield as a function of recognizable sediment sources can be made very easily from the high altitude (60,000 ft.) infrared positive transparencies.

CONCLUDING REMARKS

Antenna temperatures for the X band passive microwave radiometer have been related to soil moisture contained in the surface 6 inches of bare ground. Variation in both soil moisture and the passive microwave antenna temperature appear to limit the possibility of making accurate measurements of soil moisture. Anomalies are present in the microwave response that at present cannot be explained, but these anomalies are reproducible in repeated flights over the same point.

The results of research thus far completed indicate that it may be possible to use microwave remote sensing as an indicator of rainfall-storage capacity in hydrologic models. Scanning watersheds with an X band radiometer for wet and dry conditions within a short period of time will produce a differential response that may be related to the storage capacity of surface soils.

The percentage of incident light reflected in the visible portion of the spectrum was found to be sensitive to differences in low concentrations of suspended sediments in water, thus a technique for estimating the sediment load of ponds and lakes with low sediment concentrations may be feasible.

Qualitative methods of estimating sediment yield from watersheds from high altitude photography appear feasible. Color infrared positive transparencies define erosion areas better than other types of film used in this study.

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TABLE I. - MEAN SOIL MOISTURE AND VARIANCE

	33 Samples at Each Site					Small Sample	
	0-.5 in.	0-6 in.		0-12 in.		0-6 in.<11	
Site No.	Mean %	Mean %	Variance	Mean %	Variance	Mean %	Variance
1	2.1	13.4	1.8	17.0	2.6	12.8	1.7
2	1.4	14.1	1.5	19.6	1.5	13.5	2.4
3	4.1	15.1	1.5	17.8	4.0	15.0	1.2
4	1.0	16.0	1.6	13.2	1.6	11.2	1.3
5	6.5	13.4	4.3	15.4	4.9	14.1	2.0
6	5.9	19.8	5.4	21.0	2.1	19.0	0.73
7	10.8	22.9	3.8	26.0	4.2	23.5	2.3
8	7.0	20.5	23.8	22.4	28.8	21.9	6.6
9	6.2	15.7	3.9	17.2	5.0	16.3	5.0

TABLE II. - LAND USE CLASSIFICATION

Number of Data Points	Class	Mean Antenna Temperature (°K) X Band	KA Band
450	Pasture	278.8	290.2
62	Eroded Soils and Gullies	276.7	289.8
141	Gullied Pastures	277.8	289.8
167	Timber	277.8	288.0
358	Bare Soil (Tilled Cropland)	279.1	288.9
81	Alfalfa	276.5	286.1
29	Bermuda and Love Grass	276.5	287.9
543	Unclassified	278.2	288.7

C 2

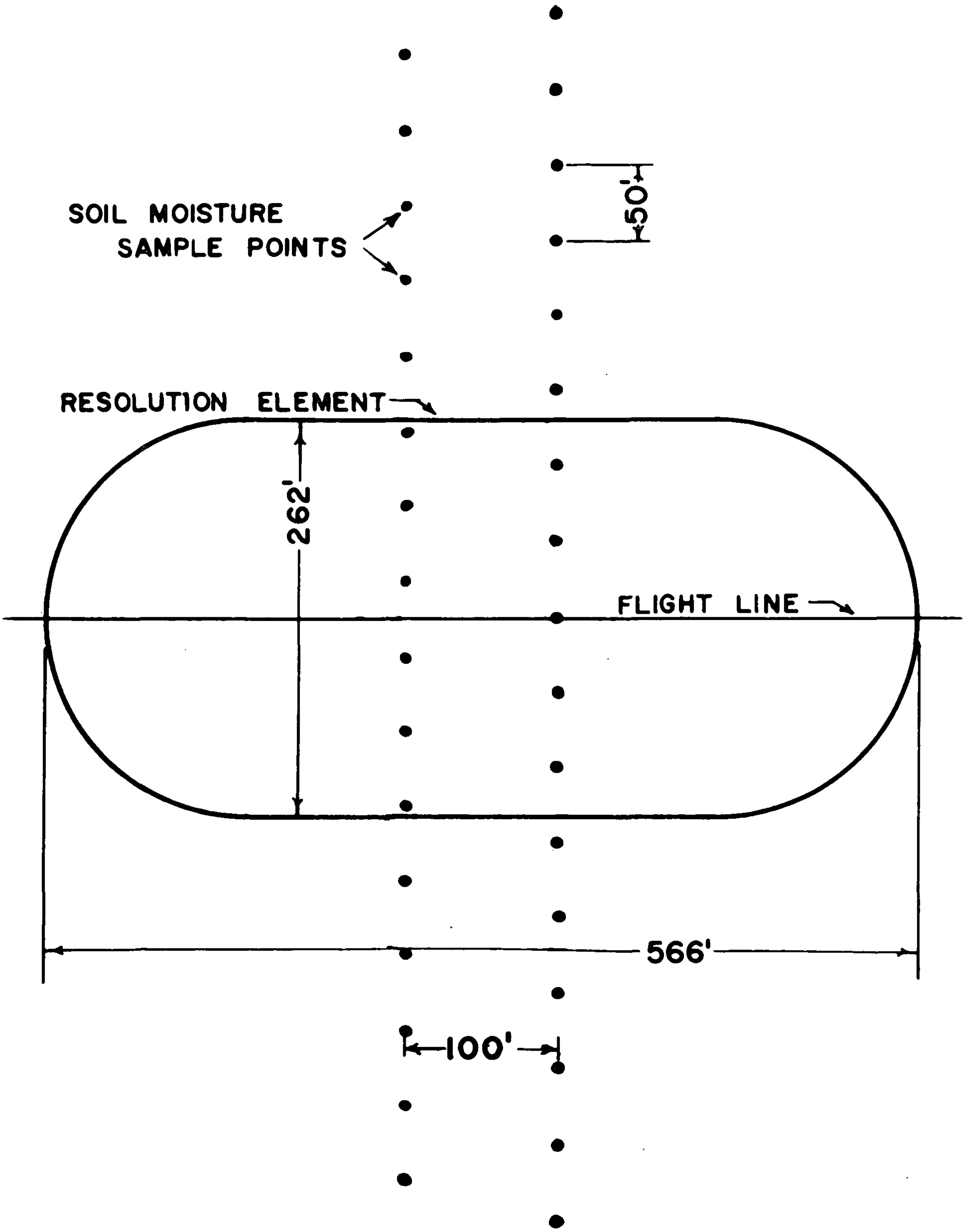

Figure 1. - Map of soil moisture sampling points at a single site with an illustration of the resolution element of the X and KA band radiometer.

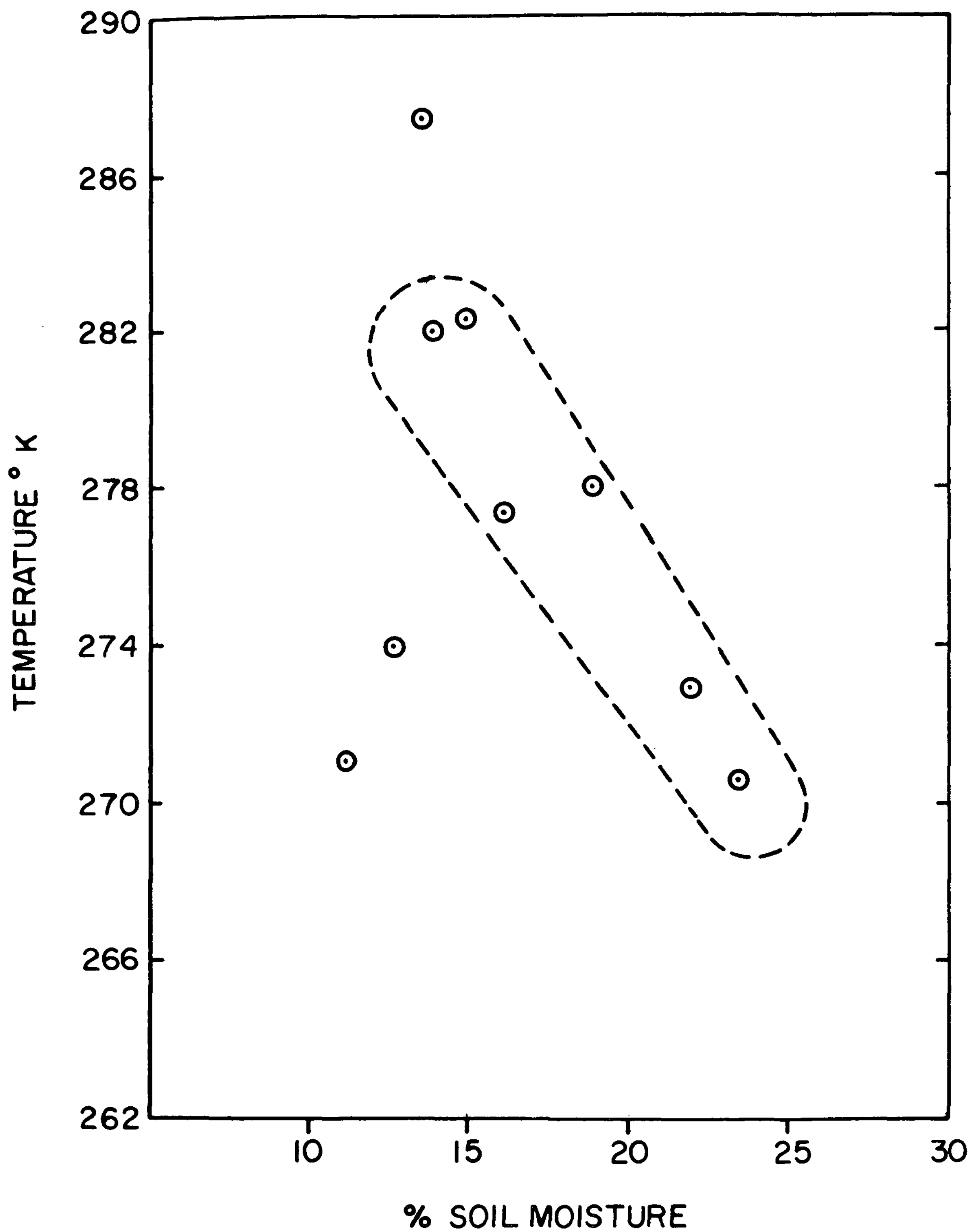

Figure 2. - Relation of X band radiometer antenna temperature to percent soil moisture (Oklahoma soils).

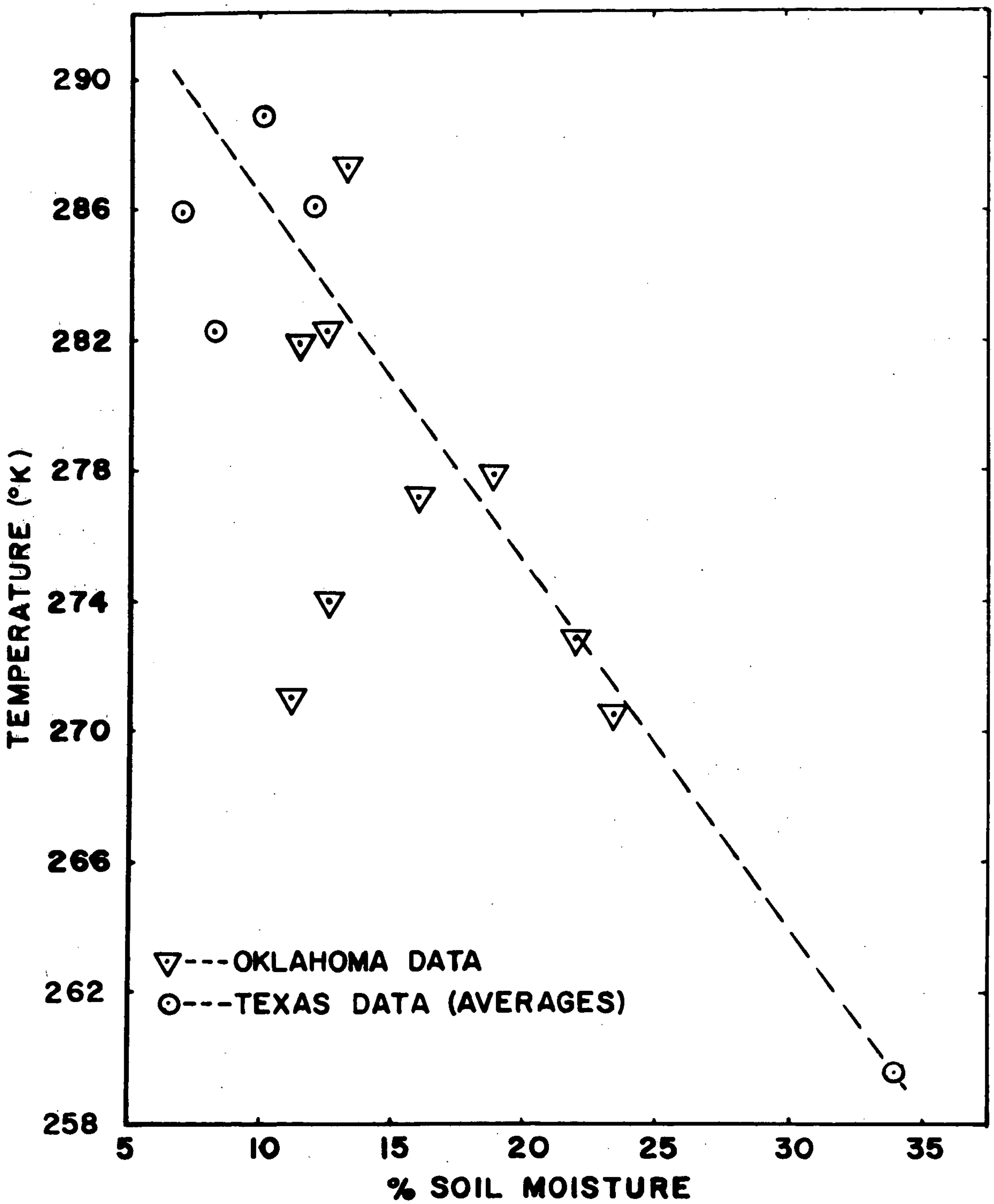

Figure 3. - Relation of X band radiometer antenna temperature to percent soil moisture (Oklahoma and Texas soils).

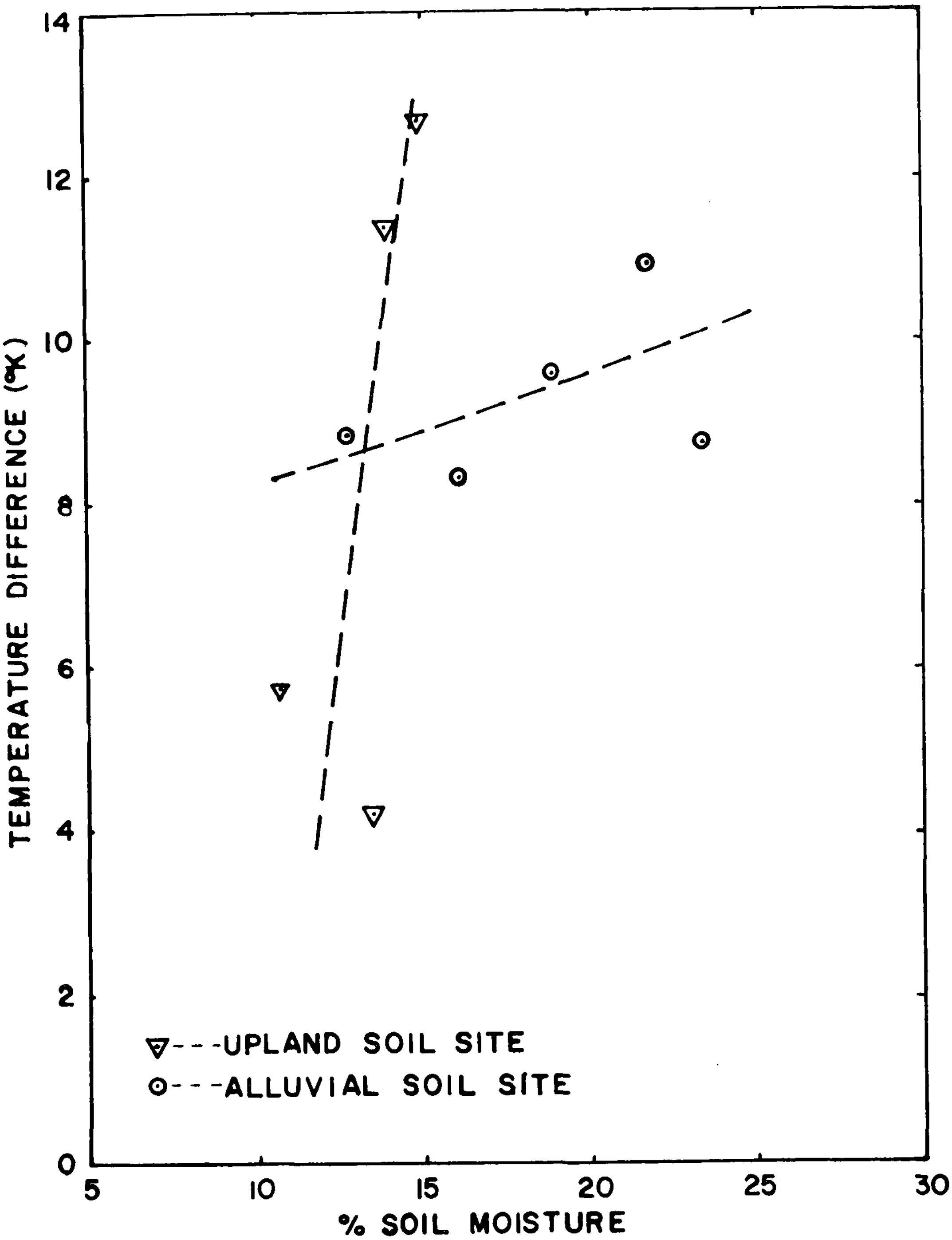

Figure 4. - Differences in antenna temperature (KA band-X band) as related to percent soil moisture (Oklahoma soils)