SPATIAL AND TEMPORAL ANALYSIS OF SOIL MOISTURE AND SOIL TEMPERATURE THROUGH A TRANSECT IN WEST-CENTRAL OKLAHOMA

By

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PREFACE

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INTRODUCTION

Physical geography is a science which studies the patterns of spatial distribution and variation of physical phenomena on the surface of the earth. Changes in phenomena over time contribute to the evolution of the landscape, differences in patterns, and variation in related phenomena. To adequately address and study the variation of physical phenomena the acquisition and assessment of measurements related to or associated with the primary patterns must be completed. Data can be acquired through the use of mechanical and electrical instruments and mapping. Data are collected to explain or determine the patterns of spatial distributions and the variation through space and over time.

Variables which effect the physical phenomena (rivers, plains, mountains, and desert) include topograhic and climatic characteristics such as aspect, slope angle, latitude and longitude, sun angle, temperature, precipitation, percent sun, relative humidity, and wind. Correlation and intercorrelation of these phenomena introduce complexity into the explanation of the spatial distribution and variation of the phenomena.

This research, in conjunction with a broader based project, will measure and analyze ground measures of soil moisture, soil temperature (at three depths), precipitation, air temperature, and topographical features. Variation in space and time are integral components of the project. Some of this data will be used to ground truth, or confirm, the remotely sensed data in another project. Because of the spatial and temporal variation in the characteristics of water and heat content of soils many fluxes will occur. Prediction of these fluxes is of prime interest (Boersma et al., 1972). Variability in ground characteristics that may influence soil conditions have been controlled in order to determine the impact of selected variables on soil moisture and soil temperature behavior. This project will assess the significance of the spatial and sequential changes observed in the measurements and state whether correlation with remotely sensed data is feasible.

Problem

For many years researchers have collected data on soil moisture and soil temperature, primarily for agricultural purposes and for other uses in engineering and construction. Measurements of these variables have been related to the effects of drought on crops and vegetation at specific locations but little effort has involved the use of these measurements over a large region to determine the effect of drought over time on soil characteristics across the zone.

Measurement of the spatial variability of soil-water contents and fluxes over large areas has been inferred rather than directly measured (Boersma et al., 1972). In situ methods can accurately estimate soil moisture throughout a three dimensional soil pedon but this information is reliable only at the point of measurement. To achieve a specified level of accuracy in estimating the areal average for most applications, a large number of point samples are required (Schmugge et al., 1980). A basic problem remains in that areal generalizations have not been derived from point measurements collected throughout a region.

Objective

Recent ability to acquire remotely sensed data on land-surface phenomena related to climate adds a new dimension to the analysis and interpretation of moisture stress or drought. An essential element in the use of remotely sensed data is the availability of reliable ground truth data. This research will monitor numerous surficial and subsurface characteristics over a period of months that vary in response to climate. Specifically, the following measurements will be collected each observation period: soil moisture and soil temperature at 15.4, 61, and 91.5 cms, precipitation, air temperature, relative humidity, and topographical features such as: aspect, slope angle, and elevation. These variables form the basis of the ground truth needed to evaluate remotely sensed data collected for climatic analysis.

This research will attempt to identify characteristics of soil moisture and soil temperature over time and through space (along a transect) that naturally possesses a significant climatic gradient and also experiences periods of moisture stress. The climatic gradient varies in potential evaporation, temperature, and precipitation. The following hypotheses will be assessed:

(1) The amount of soil moisture will increase with depth at each individual site.

It is generally known that the soil-water content changes with soil depth, but limited quantitative measures have been taken (Boersma et al., 1972). Soil-water moves from points of high temperature to points of low temperature if near a temperature gradient (Boersma, 1972). Gravimetric potential pulls water down to lower depths while surface evaporation decreases the amount of soil-water near the soil surface.

(2) The amount of soil moisture at the maximum root zone will be higher at the eastern sites compared to the western sites during the same time of year. Values should be greater in the east.

This difference should occur because the samples are spaced along a climatic transition zone.

(3) As air temperature increases across the transect from east to west, the soil temperature will increase from east to west.

An increase in elevation (304.8 m) from west to east would normally cause an environmental lapse rate of -6.3°C/304.8 m. In this study several other factors, however, have greater influence on air temperature than the lapse rate. These factors include surface heating and wind direction which drives warm air masses from the Southwest.

(4) As soil temperature increases through time from May to August, the near surface sample will undergo greater fluctuations in values than the changes that will be observed in the samples at lower depths.

(5) An increase in precipitation across the transect from west to east will create an increase in the soil moisture from west to east.

After collecting the ground data, a broader based project will utilize satellite images to evaluate if these changes along the transect can be correlated with climatic characteristics acquired as remotely sensed data.

Literature Review

A significant amount of research and data on soil moisture and soil temperature has been collected for agricultural purposes. Research including soil moisture and soil temperature in a fashion applicable for identifying changes across space (200 km transect) and through time is lacking. The importance of knowing how soil retains water and allows infiltration for plant uptake should not be ignored, but the geographical distribution and variation in soil moisture and soil temperature is also important. Ground truth data should be collected to enhance remotely sensed data and to study changes geographically. This may constitute a new means of identifying moisture-stressed areas.

Soil Moisture

According to Gardner and Kirkham (1951) soil moisture can be effectively measured through the utilization of a neutron probe. Early work concerned the understanding, calibration, accuracy, and use of the neutron moisture meter for measuring soil moisture (Gardner and Kirkham, 1951; van Bavel et al., 1954; and Taylor, 1955). Gardner and Kirkham (1951) decided that the probe should be used to measure the moisture content of the soil in the field and that a portable instrument should be developed. A significant amount of time was spent constructing a portable neutron meter. Taylor (1955) used several methods of measuring soil moisture but none proved to be completely satisfactory because of the sampling and instrument errors. The neutron method was the only technique with any possibility of being close to accurate (Taylor, 1955). By 1968, the neutron probe had proved to be an acceptable technique because of the quickness of measuring and the high accuracy of the instrument (Luebs et al., 1968). The probe allows for unlimited amounts of measurements for continuous and/or seasonal studies (Luebs et al., 1968; Visvalingam and Tandy, 1972). Because of this asset, comparison of soil moisture at specific points and across a large area through time is possible.

Early studies using the neutron probe method compared soil moisture amounts from barley fields and bare soil. The measurement of moisture content and precipitation provided the data needed to calculate the soil moisture content. The total moisture deficit was calculated from the calculated potential evaporation rate, rainfall, and percolation records. A total evaporation of 159 mm in barley was calculated from the total moisture deficit, percolation, and rainfall records. Little difference exists between the 159 mm of evaporation and the calculated evaporation (150 mm). The calculated evaporation is from measurements of radiation, air flow profiles, temperature, and humidity (Long and French, 1967).

Other studies in the 1970's used soil moisture content to determine proper irrigation periods as well as improved yield forecasting (Idso et al., 1975). Charney et al. (1977) used it to determine its effect on the desertification process with general circulation models. Another nonagricultural study by Gannon (1977) was to model sea breeze studies in central Florida because soil moisture is the primary factor.

Remotely sensed data from the thermal infrared, solar, and microwave sections of the electromagnetic spectrum were compared to soil moisture values collected in situ with gravimetric, nuclear, and electromagnetic methods. Sites of 400 square meters with uniform surface conditions were used. Average values from four points in each field were studied but the wide range in variability of soil moisture, showed that measurements must be taken over to have unbiased values (Schmugge et al., 1974).

A study to determine the significance of weather changes associated with soil moisture was made in England. Soil moisture measurements were taken on three soils of different texture. The sites had uniform elevation and slope. Rainfall measures from the Meteorological Office were used as precise values. The precipitation totals from each site were assumed to be less than or equal to the totals from the meteorological stations. Therefore, these small differences in precipitation do not cause the soil moisture fluxes. Physical properties of the soils caused the differences (Hall and Jones, 1983).

A study similar to this project statistically determined the variability in soil moisture for several sizes of plots ranging from 1 m square to 31 m square. It was found that reduction in plot size does not reduce the magnitude of variability. Other conclusions are: 1) soil moisture data are variable about the mean, 2) a large number of samples must be collected to decrease the biased estimate of the actual mean, and 3) slope angle, soil structure, vegetation, and time have an effect on the amount of variability in soil moisture (Hills and Reynolds, 1969).

From 1974 to 1977, Bell et al. (1980) have collected soil moisture data for several research sites. The data were from 58 large field sites, 40 acres each with measurements collected at specific depths. This study was made to develop a statistically based sampling system related to soil moisture variability. This should accurately define the soil moisture regime of a specific area. The results of the data show that the variability in the values are related to: 1) the moisture in the large field sites are normally distributed about the mean; 2) the variability for the entire range of field moisture contents may not be defined by a single value of the standard deviation or by the coefficient of variation, and 3) using an upper bound standard deviation parameter distinctly defines the maximum range of anticipated moisture variability.

Soil Temperature

Soil temperature is generally similar in small geographic areas (counties) and may be based on the average seasonal fluctuation from the mean, the mean annual soil temperature (MAST), and the mean cold or warm seasonal soil temperature gradient within the root zone (5 to 100 cm). Although the MAST is higher than the mean annual air temperature (MAAT), MAAT provides a general idea of the MAST for specific areas. In humid temperate areas with air temperature greater than or equal to 8.3°C and an adequate amount of rainfall, the change in MAST (on level slopes) is usually 3.6°C more than the air. When studying MAST for a pedon, it is usually the same in all horizons and at all depths (Smith et al., 1964).

Factors affecting daily soil temperature fluctuations are soil moisture, vegetation, slope, length of day, temperature of rain that falls, air circulation near the ground, and clouds. These factors, weather (the major factor), and air temperature fluxes, affect the upper 50 cm of the soil. Soil temperatures vary in the amount of fluctuation for different depths being measured. Soil temperatures below 50 cm are less affected by surface air temperatures, therefore, the fluctuation of soil temperature is minimal (Smith et al., 1964). Mueller (1970) says that soil temperature is mostly controlled by air temperature, which is conditioned by elevation, longitude and latitude, moisture, vegetation, and slope and aspect.

Mueller collected temperature data from seven soil series and found gradients of 8.2°C to 13°C from 0 to 152 cm in depth. Mueller's research stresses the regard for elevation, latitude and longitude, moisture, vegetation, slope, and aspect, rather than trends in temperature across space and through time.

Munn et al. (1978) measured soil and air temperature in three different vegetative areas, 1) meadow, 2) ecotone, and 3) forest, all at a uniform elevation. The study compared soil temperature values from each type of vegetation. Results show that temperature variations were greatest in the meadow, intermediate in the ecotone, and least in the forest. The summer soil temperatures were approximately 5°C warmer in the meadow at the 50 cm depth. This summer soil temperature was greatly influenced by the vegetative cover.

Finally, a study by Carter et al. (1980) measured the difference in soil temperature along a transect from northern Pennsylvania to northern West Virginia over a three year period. Multiple regression was used to determine if elevation and latitude have a controlling influence on the mean annual soil temperature. Correlations were calculated to determine if elevation and latitude are the variables controlling the variation in mean annual soil temperature. The multiple regression confirmed that increases in elevation and latitude contributed to a decrease in mean annual soil temperature.

CHAPTER II

STUDY AREA

Introduction

The study area, located in west-central Oklahoma was selected in an attempt to sample through a zone of climatic transition. Sites within the area were selected from east to west along highways 51 and 270. This transect extends approximately 200 km from Stillwater, Oklahoma to Woodward, Oklahoma (Figure 1). An east to west transect is necessary because climatic transition (as reflected in measured temperature and precipitation) occurs from east to west. The transect has a width of 11.3 km to permit selection of relatively uniform sites and for easy access to the sites for efficient measuring.

Uniformity of Sites

When ground data are collected across a large area at different locations, it is essential to control the variables that influence the different sites. Greater explanation can be achieved in the correlation of the ground measures with satellite information if variation is minimized. The layout of each control site must be similar because topography, land cover, land-use, soil types, size,

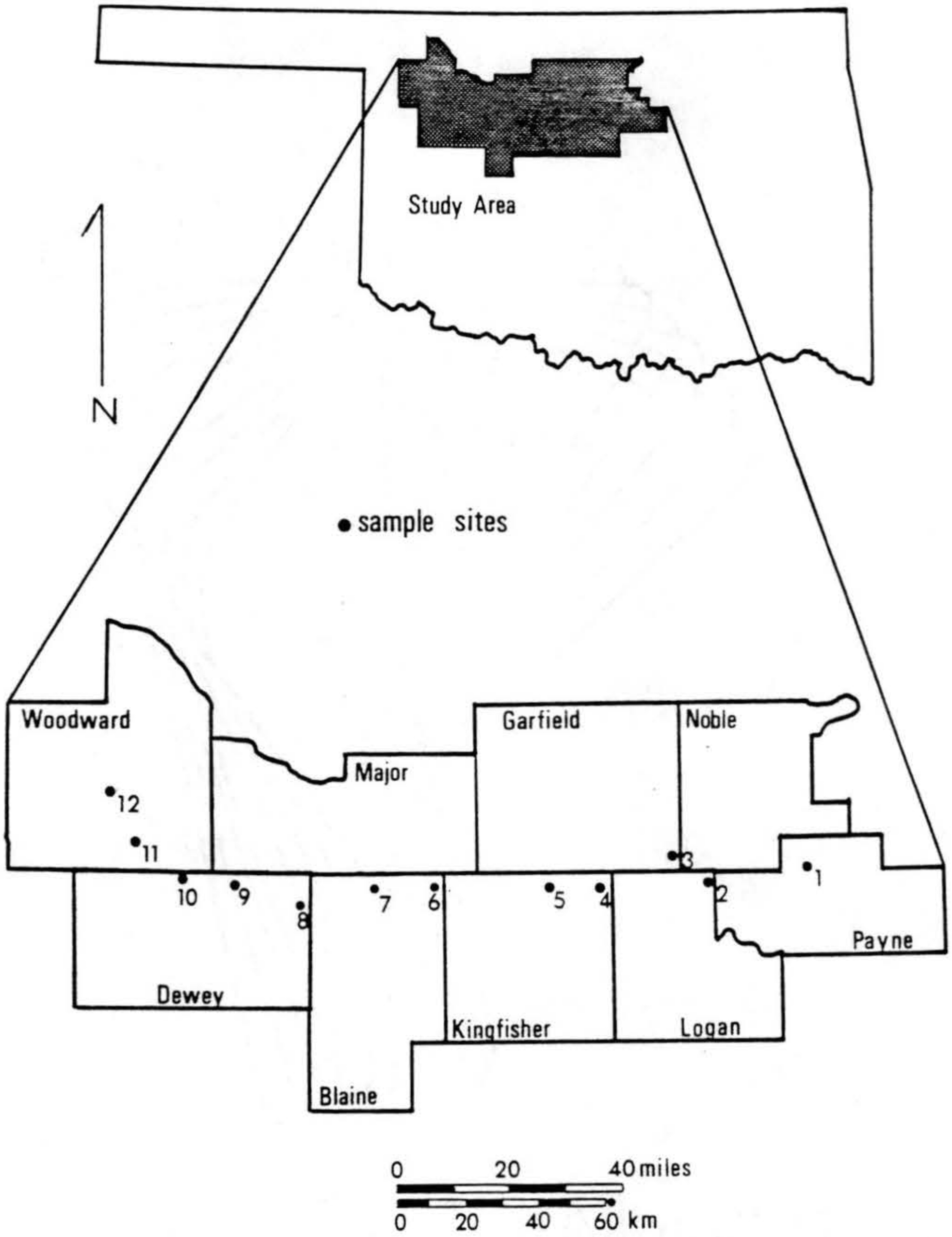

Figure 1. The Sample Site Locations Along the Transect

and aspect influence site characteristics. Significant changes in ground measures may occur with only slight differences in these variables. For example, topography and slope aspect can change the amount of runoff occurring on the sites. Land cover and land-use influence the amount of infiltration and runoff as well as redistribution of moisture. By minimizing variation in the control variables, impact on the phenomena being measured should be minimized. As a result, the ability to document and explain the onset of drought should be enhanced.

Physiography and Geology

The transect lies in the Southern Great Plains in which smooth, rolling plains extend across the 200 km area. Eleven of the twelve sample sites are located on upland topography. The study area slopes from the west at 597 m (1960 feet) above sea level to the east at 293 m (960 feet) above sea level. The slope at eleven sample sites is from 0 to 5 percent, the other site is on a 9 percent slope. Other site characteristics may be found in Appendix A.

Gray and Galloway (1969) developed a general description of Oklahoma's physiography and geology. Figure 2 includes the areas for the transect. Seven physiographic regions exist in the counties containing the transect but only four regions are located at the twelve study sites. The Redbed Plains, descended from Permian shales and clays,

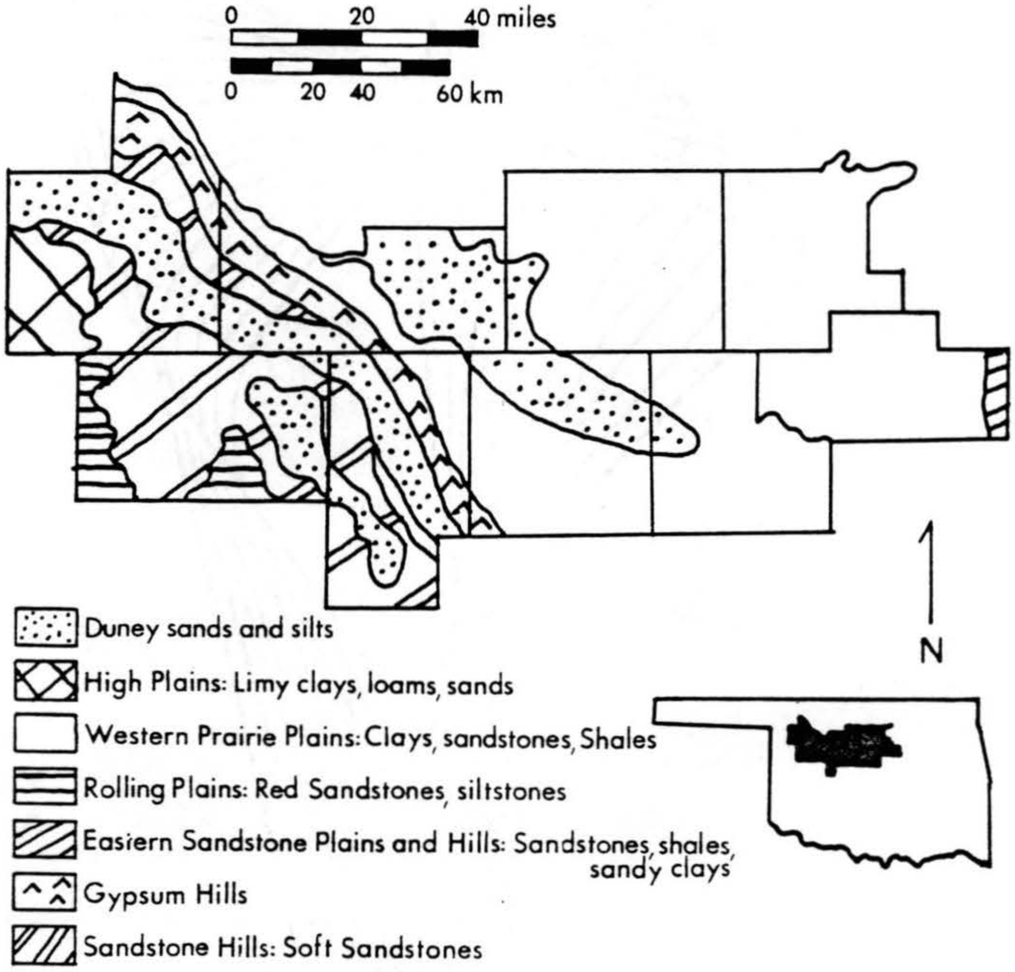

Figure 2. Physiography of the Study Area (Gray and Galloway, 1969)

extend across much of the transect. The eastern portion as well as some of the central transect is recognized as the Western Prairie Plains. These plains were formed from the Permian shales, clays, and sandstones. Dune sands and silts of Quaternary age were transported as aeolian and alluvial material by the North and South Canadian Rivers. This material was deposited in most of northern Kingfisher county as well as a diagonal band extending from northwestern Woodward county to southeastern Blaine county and eastern Dewey county. The Gypsum Hills are located directly east of the duney sands and silts. Weathered shale form the soft sandstone of the Sandstone Hills in parts of Blaine, Dewey, and Woodward counties.

Although physiographic diversity exists in the region, the twelve study sites are located on flat, uniform, upland areas within the various physiographic units. Site uniformity also includes native grasses, little slope, and similar soils to minimize surface runoff, variations in infiltration, and evapotranspiration.

Climate

The transect is characterized as having a continental climate. The average climate, however, is influenced by warm moist air carried north from the Gulf of Mexico. This influence from the Gulf, most predominant in southern and eastern Oklahoma, affects the transect area. Spring and summer winds are southerly with the period between March and

April having the highest winds, and July and August being the calmest months. Average wind velocity in the west is approximately 14 mph. The winds in the summer are hot and dry which, in combination with clear skies, cause rapid evaporation of soil moisture.

The average annual precipitation decreases from east to west along the study transect. Payne county has an annual rate of precipitation of approximately 86 cm. Further west in Blaine county, the average annual precipitation is 65 cm, and in Woodward county, the western extent of the study area, has 64 cm of rain per year. Average summer precipitations for Payne, Blaine, and Woodward are 7.8, 7.4, and 7.3 cm, respectively (USDA County Soil Surveys for Payne, Blaine, and Woodward counties).

The average temperatures for Payne, Blaine, and Woodward counties are 17.8°C, 16°C, and 15°C, respectively. Summer averages are 26°C for Payne County, 27.5°C for Blaine, and 27°C for Woodward (USDA County Soil Surveys for Payne, Blaine, and Woodward counties).

Air temperature at each of the twelve sites (field temperature) was collected for the 15 weeks observation period. Weekly average temperature was calculated for each of the 15 weeks at the eastern, 1, and central, 6, sites and a western, 11, site. These weekly averages were taken from daily temperatures (an average from the daily maximum and minimum) at the NOAA meteorologic stations nearest each study site. Normal temperatures for sites 1, 6, and 11 were also drawn from NOAA climatological data from May through August. Table I contains these three forms of temperature.

The field temperatures for the three study sites were above the normals for May through August. Standard deviations for the 15 weeks observation period at sites 1, 6, and 11, were calculated from the field temperatures and the meteorologic station weekly averages. Because of travel time between sites the time of observation is different for each site. At the eastern site, 1, six of the 15 weeks had standard deviations (SD) less than one, two weeks had SD's between one and two, another week had a SD of 2.654, and three weeks were between three and four. Weeks six, seven, and eight for site 1 had missing data. The central site, 6, had SD's of less than one for seven of the 15 weeks, SD's between one and two were calculated for four weeks, three other weeks had SD's between two and three, and one week had a SD of 3.756. A western site, 11, had two weeks of missing data, three weeks of SD's less than one, another three weeks had SD's between one and two, two weeks of SD's were between one and two, and two and three. Another week had a SD of 3.801, SD's between four and five occurred for three weeks, and only one week had a SD greater than five. Hence, the temperatures at the western site were more highly deviated from normal than were the eastern and central sites. The deviations from normal for the western site were affected by the time of the observation.

TABLE I

DIFFERENCES IN AIR TEMPERATURE (°C) FOR THE OBSERVATION PERIOD

Week	Field Observation		Weekly Average	Normal	Standard Deviation
1	20.6	Site 1	18.9	20.2	0.643
2	18.3		20.2	20.2	0.713
3	22.2		19.7	20.2	1.118
4	23.1		21.6	20.2	0.567
5	30.6		29.2	25.0	0.626
6	31.7		—	25.0	—
7	28.1		—	25.0	—
8	32.8		—	25.0	—
9	28.1		27.8	25.0	0.113
10	33.6		24.2	27.8	3.838
11	27.5		28.1	27.8	0.245
12	34.7		26.9	27.8	3.184
13	33.3		26.8	27.8	2.654
14	31.4		28.0	27.2	1.388
15	36.7		29.2	27.2	3.062
1	18.3	Site 6	19.7	20.8	0.529
2	21.7		20.8	20.8	0.340
3	22.8		20.2	20.8	1.163
4	26.1		24.2	20.8	0.718
5	32.8		27.2	26.1	2.504
6	21.7		23.6	26.1	0.718
7	25.6		24.5	26.1	0.449
8	30.0		27.2	26.1	1.252
9	28.9		24.8	26.1	1.550
10	37.2		28.0	28.8	3.756
11	24.4		30.9	28.8	2.654
12	28.9		29.8	28.8	0.367
13	31.4		27.7	28.8	1.511
14	29.7		27.3	28.1	0.980
15	25.6		30.5	28.1	2.000
1	—	Site 11	—	19.5	—
2	30.6		18.6	19.5	4.536
3	22.8		18.1	19.5	2.102
4	36.1		22.2	19.5	5.254
5	—		26.1	25.1	—
6	26.7		23.1	25.1	1.361
7	26.1		22.3	25.1	1.551
8	34.2		25.7	25.1	3.801
9	31.9		24.7	25.1	2.721
10	38.3		26.1	28.1	4.981
11	27.5		29.3	28.1	0.735
12	33.6		27.7	28.1	2.409
13	36.4		26.2	28.1	4.164
14	37.4		27.2	27.2	4.164
15	26.1		27.6	27.2	0.612

Study Area Soils

Soil samples from each horizon have been collected at each site. The soil types have been classified and certain physical properties such as soil texture and percent of sand, silt, and clay are described in Table II. The soil associations and series may be found in Tables III and IV, respectively. The physical properties of the soil are utilized in analyzing the effect they may have on the soil moisture, infiltration, retention, and evaporation. The soil-water content for a uniform, horizontal soil sample, with a constant water content, will be nearly constant with distance at a certain time along the samples (Boersma et al., 1972). Three of the sites are clay loams and three other sites are sandy loams. Soil-water should be held in the soil longer at the clay loam sites because of the higher tension in the clay. Less water will be held in the soil at the sandy loam sites because of the larger particle size and porosity; sands have less surface area and therefore hold less water. The permeability is much higher at the sandy loam sites because the particle size generates larger pore spaces.

Vegetation

Vegetation, like most charactersitics in nature, is directly influenced by external factors, specifically, topography, slope angle and aspect, soil properties, and

TABLE II

SOIL CHARACTERISTICS FOR THE OKLAHOMA TRANSECT

Site	Depth	Percent Sand	Percent Silt	Percent Clay	Soil Texture
1	1				
	2				
	3				
2	1	39.5	35	25.5	loam/clay loam
	2				
	3	37	35	28	
3	1	39.5	38.75	21.75	loam
	2	42.0	37.5	20.5	
	3	22	42.5	35.5	
4	1				silty clay
	2	17	42.5	40.5	
	3	14.5	37.5	20.5	
5	1	37	45	18	clay loam
	2	38.25	31.25	30.5	
	3	37	30	33	
6	1	29.5	32.25	24.25	clay loam
	2	49.5	22.5	28	
	3	44.5	22.5	33	
7	1	32	40	28	clay loam
	2	29.5	32.5	38	
	3	33.25	46.25	20.5	
8	1	10.5	27.5	38	sandy loam
	2	49.5	35	15.5	
	3	53.25	36.25	10.5	
9	1	37	48.75	14.25	loam
	2	34.5	43.75	21.75	
	3	32	40	28	
10	1				sandy clay loam/ loam
	2	49.5	30	20.5	
	3	52	26.5	21.75	
11	1	52	28.75	19.25	loam/sandy loam
	2	54.5	26.25	19.25	
	3	39.5	35	25.5	
12	1	40.75	41.25	18	loam
	2	38.25	38.75	23	
	3	39.5	37.5	23	

TABLE III

SOIL ASSOCIATIONS OF THE STUDY AREA

Site	Soil Association	Description
1	Zaneis	Very gently sloping, loamy soil on broad convex upland ridgetops, deep and well-drained
2	Renfrow-Vernon-Kirkland	Deep shallow prairie soils on red clay beds
3	Zaneis-Lucien-Vernon	Deep shallow very gently to steeply sloping soils of the uplands
4	Vernon-Renfrow	Deep reddish silt loams and clay loams, nearly level to gently rolling
5	Bethany-Norge	Deep, dark and nearly level to gently sloping
6	Norge-Kingfisher-Renfrow	Deep, loamy, well-drained, nearly level to sloping soils of the uplands, loamy and clayey subsoils
7	Bethany-Kirkland-Tabler	Deep well-drained and moderately well-drained nearly level soils of uplands, clayey subsoils
8	Woodward-Dill-Miles	Sandy uplands and red bed hills
9	Quinlan-Woodward	Red bed hills
10	St. Paul-Carey-Holdrege	Loamy uplands
11	St. Paul-Carey-Woodward	Gently sloping loamy red beds
12	St. Paul-Carey-Woodward	Gently sloping loamy red beds

TABLE IV

SOIL SERIES OF THE STUDY AREA

Series	Description
Rc:	Renfrow silt loam, 3-6% slope, tall grass, very slow water movement through subsoil, runoff and erosion are serious, mostly gramas and buffalo grass
KrB:	Kirkland-Renfrow silt loams, 1-3% slope, subsoil is very slowly permeable, moderately well-drained (droughty in dry periods), moisture is held tightly by clay particles unless very moist, then it is easily stored
VcB:	Vernon clay loam, 1-3% slope, droughty, shallow, slowly permeable, mixture of tall and short grasses, absorbs water slowly to very slowly but well-drained
BeA	Bethany silt loam, 0-1% slope, thick cover of tall grasses, soils are are granular and permeable in surface and subsurface, permeability is slow, high water holding capacity, moderate moisture retention
CeB:	Carey silt loam, 1-3% slope, mid and tall grasses, water erosion is serious hazard on steeper slopes, water erosion is not serious on 1-3% slopes
SaA:	St. Paul silt loam, 0-1% slope, granular and porous and absorbs water readily on the surface, the subsoil (36"), has slow permeability, lower area holds water, highly and easily penetrated by roots, mid grasses
CaB:	Carey silt loam, 1-3% slope, surface crusting, breakdown of structure in the surface layer, slightly susceptible to erosion, mid and tall native grasses, subsoil is permeable
CaC:	Carey silt loam, 3-5% slope, takes water well at the surface, similar to CaB

climate. Native grasses and trees of Oklahoma exist in specific locations because of the above mentioned factors.

The vegetation of Oklahoma varies from grassland prairie in the west to savanna and woodland regions in central and south-central Oklahoma to forest in the east (Gray and Galloway, 1969). As stated earlier, a sharp decrease in precipitation exists from east to west causing a decrease in soil moisture. Plant species change in their root system and resistance to drought as adaptation to the climate of the region. Portions of eastern Oklahoma contain tall grasses. As available moisture to plants decreases, mixed grasses begin to dominate areas (central Oklahoma). Further west, shorter grasses persist in this more arid region.

The transect is dominated by mixed grasses interspersed with small areas of cross timbers as shown in Figure 3. Although the twelve sites contain native grasses, the sites are not uniform. Natural changes in vegetation occur along the transect because of the climatic transition. With regard to vegetation, therefore, homogeneity of the sites does not exist. Typical perennial grasses along the transect are bluestems, gramas, Japanese brome, and buffalograss. Specific grass species for each site are given in Table V.

The study sites contain level slopes, similar soils, and native grasses. These factors create uniform sites for the entire area and will be considered as constants when

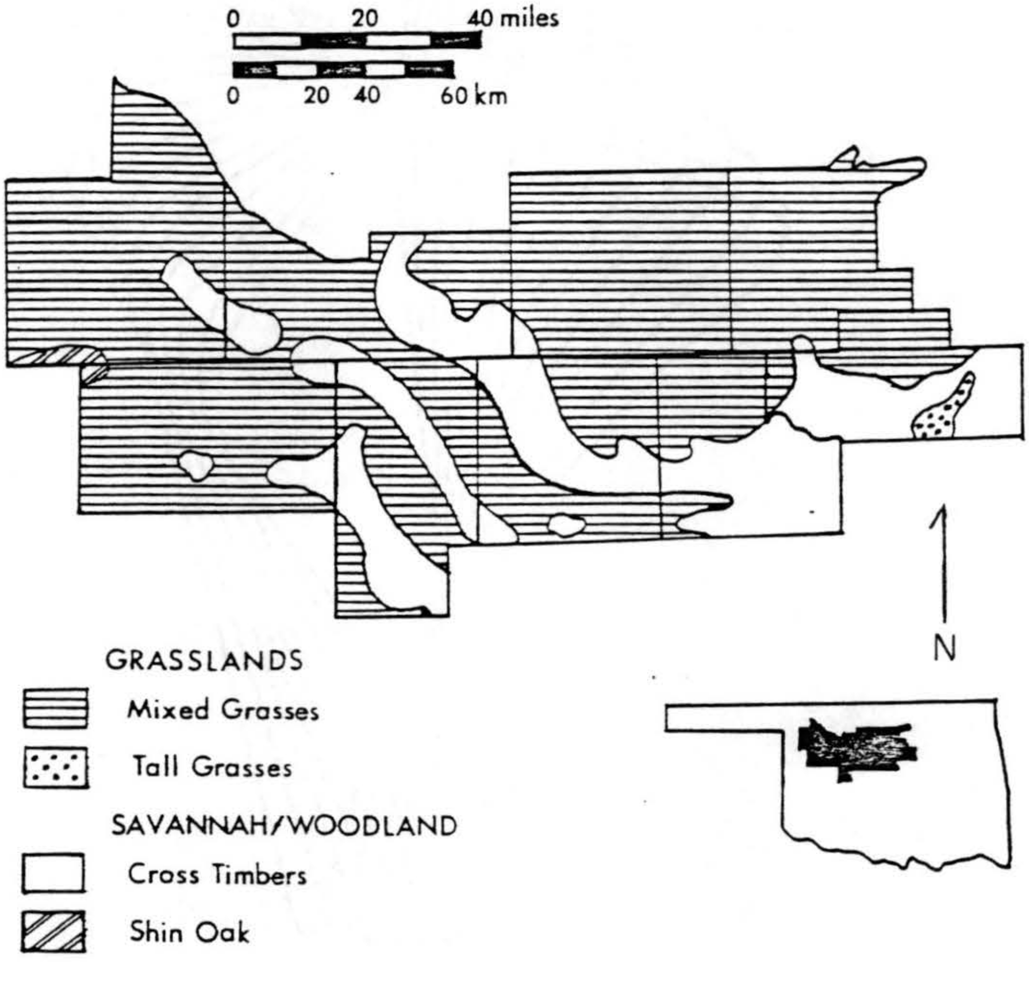

Figure 3. Natural Vegetation of the Study Area (Gray and Galloway, 1969)

TABLE V

VEGETATIVE SITE DESCRIPTIONS

Site	Grass %	Native Grass	Species Name	Type	Vegetation Density
1	40	Switch	(Panicium viragatum)	Tall	Dense
	30	Little Bluestem	(Andropogon scoparius)	Mid	
	25	Big Bluestem	(Andropogon gerardi)	Tall	
	5	Serial			
2	65	Little Bluestem	(Andropogon scoparius)	Mid	Medium
	35	Serial: Western Ragweed	(Ambrosia psilostachya)		
		Sage	(Artimisia)		
3	65	Little Bluestem	(Andropogon scoparius)	Mid	Medium
	15	Western Ragweed	(Ambrosia psilostachya)		
	8	Switch	(Panicium viragatum)	Tall	
		Big Bluestem	(Andropogon gerardi)	Tall	
	2	Buffalograss	(Buchloe dactyloides)	Short	
		Hairy Grama	(Boutelova hirsuta)	Short	
4	33	Silver Bluestem	(Andropogon saccharoides)	Mid	Dense
	33	Japanese Brome	(Bromus Japoniaes)		
	33	Western Ragweed	(Ambrosia psilostachya)		
5	45	Silver Bluestem	(Andropogon saccharoides)	Mid	Medium
	30	Japanese Brome	(Bromus Japoniaes)		
	15	Western Ragweed	(Ambrosia psilostachya)		
	10	Sideoats Grama	(Boutelova curtipendula)	Mid	
6	60	Japanese Brome	(Bromus Japoniaes)		Medium
	25	Silver Bluestem	(Andropogon saccharoides)	Mid	
	15	Serial: Snowy Partridgepea	(Chamaecrista fasciculata)		
		Blue Wildindigo	(Baptista australis)		
		Doted Grayfeather	(Liastris puncata)		
7	60	Buffalograss	(Buchloe dactyloides)	Short	Thin
	25	Japanese Brome	(Bromus Japoniaes)		
	10	Silver Bluestem	(Andropogon saccharoides)	Mid	
	5	Western Ragweed	(Ambrosia psilostachya)		

TABLE V (Continued)

Site	Grass %	Native Grass	Species Name	Type	Vegetation Density
8	65	Japanese Brome	(Bromus Japoniaes)		Med-Thin
	30	Buffalograss	(Buchloe dactyloides)	Short	
		Hairy Grama	Boutelova hirsuta)	Short	
	5	Serial: Western Ragweed	(Ambrosia psilostachya)		
		Snowy Partridgepea	(Chamaecrista fasciculata)		
		Sand Sage	(Artimisia)		
9	60	Sideoats Grama	(Boutelova curtipendula)	Mid	Thin
		Hairy Grama	(Boutelova hirsuta)	Short	
	15	Little Bluestem	(Andropogon scoparius)	Mid	
	15	Japanese Brome	(Bromus Japoniaes)		
	10	Bare Soil			
10	50	Japanese Brome	(Bromus Japoniaes)		Dense
	35	Hairy Grama	(Boutelova hirsuta)	Short	
		Buffalograss	(Buchloe dactyloides)	Short	
	10	Western Ragweed	(Ambrosia psilostachya)		
	5	Little Bluestem Serial	(Andropogon scoparius)	Mid	
11	65	Little Bluestem	(Andropogon scoparius)	Mid	Medium
	25	Silver Bluestem	(Andropogon saccharoides)	Mid	
		Western Ragweed	(Ambrosia psilostachya)		
	10	Japanese Brome	(Bromus Japoniaes)		
12	70	Sideoats Grama	(Boutelova curtipendula)	Mid	Thin
	10	Bare Soil			
	10	Little Bluestem	(Andropogon scoparius)	Mid	
	5	Japanese Brome	(Bromus Japoniaes)		
	5	Western Ragweed	(Ambrosia psilostachya)		
		Snowy Partridgepea	(Chamaecrista fasciculata)		

soil moisture and temperature measurements are evaluated. The infiltration and evaporation of moisture are also considered to be uniform and have no separate affects on the soil measurements.

CHAPTER III

METHODOLOGY

Introduction

During a sampling period from May 7th through August 13th, 1980, soil moisture, soil temperature, precipitation, air temperature, and relative humidity measurements were taken weekly. The sample sites are located along a transect of approximately 200 kilometers in west-central Oklahoma. Sampling started shortly after sunrise at the first site located in Stillwater and ended at dusk approximately 13 km south of Woodward. Sampling began early in the morning in order to complete the string of measurements in a day. Each site was sampled at approximately the same time each day.

Site Selection

The twelve study sites were initially selected from county soil survey sheets of the USDA Soil Conservation Service, used in conjunction with topographic maps. The final selection of a site was determined by field observation to verify native grassland cover rather than cultivated cover. The county survey maps were initially used to identify easily accessible sites, i.e., close to highways 51 and 270, and to identify an area with uniform vegetation and flat, upland slopes. Slope, elevation, and longitudinal measures were collected from topographic maps. Land owners, identified with help from the SCS and courthouse documents, were contacted for permission to utilize their land. The field instruments in this study require a stable soil profile because any disruption would destroy the site and generate unreliable soil moisture values. Wire fences were built to protect each site from cattle who would trample the thermocouples, access tubes, and rain gauges.

Within each site, two galvanized steel tubes, 3.81 cm in diameter, were driven into the ground to a depth of 122 centimeters. The soil was augered out of these tubes. Rubber stoppers were inserted in the open pipes to prevent any input of precipitation. Measurements were taken at 15.4 cm, 61 cm, and 91.5 cm, the latter measurement being the base of the root zone. These depths were chosen to observe the changes in soil moisture with depth throughout the root zone.

The measurement of soil temperature for this research was obtained from thermocouple psychrometers using a microvoltmeter. Thermocouple psychrometers were placed at the same three depths as the measurements taken in the access tubes. The thermocouple at the 15.4 cm depth is used to determine a temperature gradient. The thermocouple psychrometers are very sensitive to temperature gradients at shallow depths which may cause false soil temperature values at the 15.4 cm depth (McAneney et al., 1979). The thermocouple psychrometers were planted into the ground at these specific depths by augering holes. At the 15.4 cm depth, placement should be horizontal to avoid any disruption of the moisture flow in the soil adjacent to the ceramic casing (Merril and Rawlins, 1972).

Two nonrecording rain gauges were positioned on each site to collect precipitation data. These measurements may be in error given the occurrence of evaporation, but NOAA (National Oceanic and Atmospheric Administration) weather stations, in close proximity to the transect, will be utilized for the analysis of precipitation and temperature gradients likely to occur across the transect (Figure 4). NOAA weather stations were related to as many sites as possible by the Theissen polygon method. A station within the polygon, and closest to the site, was chosen to represent the precipitation at that site. A sling psychrometer, used to measure the wet bulb and dry bulb temperature was employed to calculate the relative humidity at each site on the day samples were collected.

Approximately 2.54 meters (horizontal distance) separate the two sets of thermocouple psychrometers as well as the access tubes (Figure 5). Two sets of instruments were utilized at each site to insure a reading if one set failed. Moreover, two values can be combined into an average value, an average that may designate differences in values across 2.54 meters. The 2.54 meters between the

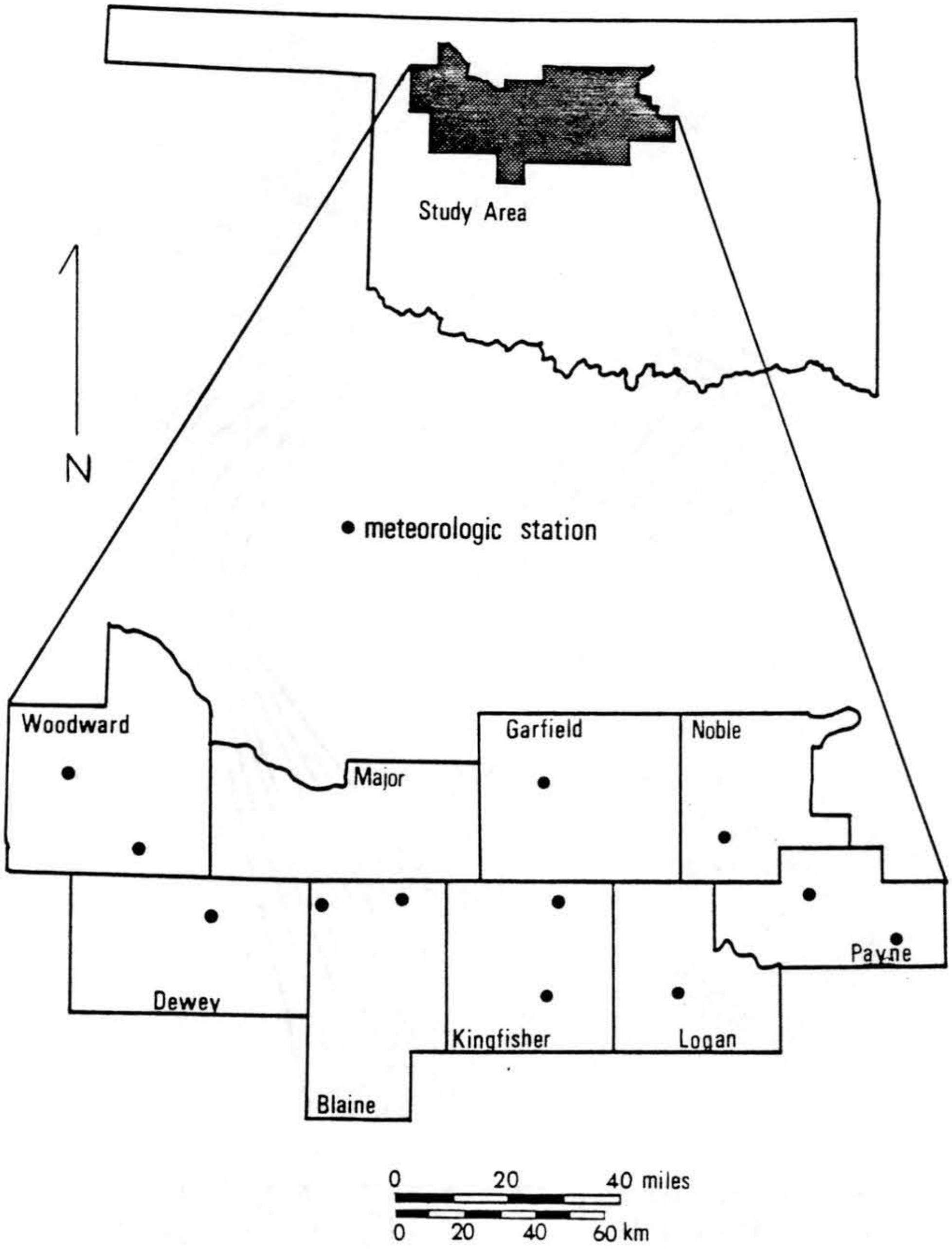

Figure 4. Location of NOAA Meteorologic Stations in the Study Area

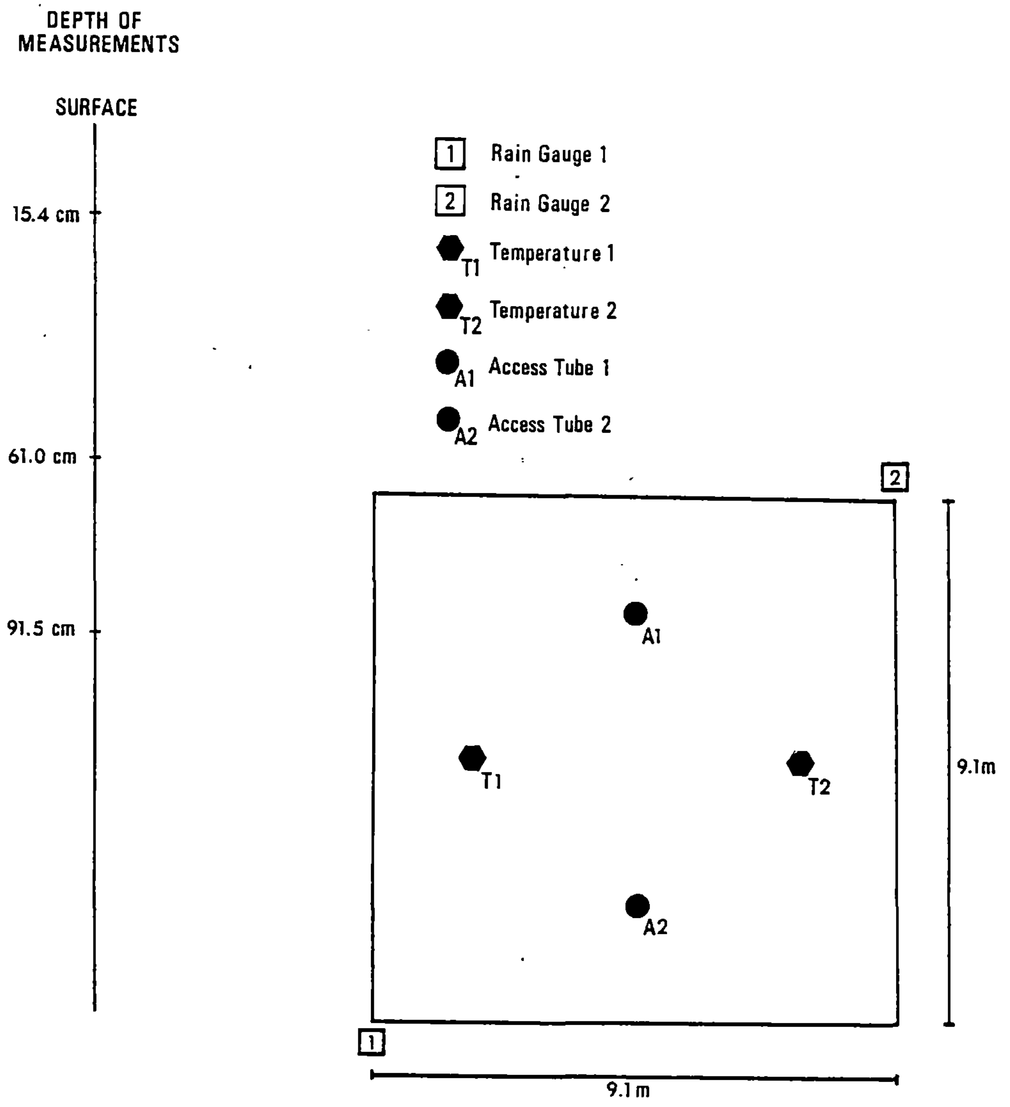

Figure 5. Sample Station Layout

access tubes is required to prevent the overlapping of dispersed neutrons from the neutron probe and to detect any variability in a site.

According to soil moisture research by Gardner and Kirkham (1951) the moisture content in soil may be taken by neutron meters in the field and that a portable instrument should be developed (Gardner and Kirkham, 1951). The probe has proved to be an acceptable technique because of the quickness of measuring and the high accuracy of the instrument (Luebs et al., 1968). It allows the soil to be measured in any physical state covering a large volume of space. The greatest depth at which data may be collected is restricted by the length of the access tube (Luebs et al., 1968; Visvalingam and Tandy, 1972). The probe and access tubes allow for unlimited numbers of measurements for continuous and/or seasonal studies (Luebs et al., 1968; Visvalingam and Tandy, 1972). Because of this asset, comparison of soil at specific points and across a large area through time is possible.

The neutron probe meter is placed over each implanted tube and the probe is dropped into the access tube to measure the amount of moisture in the soil. A radioactive source and detector are enclosed in the probe. Fast neutrons are emitted by the source which are later converted to slow neutrons after reacting with water molecules. The number of slow neutrons is equivalent to the water content of the surrounding soil (Belcher, D.J., et al., 1950).

A problem may exist using the probe because of a low degree of spatial resolution. This study decreased the resolution problem by placing two sets of tubes at each site and by measuring water content at twelve sites over a 200 kilometer area. Unlike the gravimetric method, the neutron probe method measures soil moisture changes at a precise location through time, rather than from soil variations (Visvalingam and Tandy, 1972; Belcher et al., 1950).

Potential health hazards from the probe are easily avoided if simple precautions are taken (Visvalingam and Tandy, 1972; Belcher et al., 1950). The probe should be carried for only short distances and short time periods for safety. Over a ten year span, users of the probe at North Dakota State University found no cases of high radiation exposure (Gee et al., 1976). A dosimeter is attached near the waist to record any instances of exposure to radiation.

The accuracy of the probe is thought to be above standard procedures. The standard error for the data over a larger volume of soil is less with use of the neutron probe than with standard procedures (Visvalingam and Tandy, 1972). Stewart and Taylor (1957) do not agree that the neutron probe method exceeds the gravimetric method. Bulk density of the volume of soil is required for accurate measurements of soil moisture at all depths (Luebs et al., 1968). Bulk density is helpful in estimating the amount of water which may be held in the soil. A specific bulk density was designated for the moisture calculation obtained from the Northstar computer program.

One problem with the accuracy of the neutron probe occurs when measuring moisture content at or near the surface. The fast neutrons released tend to escape into the atmosphere decreasing the accuracy of the measurements (Luebs et al., 1968). The moisture content at the surface is underestimated by five percent when a surface shield is not used (Long and French, 1967). In one study the steel and plastic tubes decreased the readings, the latter by at least fifteen percent (Stolzy and Cahoon, 1957). Another problem with access tubes is the presence of water in the borehole because of soil compaction during the installation. This compaction increases the moisture content whereas the loose backfill around the access tube, when dry, reduces the neutron count accelerating the escape of neutrons (Holmes, 1956).

When the thermocouple holes were dug, soil samples were taken from each horizon, labeled, and placed in plastic bags for laboratory analysis. The soils were dried and a particle size analysis was performed to determine the texture and the soil type for each site (Table II in Chapter 2). To complete site description, the vegetation was classified and the percent of cover for different grasses and serials was determined as shown in Table V in Chapter 2.

CHAPTER IV

ANALYSIS

Introduction

Following the collection of soil moisture, soil temperature, precipitation, air temperature, and longitude data, statistical techniques were used to interpret the relationships and variations between and within the above mentioned variables. Because of the care in which field sites were established, it was assumed that slope angle and aspect, vegetation composition, and soil texture had negligible effects on the soil moisture and soil temperature measures at the twelve sites, and therefore those variables were not statistically analyzed.

The depths for measuring soil temperature in this study were chosen to evaluate the changes and identify trends which may occur across a large area and during a growing season. In general, temperature fluctuations occur to at least 1.5 m below the surface and winter temperatures exist in the soils below 1.5 m (Shul'gin, 1965). Stabilization of fluctuations begins approximately nine meters into the soil. Soil temperature varies in response to the radiant, thermal and latent heat exchanges which take place primarily through the soil surface. Time and space variables affect the rates of temperature transport through the soil profile.

Initial statistical analysis involved simple regression and correlation. Table VI contains regression equations developed from a procedure for general linear models as written by the SAS Institute (Statistical Analysis System). It also contains the R-square value for the specific variables. R-square can range from 0 to 1 and indicates how much variation in the dependent variable can be explained by the model. Table VII contains correlation coefficients between several of the variables. Correlation measures the strength of the relationship between two variables and the correlation coefficients can range from -1 to 1. Positive correlations explain similar relationships usually having high values for both variables. Negative correlations have inverse relationships.

General trends in soil moisture and soil temperature are represented in illustrations for the eastern site (1), a central site (6), and the western site (12). If all twelve sites were analyzed, the illustrations and analysis would be cluttered and difficult to comprehend. By using an eastern, a central, and a western site, the trends which occur can be shown clearly across the entire transect.

The results from the statistical analyses and several illustrations are discussed relative to the acceptance or rejection of each individual hypothesis.

TABLE VI

REGRESSION AND R-SQUARE VALUES FOR SOIL MOISTURE AND SOIL TEMPERATURE

Variables	Regression Equation	R-Square	
STEMP15*WEEK	STEMP15 = 0.552(WEEK) + 20.099	0.483	*
STEMP15*DIST	STEMP15 = -7.00E-06(DIST) + 28.410	0.019	
STEMP61*WEEK	STEMP61 = 0.566(WEEK) + 17.636	0.761	*
STEMP91*WEEK	STEMP91 = 0.569(WEEK) + 16.171	0.791	*
STEMP61*DIST	STEMP61 = -2.681(DIST) + 23.713	0.004	
STEMP91*DIST	STEMP91 = -2.092(DIST) + 21.934	0.002	
SMOIS15*WEEK	SMOIS15 = -0.008(WEEK) ± 0.221	0.152	*
SMOIS61*WEEK	SMOIS61 = -0.010(WEEK) + 0.308	0.227	*
SMOIS91*WEEK	SMOIS91 = -0.006(WEEK) + 0.306	0.159	*
SMOIS15*DIST	SMOIS15 = 06.00E-07(DIST) + -0.201	0.245	*
SMOIS61*DIST	SMOIS61 = 1.070E-06(DIST) + -0.396	0.620	*
SMOIS91*DIST	SMOIS91 = 7.007E-07(DIST) + -0.145	0.513	*

* Significant values at 0.05 level

TABLE VII

CORRELATION COEFFICIENTS FOR SOIL, TOPOGRAPHIC AND CLIMATIC CHARACTERISTICS

Variables	Correlation Coefficient	
SMOIS15*SMOIS61	0.66	*
SMOIS15*TEMP	-0.51	*
SMOIS15*DIST	0.48	*
SMOIS61*SMOIS91	0.85	*
SMOIS61*ELEV	-0.78	*
SMOIS61*DIST	0.78	*
SMOIS61*TEMP	-0.58	*
SMOIS9		
SMOIS91*ELEV	-0.65	*
SMOIS91*DIST	0.65	*
STEMP15*STEMP61	0.77	*
STEMP15*STEMP91	0.75	*
STEMP15*TEMP	0.84	*
STEMP15*WEEK	0.85	*
STEMP15*DIST	-0.13	
STEMP61*STEMP91	0.96	*
STEMP61*WEEK	0.85	*
STEMP61*TEMP	0.86	*
STEMP91*TEMP	0.84	*
STEMP91*WEEK	0.87	*

* Significant values at 0.01 level

Hypothesis 1

> The amount of soil moisture will increase with depth at each individual site.

The three-space plots illustrate the changes in the amount of soil moisture at each depth through time and distance. The plot of soil moisture (Figure 6) at 15.4 cm has an irregular distribution which indicates that at that depth, surface dynamics affect soil moisture. The downward trend of this plot indicates a decrease in soil moisture with time (May through August). A rapid increase in precipitation or a decrease in temperature may have caused the abrupt increase in soil moisture for week 13 at sites 1 and 12. The correlation between soil moisture at 15.4 cm and air temperature is -0.51 which means that soil moisture is indirectly related to air temperature with regard to the variation observed.

Soil moisture at greater depths (Figures 7 and 8) also decreased with time, but at a more gradual and consistent rate. The moisture loss at greater depths were much less rapid. Overall, the amount of soil moisture is greater for the lower depths, 61 cm and 91.5 cm, than for the shallow depth, 15.4 cm. Soil moisture at 91.5 cm for site 1 (Figure 8) is generally less than soil moisture at 61 cm for site 1 (Figure 7). Sites 6 and 12, however, have the opposite trend; soil moisture at 91.5 cm is greater than soil moisture at 61 cm.

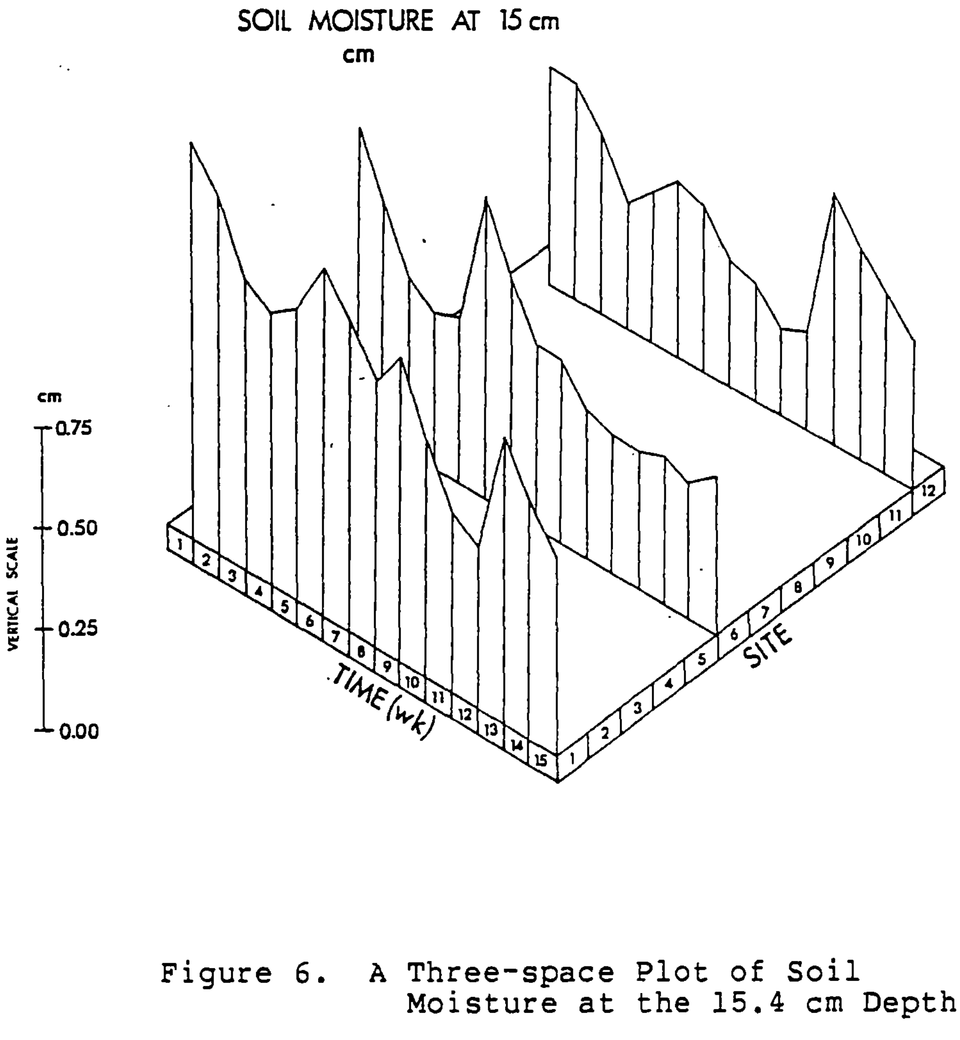

Figure 6. A Three-space Plot of Soil Moisture at the 15.4 cm Depth

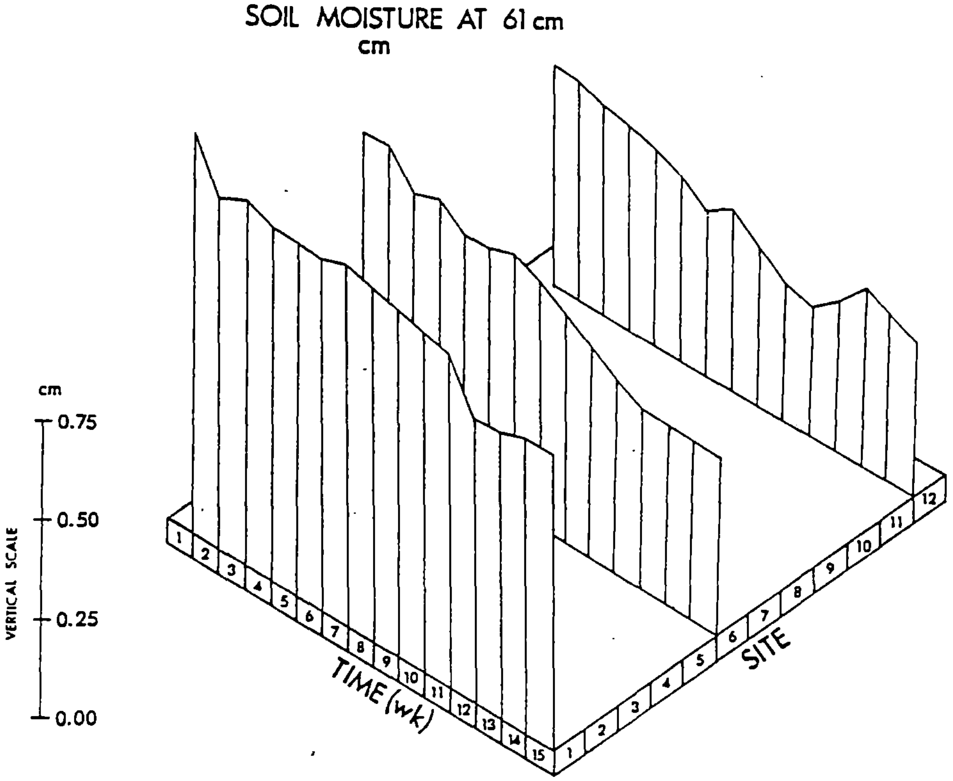

Figure 7. A Three-space Plot of Soil Moisture at the 61 cm Depth

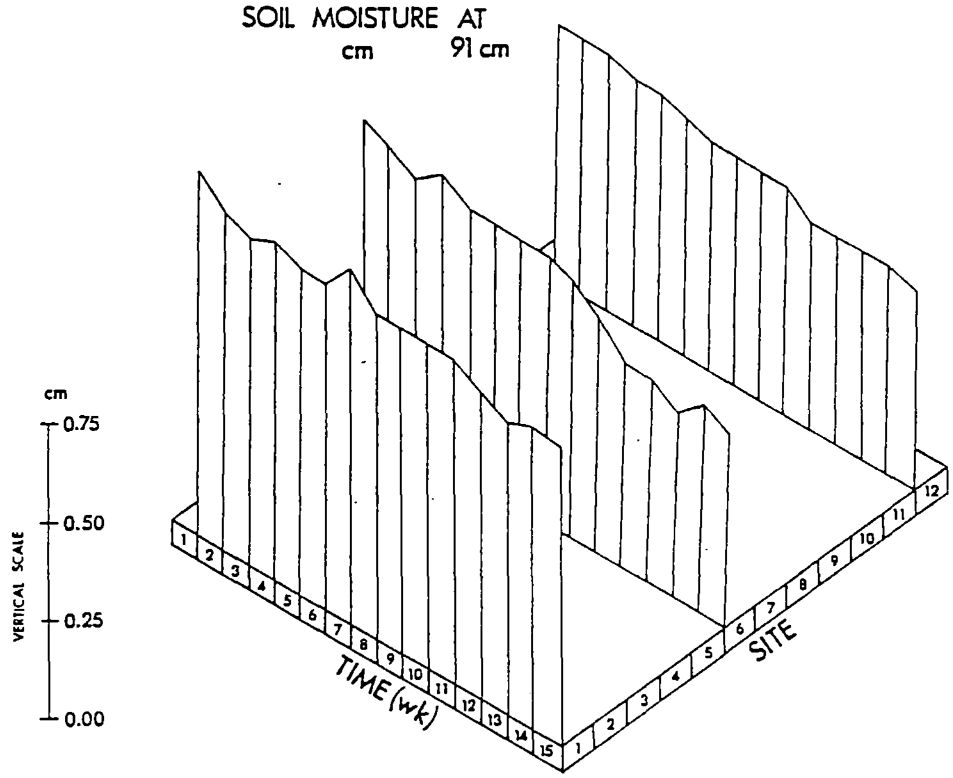

Figure 8. A Three-space Plot of Soil Moisture at the 91.5 cm Depth

The soils were saturated before data collection began. As air temperature increased and plant growth occurred the amount of soil moisture decreased. Soil-water is removed by the plant roots at different rates and at different soil depths. Evaporation of soil-water occurs at the soil surface depth of 15.4 cm. The combination of evaporation and root-uptake of water cause the lower soil moisture values for the 15.4 cm depth. Higher soil moisture values occur at depths of 61 cm and 91.5 cm because of the vertical movement of water in the soil, and the protection from surficial climatic variables. The grasses change across the transect, therefore the root zone depth also changes, this may increase or decrease the soil moisture at all three depths.

Soil moisture at 15.4 cm compared to 61 cm results in a positive correlation of 0.66. High soil moisture amounts at 61 cm are expected when high moisture amounts exist at 15.4 cm. A more significant relationship is found between soil moisture at 61 cm and 91.5 cm (0.84 correlation). The absence of surficial variables contributes to the more significant correlation. Hence, the evidence supports the acceptance of hypothesis one.

Hypothesis 2

> The amount of soil moisture at the maximum root zone will be higher at the eastern sites compared to the western sites during the same time of year. Values should be greater in the east.

The maximum depth in which the root zone effects are sampled along the transect is 91.5 cm. Although the types of native grasses vary along the transect and the maximum depth of the root zone varies (known from observation), the soil moisture at the maximum root zone will be discussed.

Soil moisture values (from minimum to maximum) are different at the eastern (1), central (6), and western (12) sites. This difference in soil moisture takes place over a 15 week observation period. The eastern site (1) at the 91.5 cm depth has a minimum soil moisture value of 0.75 cm and a maximum value of approximately 0.90 cm (Figure 9). The soil moisture values for the central site (6) at the 91.5 cm depth are lower than those at the eastern site (Figure 10). The range in soil moisture for site 6 is from slightly less than 0.50 cm to 0.75 cm. The amount of soil moisture at the western site (12) is the lowest of the three sites (Figure 11). It ranges from 0.50 to 0.65 cm. Therefore, at site 1 the soil moisture at the 91.5 cm depth is greater than that at sites 6 and 12. Site 6 contains more soil moisture than site 12. The graphs, Figures 9, 10, and 11, clearly illustrate the

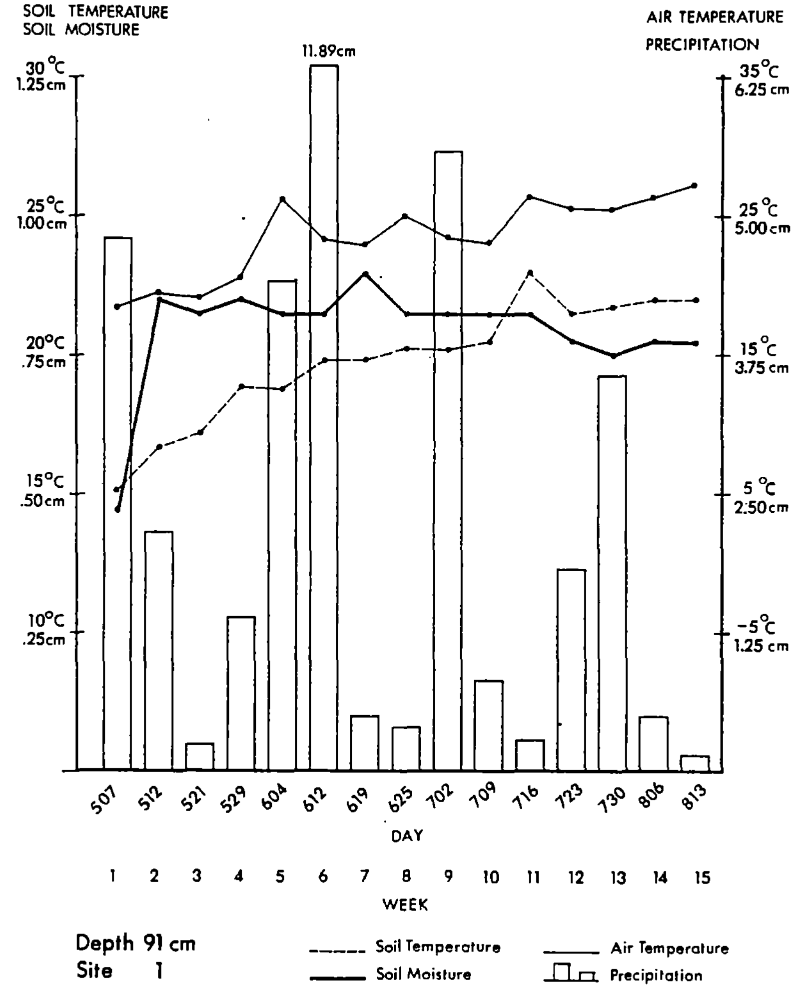

Figure 9. Relationships between Soil and Surface Characteristics for Site 1, Depth 91.5 cm

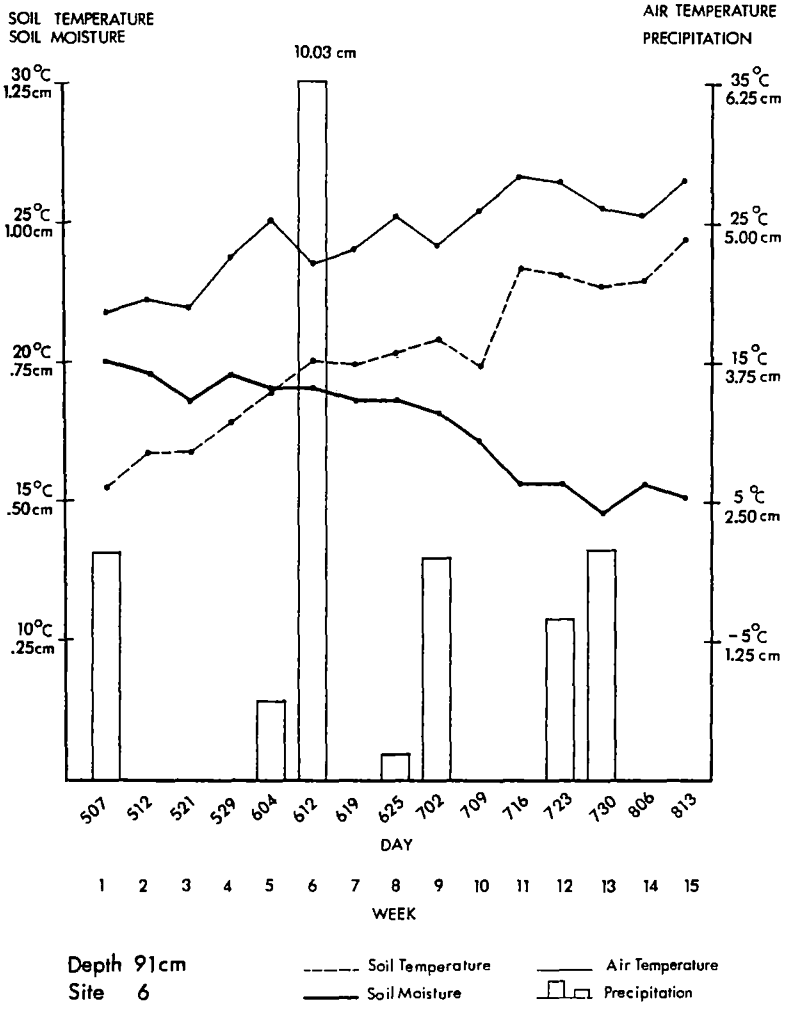

Figure 10. Relationships between Soil and Surface Characteristics for Site 6, Depth 91.5 cm

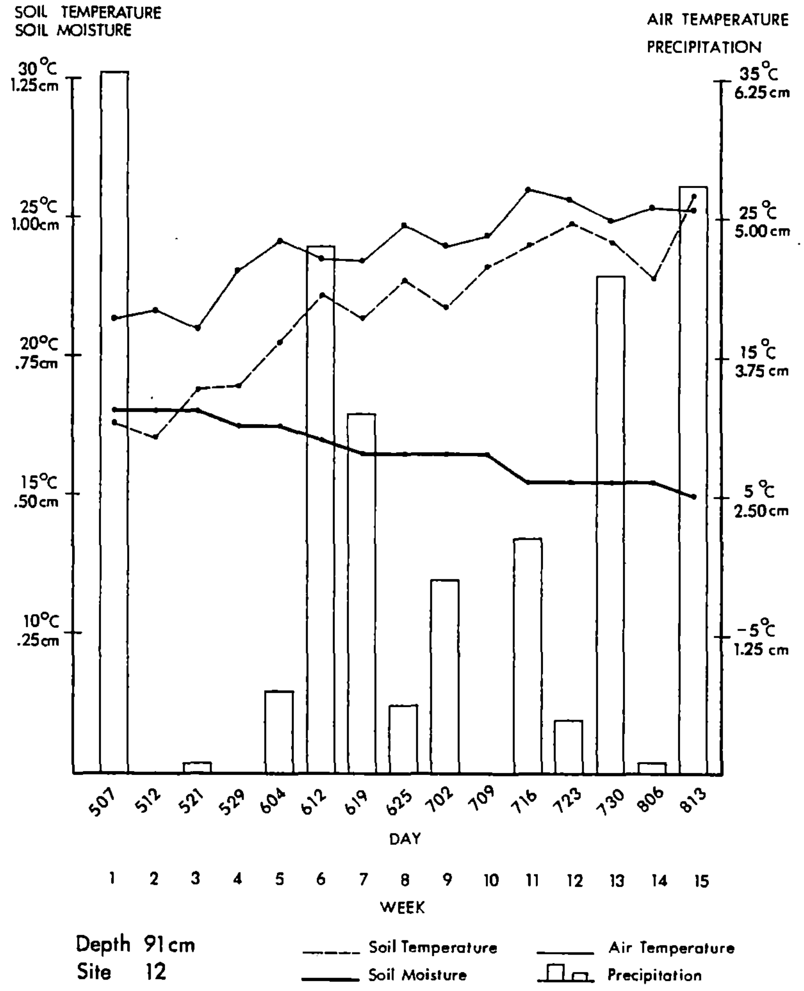

Figure 11. Relationships between Soil and Surface Characteristics for Site 12, Depth 91.5 cm

decrease in soil moisture from east to west. Figure 8 also illustrates this change.

Correlations of the mean soil moisture at the three depths for the combined 12 site locations over the 15 week observation period are presented in Table VII. The east-west location (DIST) has little or no effect on soil moisture at 15 cm (0.48) but correlation between location and soil moisture at 61 cm is 0.78. It is -0.65 for location and soil moisture at 91.5 cm. Table VI contains R-square values for the soil moisture at the two lower depths and the east-west location (DIST). The significant relationships between the east-west location and soil moisture explain 62.0 percent of the variation in soil moisture at 61 cm and 51.3 percent at 91.5 cm. The less significant relationship between soil moisture at 15.4 cm and location occurs because of external features. Precipitation, evaporation, vegetation cover, and percent sun effect the amount of moisture in the near surface soil more than at lower depths. These external features change daily which causes daily changes in soil moisture at the 15.4 cm depth. Prolonged wetness at the 91.5 cm depth caused the less significant correlation for for soil moisture and location. The most significant correlation between location and soil moisture occurred at the 61 cm depth. This position in the soil profile is the critical depth for measuring soil moisture because a transition in soil moisture exists. Correlations between soil moisture and elevation at the lower depths indicate that as elevation increases the soil moisture decreases. The 61 cm depth of soil moisture correlates -0.77 with elevation, the 91.5 cm depth correlates -0.65 with elevation. Elevation increased from east to west, therefore, the soil moisture decreased from east to west. These significant relationships between elevation and soil moisture at the maximum root zone provide the basis for accepting hypothesis 2.

Hypothesis 3

> As air temperature increases across the transect from east to west, the soil temperature will increase from east to west.

Soil temperature responds to meteorologic changes. Daily changes in weather strongly influence the soil temperature near the surface. The transfer of energy for cooling and heating the soil also occurs at the surface, the contact between the atmosphere and lithosphere. Before this energy turns into heat, it must be absorbed by the soil. Several internal and external factors affect the amount of absorbed energy. These factors, thermal properties of the soil, and wind turbulence affect the magnitude of the change in soil temperature. The most severe changes in soil temperature occur near the soil surface and diurnal changes in temperature do not exist below 50 cm (Buol et al., 1980). Hillel (1982) agrees that daily surface fluxes are not reflected in the soil temperatures at lower depths. A lag time occurs before a change in soil temperature happens below 50 cm, with change at these depths occurring from season to season.

Table VII contains correlation coefficients between soil temperature, air temperature, time, soil moisture, location, and elevation. Air temperature is significantly correlated with soil temperature at all three depths. The data values for air temperature and soil temperature have generally parallel relationships as the correlations exhibit: 0.84 for the 15.4 cm depth, 0.86 for the 61 cm depth, and 0.84 for the 91.5 cm depth. Obviously, air temperature is a significant control of soil temperature to the depth evaluated in this study.

Figures 9 through 17 are graphs containing soil moisture, soil temperature, and precipitation. The graphs present an increase in soil temperature with an increase in air temperature from week 1 to week 15. The correlations confirm the positive influence of air temperature on soil temperature.

The correlations for east-west location versus soil temperature for all three depths are not significant; 1.90, 0.40, and 0.20 percent for 15.4, 61, and 91.5 cm, respectively. As stated in the hypothesis, the increase in soil temperature occurs from east to west but the change in location does not greatly effect the increase in soil temperature, the increase comes mainly from an increase in air temperature. Therefore, hypothesis 3 is accepted.

Hypothesis 4

> As soil temperature increases through time from May to August, the near surface sample (15.4 cm) will undergo greater fluctuations in values than the changes that will be observed in the samples at lower depths.

Time (WEEK) and soil temperature are positively correlated at all depths: 15.4 cm (0.68); 61 cm (0.85); and 91.5 cm (0.87). As the summer season passes, the atmospheric temperature increases, which then increases the soil temperature.

Figures 9 through 17 illustrate that soil temperature increases through time. The temperature at each depth has an upward trend from week 1 to week 15. At the 15.4 cm depth at all three sites (1, 6, 12), greater fluctuations in soil temperature values occur compared to those at lower depths (Figures 12, 13, and 14). The sampling time was different for each site and daily temperature cycles affect the 15.4 cm depth.

The graphs for each depth and each site are compared to each other to show that, for example in Figures 9 and 10, the soil temperature for the 15.4 cm depth at site 1 is always greater than the soil temperature at the 61 cm depth, excluding weeks 1 and 2. Prolonged cloudiness or rain may have caused the lower soil temperatures at 15.4 cm for weeks 1 and 2. All soil temperature values at the 15.4 cm and 61 cm depths are greater than those

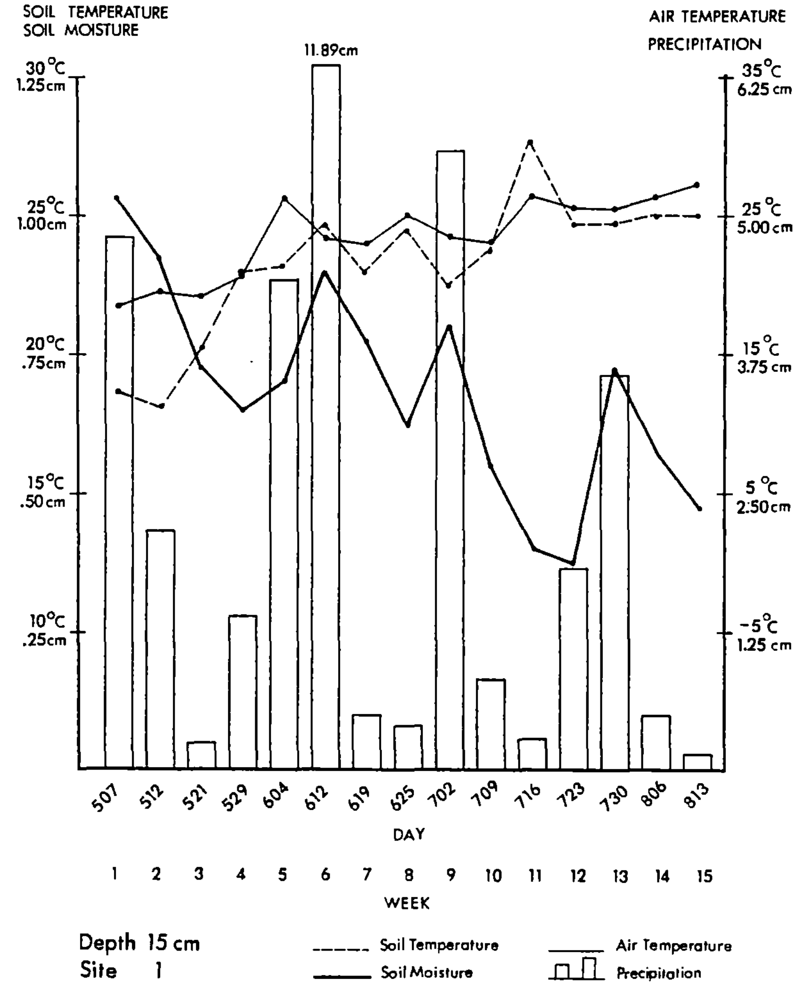

Figure 12. Relationships between Soil and Surface Characteristics for Site 1, Depth 15.4 cm

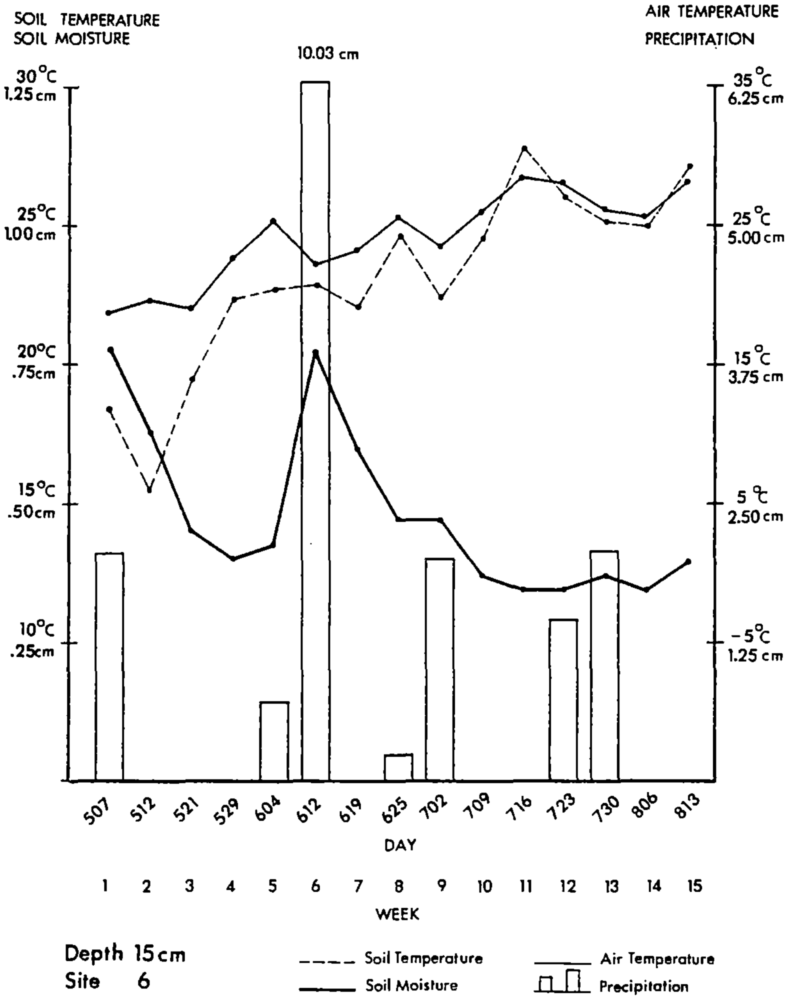

Figure 13. Relationships between Soil and Surface Characteristics for Site 6, Depth 15.4 cm

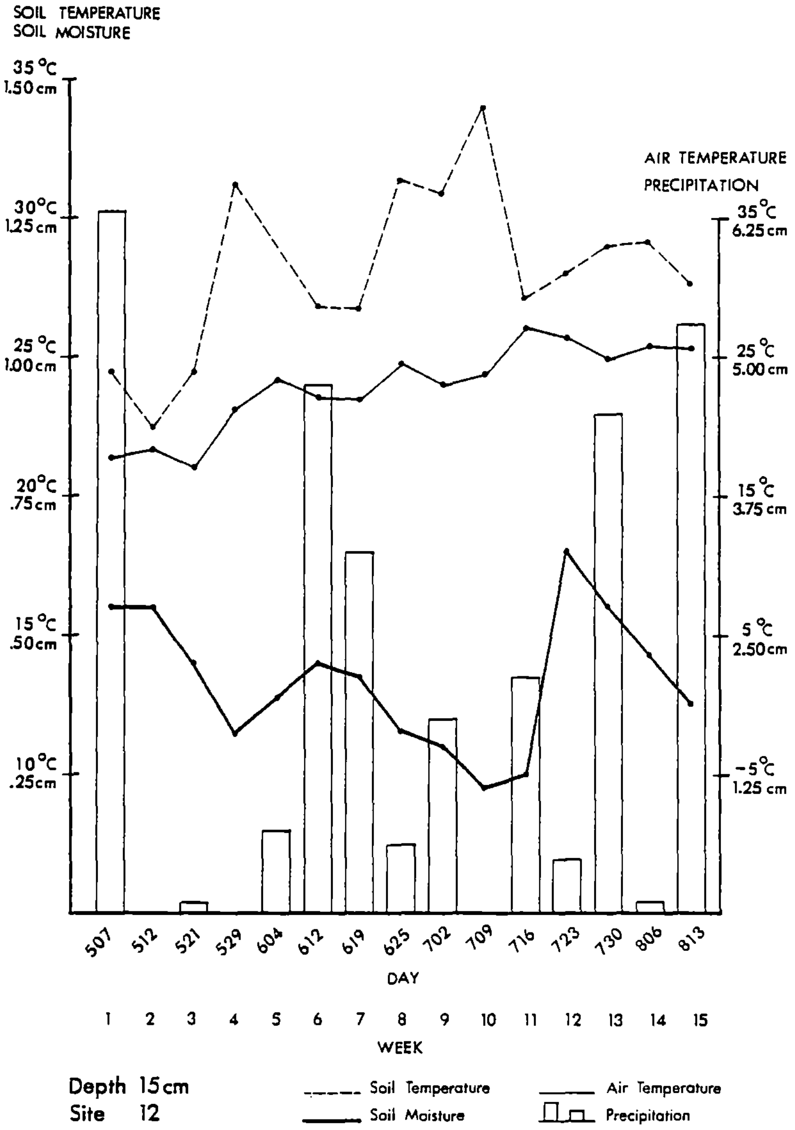

Figure 14. Relationships between Soil and Surface Characteristics for Site 12, Depth 15.4 cm

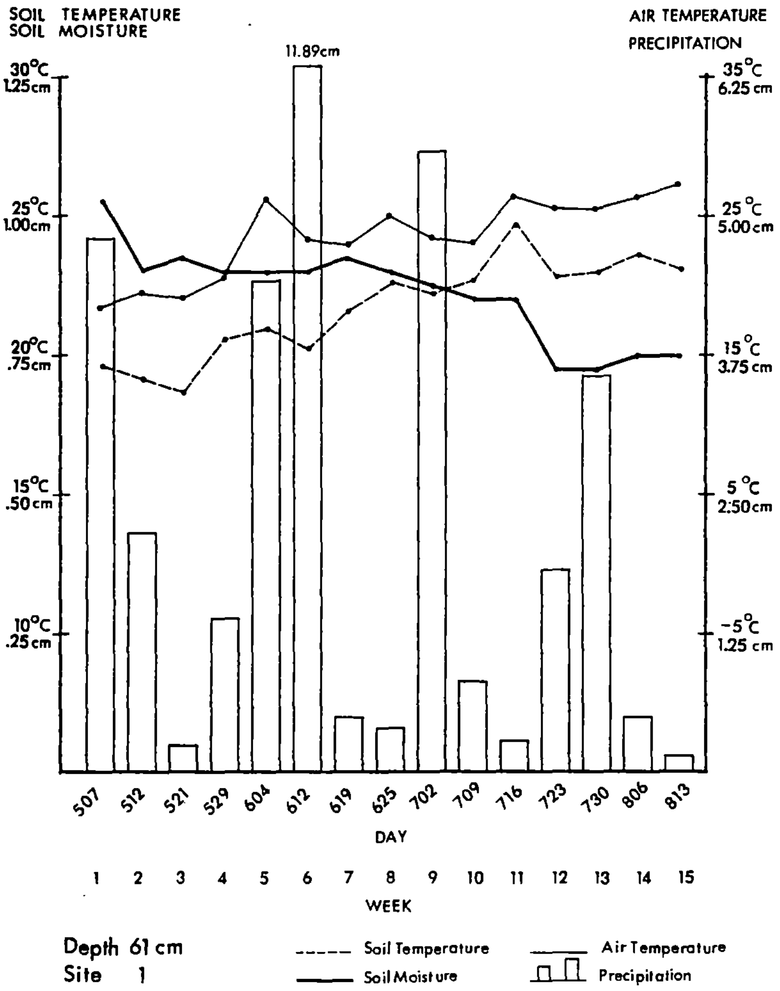

Figure 15. Relationships between Soil and Surface Characteristics for Site 1, Depth 61 cm

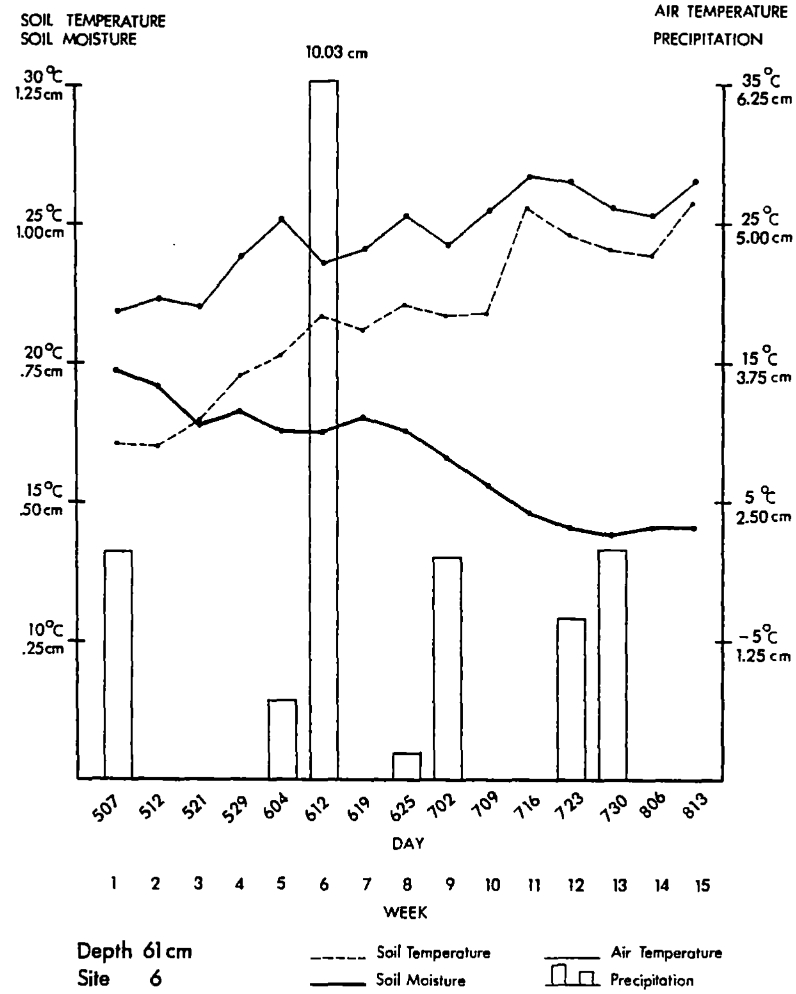

Figure 16. Relationships between Soil and Surface Characteristics for Site 6, Depth 61 cm

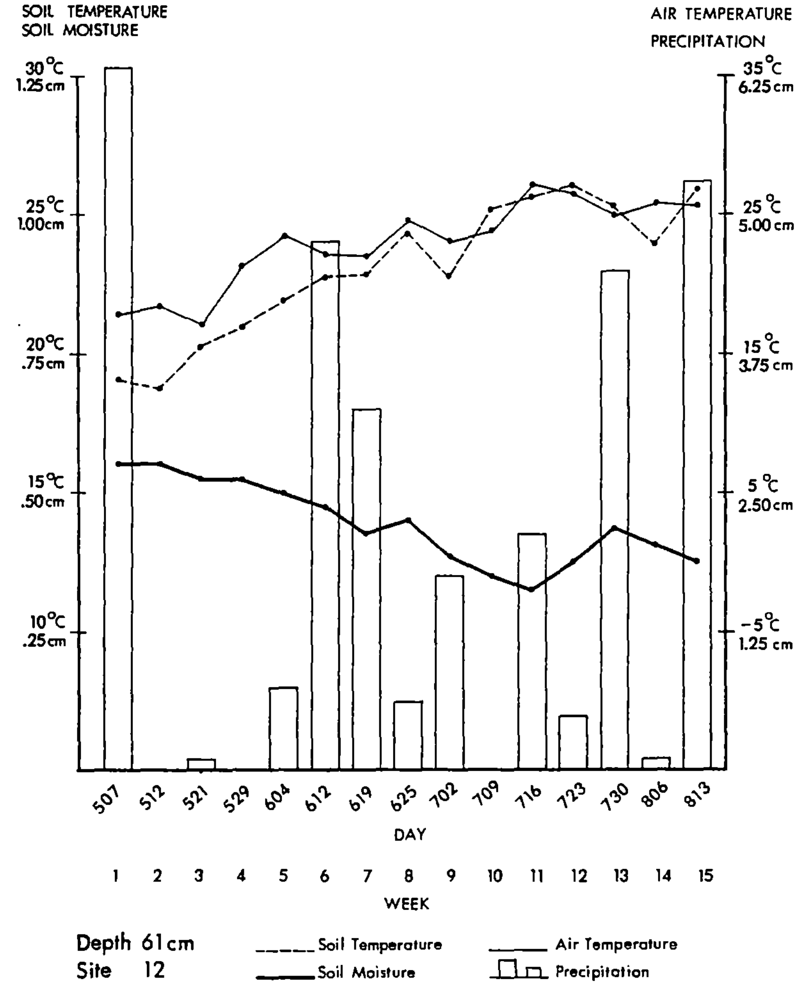

Figure 17. Relationships between Soil and Surface Characteristics for Site 12, Depth 61 cm

temperatures for the 91.5 cm depth at site 1 (Figure 9). The same is true for the central site (Figures 10, 13, and 16) and the western site (Figures 11, 14, and 17). The difference in soil temperature between the shallow depth and the deepest depth is greatest for site 12 and least for site 1. The major reason for these differences in soil temperature is because of the time of day at which the measurements were taken.

Variation in soil temperature with time was observed. R-square values show that time accounts for 48.3 percent of the variation found in the soil temperature at 15.4 cm. Time accounts for 76.1 and 79.1 percent of the soil temperature at 61 cm and 91.5 cm, respectively.

The influence of surface variables at the lower depths exists over seasonal or annual cycles, hence, the variation in soil temperature at the lower depths is decreased. Figure 18 shows the variation in soil temperature from season to season. Soil temperature increased from May to August at all three depths. The soil temperature for the surface depth fluctuated from normal more than the lower depths. But over time, from May to August, the soil temperatures at 61 and 91.5 cm increased because of the increase in air temperature and the movement of energy into the soil.

The information in Figures 9 through 17 along with the evidence above, prove that soil temperature increases over time and fluctuations in soil temperature at the 15.4

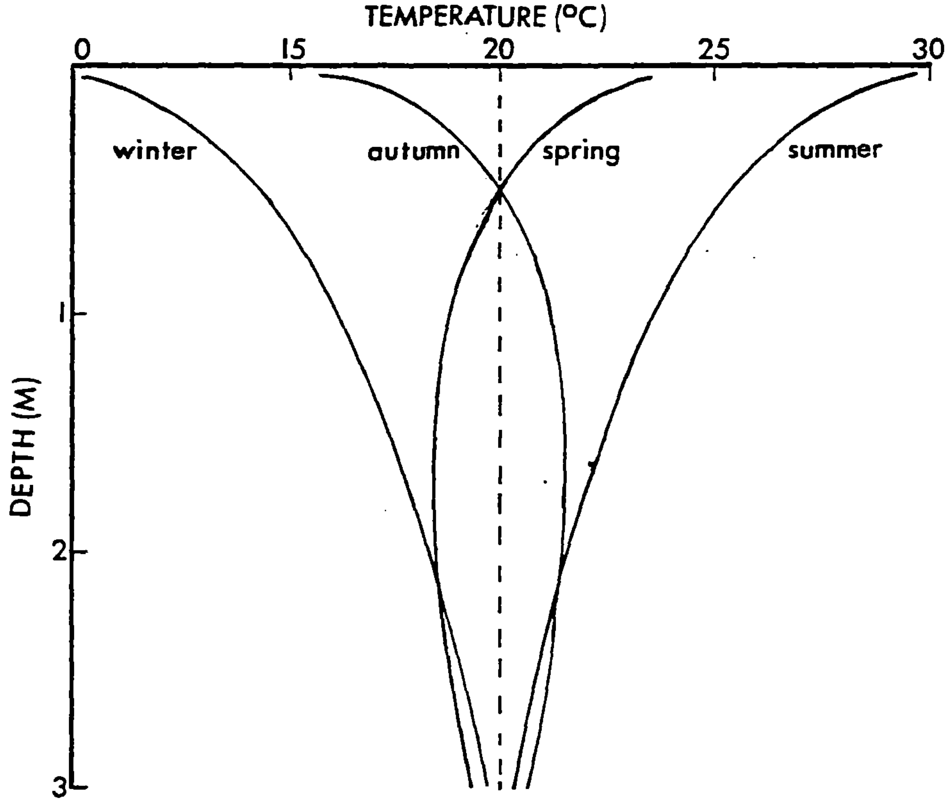

Figure 18. The Soil Temperature Profile as It Might Vary from Season to Season in a Frost Free Region (adapted from Hillel, 1982)

cm depth are greater than the changes observed in the lower depths.

Hypothesis 5

> An increase in precipitation across the transect, from west to east, will create an increase in the soil moisture from west to east.

Although this summer was unusually wet, a decrease in soil moisture occurred from east to west. The change in soil moisture for the 15.4 cm depth greatly fluctuates over time and along the transect. Normally, any significant precipitation event causes an increase in soil moisture at the 15.4 cm depth. This generalization includes the western as well as the eastern part of the transect. As expected, the lower depths of soil moisture curves are smoother and indicate an increase in soil moisture from west to east, excluding the 91.5 cm depth at site 12 (Figures 7, 8, 9, 10, 11, 15, 16, and 17). Given a normal rate of precipitation for the months of May through August, a more pronounced increase in soil moisture from west to east should appear. Hypothesis 5 is accepted because of the supporting illustrations from this research.

Summary

This research has found that changes in climatic characteristics produce changes in soil moisture and soil temperature over time and across the transect. The five hypotheses were accepted because of statistical and illustrative information. Concluding statements follow in Chapter 5.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The overall objective was to analyze the spatial and temporal behavior of soil conditions through a transect located within a climatic transition zone and to identify statistically significant interrelationships that may, in the future, be evaluated through remote sensing techniques. Because of the occurrence of high soil moisture conditions in response to the unusually frequent precipitation throughout the 15 weeks period, pronounced climatic stress did not occur. The type of climatic stress expected for this study was moisture stress in plants. The water content in the soil, and the matric potential of the soil influence moisture stress situations. A soils matric potential is important for the ability of the root hair to pull water away from soil particles. Soil-water retention is a function of matric suction. The water retention curve relates water content to suction. Texture and specific area influence water retention at higher suction whereas structure influences it at low matric suction. In this study, minor differences in particle size exist between the study sites, therefore, the water retention curves should be similar for the twelve sites. Hence, the value of the data for assessing stressful climatic conditions may be suspect. Several conclusions, however, can be derived from these detailed observations.

Soil moisture, soil temperature, air temperature, and precipitation were measured to determine what effect the climatic variables would have on the soil variables over time and across the transect. The following conclusions are drawn from the data observation and analysis.

First, soil moisture significantly increased with depth at each individual site. Figures, in Chapter 4, illustrate the increase in soil moisture with depth. Second, the depth of the maximum root zone depth (91.5 cm) at the eastern site (1) contains a greater amount of soil moisture than does the same depth at the western site (12). Elevation and the climatic transition zone (near Canton, OK) contributed to the change in soil moisture through the transect. Third, air temperature, a major climatic variable, increased from east to west and contributed to the significant increase in soil temperature from east to west. Correlations between air and soil temperatures and the graphic trends seen in Figures 9 through 17, identify the increase in soil temperature from east to west. The actual position of the site along the transect did not cause the change in soil temperature.

Fourth, soil temperature increased significantly through time from May to August. Time is a major controlling factor for the increase in soil temperature. As air temperature increases from May to August, it contributes to the increase in soil temperatures from May to August. Greater fluctuations in the soil temperatures near the surface (15.4 cm) were observed compared to the fluctuations at lower depths. Fifth, a significant increase in soil moisture occurred from west to east but not because of the general increase in precipitation across the transect from west to east. This west to east increase was affected by the frequent rainstorms throughout the observation period which randomly affected all or part of the transect. Hence the precipitation did not decrease from east to west as was expected. Reasons for the decrease in soil moisture from east to west are related to climatic and topographic parameters. A climatic transition zone exists between the eastern and western sites. Generally, wind velocity increases westward which may cause greater evaporation of soil moisture at the western sites. An increase in elevation of 304 m occurred from east to west which would also contribute to the observed trend. Correlations clearly illustrate that the increase in elevation helped explain the decrease in soil moisture in the western portion of the study area. The conclusions drawn from the data indicate that the climatic changes which occurred during the research period and across the transect influence soil characteristics. Additional sample periods, however, are probably necessary, especially during a dry summer, in an effort to acquire data which indicates stress. The relationships between ground-truth data and satellite observations may be maximized if stressful conditions have been measured.

Recommendations

Because of the wet summer, the study should be continued in 1986. When trying to study drought behavior, another data set would permit year to year comparison and also have the chance to detect stressful conditions which were lacking in 1985. Normally, the same time period would be drier which would provide the required data to identify stressful conditions. Results of the ground data can be utilized, however, in conjunction with the satellite data to interpret the conditions detected by the satellite. The ground data are detailed observations that can be directly linked to digital images for the time and location.

If research is continued, the number of sites could be reduced. A greater distance between sample locations should not significantly effect the goal of the overall research program. The number of measurements taken (1 time/week) could also be reduced to once every two or three weeks. Carter (1980) measured monthly soil temperature and computed mean annual soil temperature (MAST). The average difference in soil temperature between the 25 and 50 cm depths was 0.1° C. Seasonal readings at 25 and 50 cm depths had a difference of 0.2° C for MAST. Comparison of MAST at the 25 and 50 cm depths were not influenced by the time of measurements or weekly weather fluctuations (Carter et al., 1980). Measurement of the soil moisture and soil temperature at three depths, with two sets of data at each of the twelve sites produced a large data set. While a decrease in the number of sites and the amounts of observations taken (1 time/2 or 3 weeks) would produce less data, a smaller number of observations should be able to detect the initiation of climatic stress in soil characteristics along the transect. Another method to collect soil moisture is to auger holes at various sites along the transect and measure the amount of moisture by laboratory analysis.

The data set that was built from this research contains data beyond the realm of this study. Many external and internal factors contribute to fluxes in soil moisture and soil temperature, hence, a more detailed analysis is suggested for further research. Analysis for this research was based on a linear statistical model. The linear model showed important conclusions but for future analysis, the curvilinear model and multiple regression analysis could be utilized to evaluate the numerous climatic variables.

The weather data collected in the field was precipitation, air temperature, and relative humidity. Plastic rain gauges were used to collect the precipitation but because of a lag of 7 or 8 days between readings, some of the precipitation evaporated. Evaporation changed the actual amount of precipitation that occurred at each site. Therefore, a total amount of precipitation for the 7 or 8 days between observations was taken from surrounding NOAA weather stations. Future measurements of precipitation at the sites could be made by (1) installing rain gauges that eliminate any affect from evaporation or (2) having the land user measure it as it occurs.

Temperature was measured with the dry bulb on a sling psychrometer. More exact measures of temperature, taken at the atmosphere/soil interface would provide a more accurate account of the energy available to the plants and soil. A better indication of climatic stress (drought) at each site could be found from the temperature at the soil surface.

Evapotranspiration is an important factor contributing to an area undergoing stressful climatic conditions. General evapotranspiration measurements are available from NOAA weather stations but site specific measurements are preferred. Therefore, data collected at the sites and from NOAA meteorologic stations could be placed into an equation to calculate the potential evapotranspiration (PET) for each site. The equation is from the Christiansen method (Appendix B).

Wind velocity increases from east to west (Climate of the States, 1980). Installing a recording device to measure wind could contribute to the assessment of stressful climate conditions. Strength and duration of the wind are critical variables in relationship to evaporation and transpiration of water.

If the independent variables such as wind and PET are measured in addition to precipitation and air temperature (2.54 or 5.08 cm above the soil surface), a different statistical model is suggested. Soil moisture and temperature are dependent variables which could behave differently because of the independent variables mentioned above. Stepwise regression measures the independent variables one at a time to confirm the "best" model for a specific dependent variable. Stepwise regression chooses the "best" model with one variable, two variables, three variables, etc., until all independent variables are modeled separately and together. Then the researcher decides the amount of steps required to "best" model the dependent variable.

Concluding Statement

The need for such data exists in order to confirm remotely sensed data. The ground data provide information about relationships across space and therefore, are valuable without further application. However, costs and time associated with data collection are so great that remote sensing provides a more economical procedure if it accurately detects reality.

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APPENDIXES

APPENDIX A

LOCATION CHARACTERISTICS

Site	Topographic Map	Legal Description	County	Longitude	Slope %	Slope Aspect	SCS Sheet and Type	Elevation
1	Stillwater North	T19N, R2E, S4 SE 1/4 SE 1/4	Payne	671940	3	270 WNW	14, 81	960 ft.
2	Orlando East	T19N, R2W, S12 SW 1/4 SE 1/4	Logan Logan	647560 647560	2 2	260 WSW 260 W-SW	5, Rc 5, Rc	1130 ft. 1130 ft.
3	Orlando West	T20N, R3W, S26 NE 1/4 NW 1/4	Garfield	635700	5	10 NNE	90, KrB	1160 ft.
4	Lovell	T19N, R5W, S15 SW 1/4 SE 1/4	Kingfisher	615480	4	350 NNW	9, VcB	1000 ft.
5	Hennessey	T19N, R6W, S18 NW 1/4 SW 1/4	Kingfisher	600100	2	225 SW	7, BeA	1160 ft.
6	Ames	T19N, R10W, S13 SW 1/4 SW 1/4	Blaine	569525	4	45 NE	8, BeA	1170 ft.
7	Okeene	T19N, R11W, S15 SE 1/4 SW 1/4	Blaine	557390	9	28 NNE	6, BeA	1240 ft.
8	Canton SW	T19N, R14W, S33 NW 1/4 NE 1/4	Dewey	527290	4	0 N	23, CeB	1750 ft.
9	Seiling	T19N, R16W, S11 NW 1/4 SW 1/4	Dewey	510480	2	45 NE	11, SaA	1765 ft.
10	Mutual NE	T19N, R18W, S1 NW 1/4 NW 1/4	Dewey	493170	4	194 SSW	8, CeB	1850 ft.
11	Mutual	T20N, R19W, S3 NW 1/4 SE 1/4	Woodward	481060	2	45 NE	96, CaB	1900 ft.
12	Sharon	T22N, R19W, S32 NW 1/4 SW 1/4	Woodward	476440	1	225 SW	68, CaC	1960 ft.

APPENDIX B

POTENTIAL EVAPOTRANSPIRATION

THE CHRISTIANSEN METHOD

PET = (0.473) (RT) (CT) (CW) (CH) (CS) (CE) (CM)

RT = Solar radiation at the top of the atmosphere
CT = Air temperature
CW = Wind speed in miles per day
CH = Relative humidity
CS = Percent of available sunshine
CE = Topographic elevation
CM = PET coefficient (seasonal)

APPENDIX C

SOIL MOISTURE AND SOIL TEMPERATURE DATA

1	507	.41	.41	.37	18.62	17.58	15.52
2	507	.41	.40	.00	17.58	21.70	15.52
3	507	.	.	.	18.60	16.60	15.55
4	507	.	.	.	22.74	16.55	15.50
5	507	.15	.31	.26	19.65	19.60	16.50
6	507	.31	.32	.28	19.65	18.60	16.55
7	507	.05	.36	.37	.	.	.
8	507	.26	.37	.34	22.75	17.60	16.55
9	507	.	.	.	18.65	17.60	16.55
10	507	.	.	.	18.63	.	16.55
11	507	.31	.31	.30	18.00	16.55	15.50
12	507	.30	.28	.29	18.60	17.60	15.50
13	507	.	.	.	17.60	15.50	14.60
14	507	.	.	.	.	.	.
15	507	.	.	.	19.50	19.25	18.25
16	507	.	.	.	19.25	18.25	17.20
17	507	.	.	.	20.75	18.90	16.75
18	507	.	.	.	22.50	18.00	17.50
19	507	.	.	.	22.25	18.75	17.25
20	507	.	.	.	21.25	17.50	16.50
21	507	.	.	.	19.25	15.50	15.25
22	507	.	.	.	19.75	15.75	14.75
23	507	.	.	.	24.75	19.25	17.50
24	507	.	.	.	24.25	18.75	17.50
1	515	.37	.37	.33	18.25	19.50	17.50
2	515	.36	.35	.34	19.25	18.75	16.25
3	515	.30	.37	.35	18.60	18.75	18.00
4	515	.32	.38	.35	18.10	18.10	17.00
5	515	.22	.31	.25	17.00	20.00	19.00
6	515	.31	.31	.28	18.00	18.50	17.00
7	515	.06	.37	.33	16.00	17.00	16.00
8	515	.20	.34	.33	21.00	18.00	17.00
9	515	.27	.36	.31	16.50	18.00	17.50
10	515	.29	.37	.33	16.00	.	17.00
11	515	.25	.27	.28	15.00	17.00	16.50
12	515	.24	.30	.30	16.00	17.00	17.00
13	515	.18	.30	.30	17.00	18.00	16.50
14	515	.14	.30	.31	17.00	16.00	16.50
15	515	.12	.18	.21	17.00	18.50	18.50
16	515	.13	.17	.21	17.00	17.50	17.00
17	515	.15	.20	.23	18.50	19.00	18.00
18	515	.17	.19	.25	18.50	19.00	17.50
19	515	.08	.14	.16	20.50	18.50	18.00
20	515	.09	.15	.20	20.50	18.50	17.00
21	515	.10	.23	.27	16.50	16.00	14.50
22	515	.17	.22	.28	18.00	16.00	15.00
23	515	.22	.22	.26	23.00	19.00	17.00
24	515	.21	.22	.25	22.00	18.50	17.00
1	521	.31	.37	.33	20.10	18.75	17.25
2	521	.29	.36	.33	24.75	18.50	17.10
3	521	.28	.36	.35	20.00	18.75	17.50
4	521	.28	.37	.35	19.75	18.25	17.75
5	521	.27	.29	.27	21.00	19.50	17.50
6	521	.32	.31	.26	20.00	19.75	19.25
7	521	.10	.34	.31	18.50	17.00	16.00
8	521	.12	.32	.32	23.25	18.25	17.00
9	521	.21	.34	.31	19.75	18.50	17.50
10	521	.22	.33	.30	19.75	.	17.25
11	521	.19	.27	.27	19.75	18.00	16.25
12	521	.16	.24	.26	19.25	17.75	17.25
13	521	.10	.30	.30	20.50	18.75	17.25
14	521	.10	.27	.28	20.00	18.50	17.00
15	521	.07	.13	.18	21.75	19.25	18.25
16	521	.08	.13	.18	22.00	20.50	19.50
17	521	.10	.17	.21	22.75	20.50	18.75
18	521	.11	.17	.23	23.50	20.25	18.50
19	521	.04	.12	.14	23.50	19.50	17.00
20	521	.05	.13	.18	22.50	19.50	18.00
21	521	.07	.20	.23	20.25	16.75	17.75
22	521	.14	.20	.29	20.50	17.75	16.50
23	521	.18	.20	.26	24.25	20.00	18.50
24	521	.17	.22	.26	24.75	20.50	19.00
1	529	.26	.36	.33	23.00	21.00	19.00
2	529	.30	.35	.34	25.75	20.25	18.75
3	529	.29	.36	.34	25.25	20.00	19.00
4	529	.31	.37	.35	25.50	20.25	18.75
5	529	.31	.30	.27	23.00	.	16.75
6	529	.29	.31	.27	22.75	20.75	20.25
7	529	.09	.36	.35	20.25	18.25	16.00
8	529	.13	.31	.33	24.75	19.25	17.75
9	529	.17	.35	.33	21.50	19.75	18.50
10	529	.18	.35	.34	21.75	.	18.50
11	529	.17	.28	.29	22.50	19.25	17.75
12	529	.15	.25	.28	22.25	19.75	17.75
13	529	.09	.30	.31	22.50	19.00	17.50
14	529	.09	.26	.29	22.25	19.25	17.25
15	529	.06	.12	.18	23.75	20.25	19.50
16	529	.06	.12	.18	22.75	19.50	17.75
17	529	.08	.18	.23	25.75	22.75	19.50
18	529	.10	.18	.25	27.00	22.00	19.25
19	529	.04	.11	.15	26.75	19.25	17.00
20	529	.05	.12	.18	25.00	17.75	15.00
21	529	.07	.21	.24	22.00	16.50	15.25
22	529	.11	.21	.28	22.75	16.75	15.25
23	529	.13	.20	.24	31.50	20.75	18.25
24	529	.12	.21	.25	31.00	21.25	19.50
1	604	.28	.36	.33	23.25	21.75	18.75
2	604	.32	.35	.32	24.25	20.25	18.75
3	604	.	.	.	.	.	.
4	604	.	.	.	.	.	.
5	604	.28	.30	.27	24.25	24.50	21.25
6	604	.25	.29	.27	23.75	21.75	20.25
7	604	.08	.29	.34	21.75	19.25	17.25
8	604	.11	.28	.33	25.75	20.25	18.50
9	604	.19	.32	.32	22.50	21.00	19.75
10	604	.19	.32	.34	22.50	.	19.50
11	604	.17	.26	.28	23.00	20.25	19.25
12	604	.16	.24	.28	22.50	20.00	18.75
13	604	.08	.27	.30	24.25	22.00	20.00
14	604	.08	.23	.27	23.75	21.25	19.50
15	604	.06	.10	.17	25.00	23.50	22.50
16	604	.06	.10	.17	24.75	22.75	21.25
1	612	.36	.37	.33	24.75	20.25	19.75
2	612	.35	.35	.32	24.75	20.25	19.75
3	612	.30	.36	.34	26.00	21.00	20.25
4	612	.32	.37	.35	26.25	21.00	19.25
5	612	.34	.32	.29	21.75	23.50	21.75
6	612	.32	.31	.30	20.00	21.25	20.25
7	612	.26	.33	.33	23.00	20.25	18.50
8	612	.	.	.	27.50	21.75	19.25
9	612	.23	.32	.32	23.00	21.75	20.25
10	612	.26	.31	.33	23.00	.	20.00
11	612	.31	.26	.28	23.50	21.75	20.25
12	612	.30	.24	.28	22.25	21.50	19.75
13	612	.28	.27	.30	.	22.50	20.50
14	612	.26	.30	.28	22.75	21.75	20.25
15	612	.19	.17	.15	21.25	22.25	22.00
16	612	.19	.16	.17	21.50	21.75	21.00
17	612	.23	.16	.22	23.25	24.00	22.25
18	612	.25	.16	.24	22.75	22.75	22.00
19	612	.12	.09	.14	24.75	22.50	21.00
20	612	.12	.11	.16	24.50	22.25	21.50
21	612	.18	.16	.21	21.00	19.50	18.75
22	612	.14	.20	.27	23.75	20.75	18.75
23	612	.20	.19	.24	27.25	22.50	22.25
24	612	.15	.19	.24	26.50	23.00	22.00
1	619	.31	.37	.34	23.00	22.75	19.50
2	619	.33	.37	.37	24.00	20.50	20.00
3	619	.28	.35	.33	26.25	22.00	21.25
4	619	.28	.35	.33	26.75	22.75	21.00
5	619	.15	.31	.30	23.75	21.75	21.50
6	619	.27	.28	.31	23.50	22.75	21.50
7	619	.15	.32	.32	22.00	20.25	19.00
8	619	.14	.28	.32	25.75	21.75	20.00

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 9 619 .15 .28 .32 22.75 22.25 21.00
10 619 .16 .29 .31 22.75   .   20.25
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13 619 .20 .27 .29   .   22.25 21.00
14 619 .18 .25 .27 23.00 22.00 20.50
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17 619 .   .   .     .     .     .
18 619 .17 .14 .22 25.00 24.00 21.75
19 619 .08 .09 .13 25.00 22.75 21.50
20 619 .08 .09 .14 24.75 23.00 21.50
21 619 .16 .12 .18 23.00 20.75 19.25
22 619 .13 .17 .25 23.00 20.00 18.50
23 619 .19 .18 .23 26.25 22.50 20.75
24 619 .15 .16 .23 27.25 23.25 22.00
 1 625 .25 .35 .33 24.50 24.25 20.75
 2 625 .28 .36 .32 25.50 21.00 20.00
 3 625 .26 .36 .35 28.25 22.25 21.25
 4 625 .22 .36 .36 29.50 23.00 21.00
 5 625 .25 .30 .28 26.00   .   23.25
 6 625 .21 .29 .29 25.50 23.25 21.75
 7 625 .10 .31 .32 23.50 20.50 19.00
 8 625 .12 .27 .30 26.50 21.75 19.75
 9 625 .11 .30 .32 24.25 22.00 20.25
10 625 .10 .29 .33 24.75   .   20.50
11 625 .19 .26 .27 25.25 22.25 20.75
12 625 .19 .24 .27 24.25 21.75 19.75
13 625 .13 .27 .30   .   23.50 21.50
14 625 .13 .24 .27 24.75 21.50 20.25
15 625 .09 .18 .   27.00 23.75 23.00
16 625 .09 .16 .   26.75 23.50 22.00
17 625 .   .   .     .     .     .
18 625 .12 .14 .23 29.00 25.25 22.25
19 625 .04 .09 .13 30.50 24.75 22.00
20 625 .05 .09 .14 30.00 22.75 21.25
21 625 .08 .10 .16 24.50 20.75 18.75
22 625 .11 .16 .27 25.25 20.75 19.00
23 625 .14 .18 .23 31.25 24.25 22.00
24 625 .11 .17 .23 31.50 24.50 23.50
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 4 730 .18 .24 .36 27.00 23.00 22.75
 5 730 .15 .18 .19 27.25   .   25.75
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6	730	.14	.18	.19	26.25	25.25	24.25
7	730	.09	.21	.21	25.75	23.00	21.75
8	730	.09	.26	.27	26.00	24.25	22.75
9	730	.12	.22	.22	26.25	25.00	24.00
10	730	.11	.22	.27	25.25	.	23.00
11	730	.16	.19	.19	26.00	24.50	23.00
12	730	.14	.16	.19	24.50	23.50	22.00
13	730	.14	.23	.25	.	25.75	23.75
14	730	.12	.22	.23	25.25	24.25	23.00
15	730	.13	.14	.	25.00	24.75	24.00
16	730	.16	.15	.	24.75	24.00	23.00
17	730	.	.	.	.	.	.
18	730	.18	.08	.15	26.25	25.75	24.75
19	730	.09	.08	.15	26.75	25.25	24.00
20	730	.12	.11	.12	27.25	25.25	23.00
21	730	.15	.19	.17	24.25	22.50	21.00
22	730	.18	.11	.23	25.25	22.75	20.75
23	730	.22	.19	.22	29.25	25.50	24.00
24	730	.22	.16	.20	28.75	25.00	24.00
1	806	.23	.29	.31	25.00	24.00	22.50
2	806	.24	.30	.31	24.75	23.25	21.50
3	806	.12	.23	.33	26.75	24.25	25.00
4	806	.14	.21	.31	27.00	25.00	23.75
5	806	.13	.15	.16	26.50	26.00	26.00
6	806	.10	.16	.18	25.75	26.00	25.75
7	806	.05	.22	.21	25.00	.	22.00
8	806	.06	.23	.23	25.50	24.75	23.25
9	806	.11	.21	.22	25.50	25.25	24.25
10	806	.10	.02	.26	26.25	.	24.00
11	806	.14	.18	.19	26.00	24.75	23.50
12	806	.13	.17	.22	24.25	23.00	22.00
13	806	.10	.23	.24	.	24.75	23.25
14	806	.09	.23	.24	24.00	24.25	23.00
15	806	.08	.13	.	25.25	24.75	23.75
16	806	.09	.13	.	25.00	24.50	23.50
17	806	.	.	.	.	.	.
18	806	.12	.08	.16	25.50	26.25	23.25
19	806	.05	.08	.10	24.50	24.25	23.00
20	806	.06	.10	.12	26.75	24.75	23.50
21	806	.	.	.	23.00	22.00	23.75
22	806	.	.	.	22.00	20.75	19.00
23	806	.	.	.	29.50	24.00	23.00
24	806	.	.	.	28.75	23.75	22.75
1	813	.19	.29	.31	25.00	23.00	21.75
2	813	.21	.30	.31	27.25	23.25	22.25
3	813	.12	.23	.31	30.25	24.50	24.25
4	813	.14	.21	.29	30.75	24.25	22.75
5	813	.13	.14	.16	30.00	.	27.00
6	813	.11	.16	.17	29.50	27.25	25.75
7	813	.06	.21	.21	27.25	.	22.50
8	813	.09	.22	.23	28.25	25.05	23.75
9	813	.06	.22	.21	28.00	26.00	24.75
10	813	.06	.21	.27	29.00	.	24.75
11	813	.16	.19	.20	27.50	25.75	24.25
12	813	.15	.17	.20	27.00	25.50	24.00
13	813	.12	.22	.24	26.50	26.25	24.50
14	813	.14	.19	.22	26.50	25.25	24.00
15	813	.	.	.	.	.	.
16	813	.	.	.	.	.	.
17	813	.	.	.	.	.	.
18	813	.10	.08	.16	26.00	27.75	25.75
19	813	.07	.08	.17	26.25	26.75	25.50
20	813	.07	.08	.11	26.25	26.50	25.25
21	813	.16	.10	.13	24.50	23.75	22.50
22	813	.13	.10	.24	24.75	23.75	22.25
23	813	.15	.15	.20	27.75	26.25	25.50
24	813	.14	.14	.19	27.50	26.75	26.00

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VITA

Susan Elizabeth Panciera

Candidate for the Degree of

Master of Science

Thesis: SPATIAL AND TEMPORAL ANALYSIS OF SOIL MOISTURE AND SOIL TEMPERATURE THROUGH A TRANSECT IN WEST-CENTRAL OKLAHOMA

Major Field: Geography

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