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SPATIAL AND TEMPORAL SOIL WATER CONTENT
CHANGES WITHIN A SLOPING LANDSCAPE

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Martin John Rosek

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SPATIAL AND TEMPORAL SOIL WATER CONTENT CHANGES WITHIN A SLOPING LANDSCAPE

By

Martin John Rosek

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ABSTRACT

SPATIAL AND TEMPORAL SOIL WATER CONTENT CHANGES WITHIN A SLOPING LANDSCAPE.

By

Martin John Rosek

Soil physical properties and the amount of soil water within a sloping landscape are largely determined by landscape position. This study determined temporal dynamics of soil water within a sloping landscape by (1) examining the spatial variability of selected soil properties that regulate water retention; (2) quantifying water balance by slope position; (3) determining the minimum amount of stored soil water data required to estimate the amount of soil water within a sloping landscape using geostatistics. Neutron probe access tubes were placed at two meter intervals, in two transects, across a sloping topography of Kalamazoo loam (fine-loamy, mixed, mesic, Typic Hapludalfs) and Oshtemo sandy loam (coarse-loamy, mixed mesic, Typic Hapludalfs) at Kellogg Biological Station in southwestern Michigan. Volumetric water content of the soil was monitored approximately weekly in the spring, summer and autumn of 1990 and 1991 at 15, 30, 60, 90, 120, and 150 cm by neutron attenuation. Soil samples from a 48 by 34 meter grid between the access tubes were described and sampled. Water content of each sample point was estimated with CERES Maize for

two sample dates. Selected volumetric water per 150 cm soil depth values were removed from the data sets, then kriged and cokriged for mm soil water at locations where data points were removed. The Ap horizon of the lower backslope, footslope, and toeslope display a greater mean thickness, percent silt and organic carbon, relative to upslope soils. The Bt1 horizon and control-section display a greater mean silt and clay below the middle of the backslope. The amount of soil water was least within the upper backslope position, moderate within the summit and lower backslope positions, and greatest within the footslope and toeslope positions. Cokriging estimation of stored soil water, using mm soil water per 150 cm soil depth at field capacity as the auxiliary variable, reduced the required sample distance to twice the range of spatial dependence in the direction parallel to the contour of the slope. Variogram models of the amount of soil water from large data sets could be used to predict the amount of soil water in other studies with similar landscape and soil conditions.

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INTRODUCTION

In 1987 a Long Term Ecological Research (LTER) project in agroecosystems was established at the Kellogg Biological Station (KBS) in southwest Michigan. The goal of this research was to understand interactions among organisms and between organisms and their environment in agricultural ecosystems sufficiently well to manage these interactions for levels of agronomic yield that are economically and environmentally sound. The global hypothesis of the LTER project was that agronomic management based on ecological concepts can substitute for reliance on chemical subsidies in production-level agriculture (Robertson et al., 1986). Management of soil-water, on an ecological basis (i.e., cropping systems and soil management practices), can substitute for or reduce producer water inputs (irrigation) and reduce soil-water outputs. Effective crop management should incorporate landscape position based practices (i.e., variable planting and fertility rates for each slope position, contour plowing, grassed waterways) to reduce losses of water, nutrients, and pesticides, from the cropping system to groundwater and atmospheric outputs. This is illustrated in the conceptual model for the LTER project (Figure i.1).

Effective management of soil-water within agricultural landscapes, which minimize external inputs and outputs and optimize yield, requires a solid understanding of the mechanisms that regulate soil-water-landscape interactions. Soil productivity, water movement, and nutrient losses are inherently governed by landscape position.

Water is the medium in which biological and chemical transformations of nutrients occur and in which different nutrient forms move and are transported in the soil profile, either to plant roots or out of the profile and eventually into the ground water

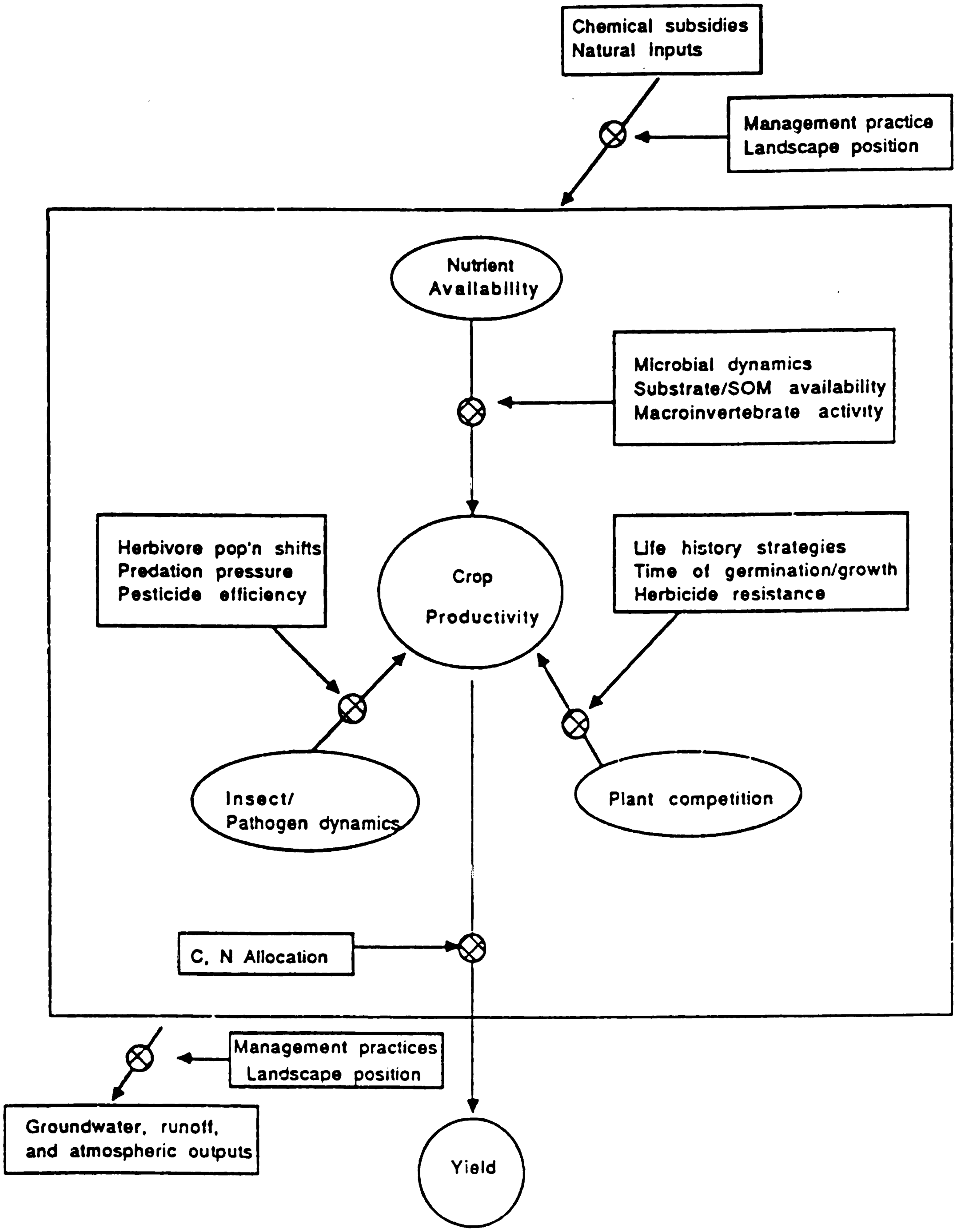

Figure i.1. General conceptual model for the LTER project.

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(Nielsen et al., 1973). To predict nutrient behavior in soil, therefore, one must first be able to predict water retention and distribution. Water distribution studies are made more complex soil by characteristics common to most soils. These characteristics complicate the prediction of water distribution under a variety of landscape conditions.

Much of the literature in soil spatial variability suggests that most soil profile characteristics contain components that are spatially dependent within single map units and even individual fields (Campbell, 1977, 1978; Burgess and Webster, 1980; Gajem et al., 1981; Vieira et al., 1981; Yost et al., 1982). Since soil-water distribution is a function of soil profile characteristics, the quantification of the spatial variability of those profile characteristics should make it possible to predict the spatial variability of water distribution for a given set of soil and landscape conditions. This study makes such a quantification and comparison between soil profile and soil-water properties for the characterization of soil-water distribution.

Water can be a major limiting factor for crop production in sandy soils of southwest Michigan. Since these soils are formed in glacial materials, they can be quite variable, and have significant differences in water holding capacity within the landscape. Many of the landscapes where these soils are found have complex topographies, which contributes to the differential drying patterns. These soils tend to loose water first on the more steeply sloping (backslope) positions, followed by the upper more level area (summit), while the lower portion of the landscape below the backslope (toeslope) tends to dry last (Helvey et al., 1972; Hall, 1983). Knowledge of water retention and distribution in soils can be used to more efficiently manage agricultural ecosystems. For example, the yield potential of soils within sloping landscapes varies dramatically, mainly because of differences in the ability to retain and supply plant available water. To more efficiently manage such systems, different amounts of inputs (i.e. plant population, fertilizer, pesticides, etc.) should be made to the

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Study Site

The study was conducted at the W. K. Kellogg Biological Station (KBS), in the northeast corner of Kalamazoo County, Michigan (Figure i.2). KBS is situated on the pitted Galesburg-Vicksburg outwash plain (Monahan et al., 1983). The study area is located at the east end of the north (reserve) field of the LTER (Figure i.3). A small north-south valley dissects a level plain where the valley floor dips downslope north to an outlet (Figure i.4). The valley is approximately 4.4 meters deep and from 90 to 140 meters wide. The study site consisted of distinct summit, backslope, and toeslope components (Ruhe, 1960) and the research was conducted on the east side of the valley where the gradient of the backslope ranged from 4.6% to 5.6%. The backslope on the west side of the valley ranged from 8% to 10%. The dominant soils on this landscape are Kalamazoo Loam (Fine-loamy, mixed, mesic, Typic Hapludalfs) and Oshtemo Sandy Loam (Coarse-loamy, mixed, mesic, Typic Hapludalfs). Stratified sand and gravel is found from the lower profile of these soils to the contact with glacial till, which is approximately 15 meters below the surface, as indicated by well logs from the area. Both Kalamazoo and Oshtemo soils are well drained and are found on all positions of the landscape, including the toeslope.

Hypotheses

It is the hypothesis of this study that landscape position controls soil physical properties through soil formation (i.e. organic matter accumulation, formation of soil horizon and soil structure, and clay translocation) which in turn effects soil moisture.

Figure i 2

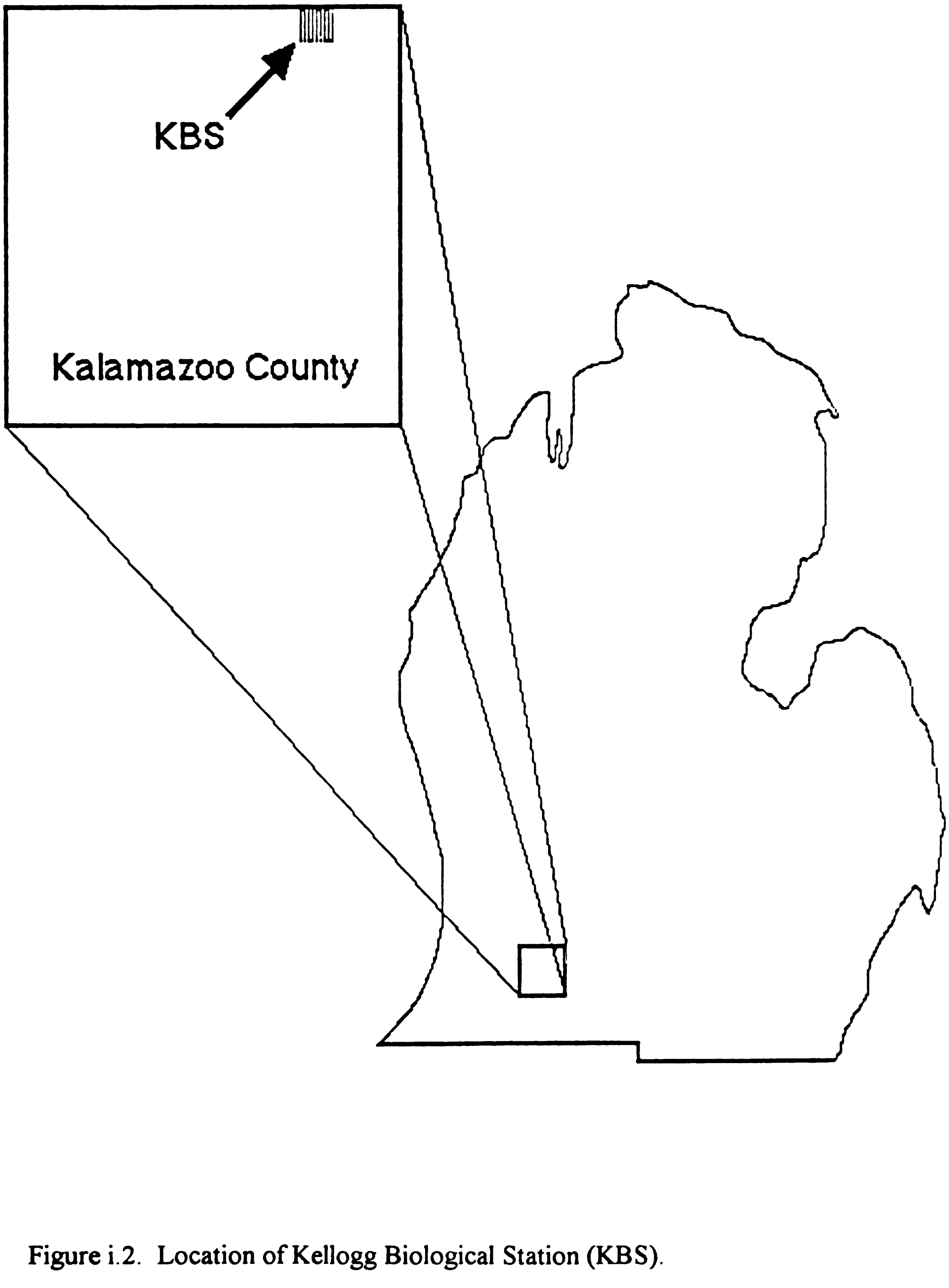

Figure i.2. Location of Kellogg Biological Station (KBS).

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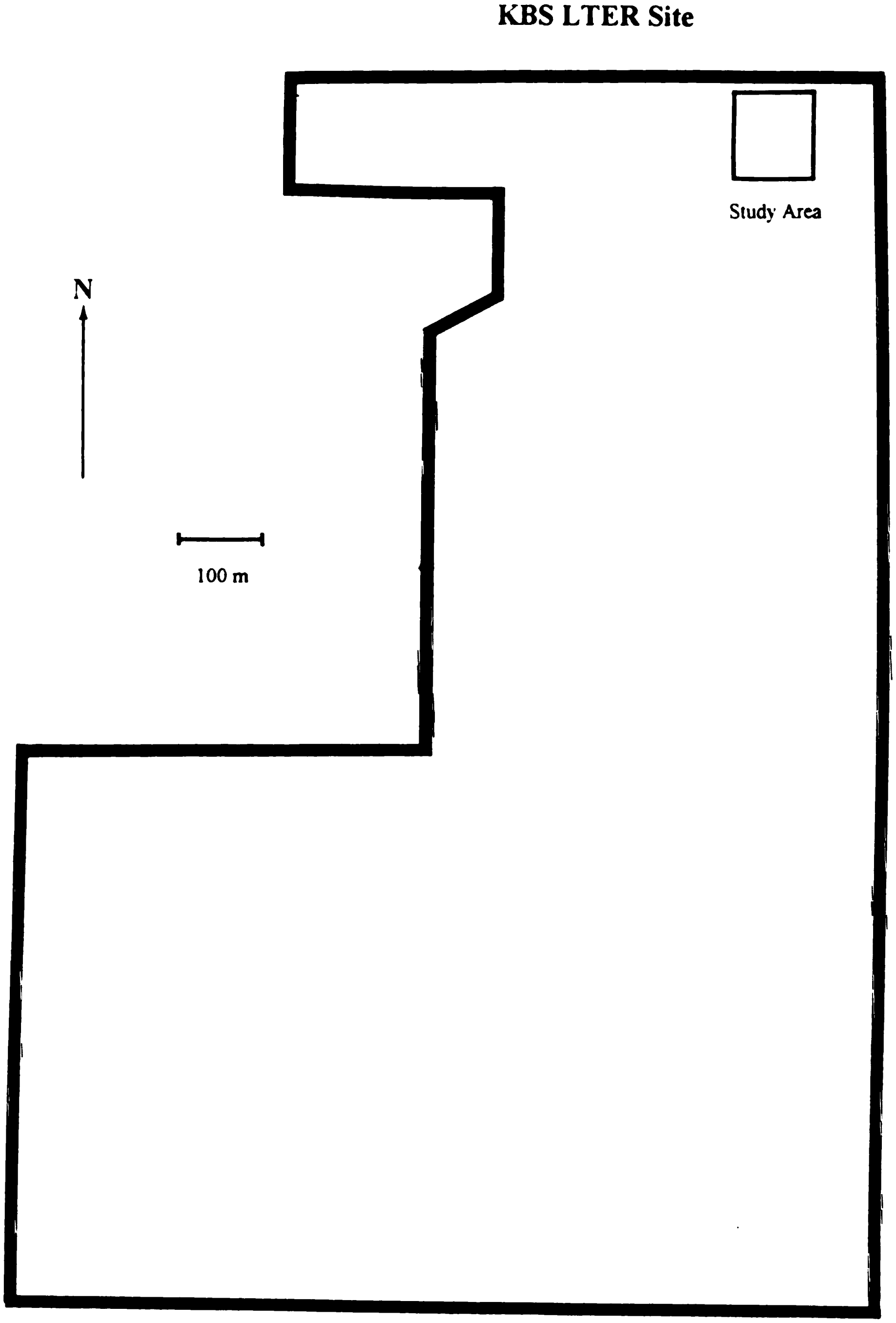
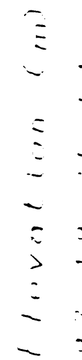


Figure i.3. Schematic diagram of the LTER with the location of the study area.


Elevation (m)

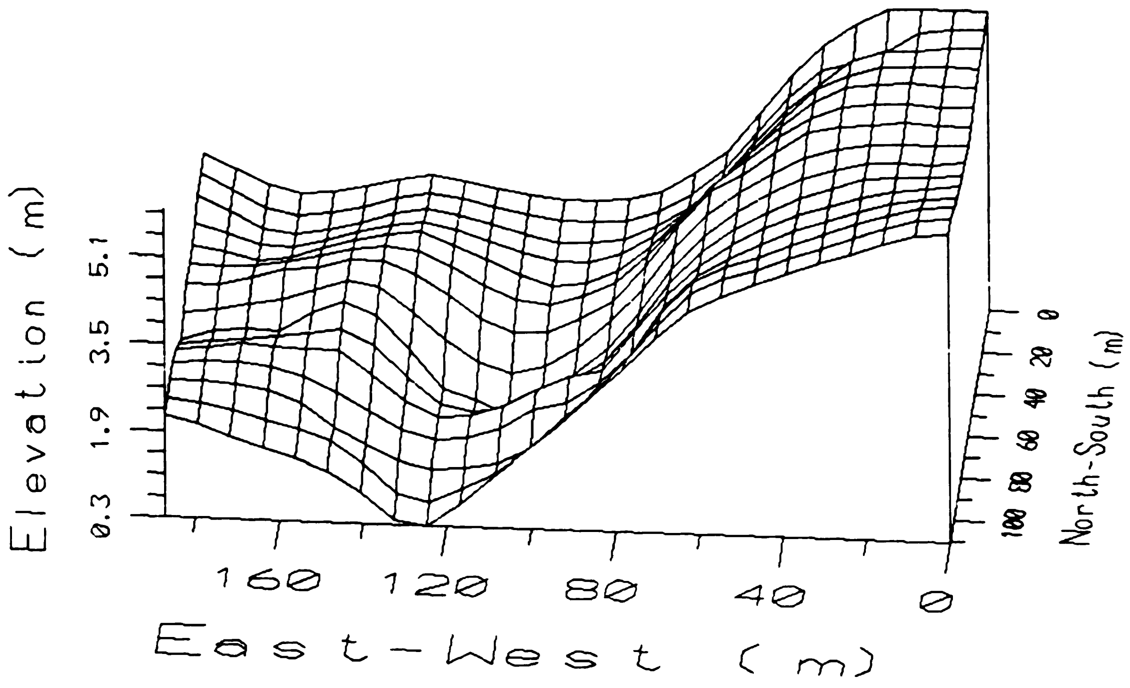


Figure i.4. Topography of the study area, looking south.

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Landscape position, in part, determines how much precipitation infiltrates into the soil profile. Infiltration of precipitation is a major factor in soil development and soil-water content. On a landscape with summit, backslope, and toeslope components, overland and lateral subsurface flow of water is most likely to be small on the summit and toeslope positions, while possibly significant on the backslope. Overland and lateral subsurface flow from the backslope is likely to become overland and subsurface flow to the toeslope, adding water to the soils in the toeslope position. Thus, in a sloping landscape where all of the soils are well drained, such as the study site, infiltration of precipitation may be lowest in the backslope soils, moderate in the summit soils, and greatest in the toeslope soils. From this the following corollaries of this study are made:

1. Soil water content is affected by landscape position in the following modes:
    a. Soil water content is directly affected by landscape position due to the effect of runoff and runon.
    b. Within a given landscape where the parent material is the same throughtout the landscape, soil-water content is indirectly affected by landscape position because the degree of soil development, erosion, and deposition effect soil water holding capacity.

       The more developed the soil profile (on a given landscape) the greater its water holding capacity. Soil development is dependent on the amount of precipitation and infiltration. Thus, in this sloping landscape where all the soils are well drained, soil development is greatest in the toeslope soils, moderate in the summit soils, and least in backslope soils.

Therefore, for much of any given year, the amount of soil water will be greatest in the toeslope soils, moderate in the summit soils, and lowest in the backslope soils.

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2. Soil development and the amount of soil water vary spatially on this sloping landscape.

Objectives

The goal of this research was to determine the temporal dynamics of soil water within a sloping landscape. This goal was achieved by the following objectives:

1. Characterize the spatial distribution of soils within a sloping, erosional landscape at Kellogg Biological Station (KBS) in southwest Michigan.
2. Determine water balance that occurs within each slope component of the landscape of the study site.
3. Determine the minimum amount of sample data required to characterize the amount of soil water within a sloping landscape at KBS, using soil profile variability.

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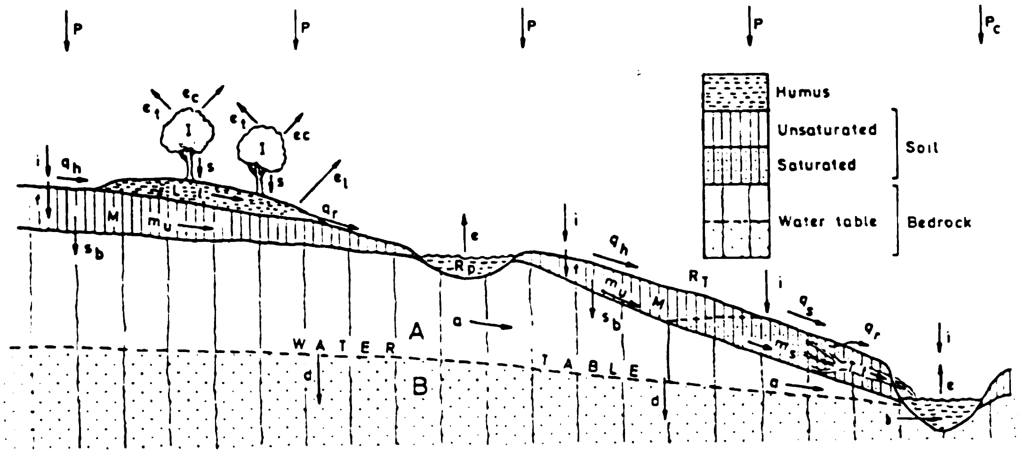
CHAPTER 1

LITERATURE REVIEW

MOVEMENT OF WATER ON AND WITHIN SLOPES

The distribution of water in soils is governed by a complex set of interrelated factors. After climatic effects, the major controlling factors are determined by soil and vegetative properties, topographic characteristics such as slope form and gradient, and positional attributes such as relative height and distance from the slope base (Gerrard, 1981). Water can move across, through, and be stored in soil in a variety of ways as illustrated in Figure 1.1. Of those in Figure 1.1, infiltration, Horton overland flow, saturated overland flow, saturated throughflow, return flow, pipe flow, and deep seepage are the major pathways for water movement on and within slopes.

Infiltration is simply the process of water entering the soil. In general,capacity for infiltration displays a rapid initial rate which drops quickly to some constant value. This decrease in infiltration capacity occurs primarily for two reasons. First, as soil-water content increases, wetting causes a reduction of the hydraulic gradient near the surface. Second, reduction of soil pore diameter by clay mineral swelling upon wetting, combined with the washing of fines into soil pores, impede infiltration (Gerrard, 1981). Infiltration rate is determined by external factors such as rainfall intensity and duration and rain drop size, and soil characteristics such as texture, structure, slope, profile depth, type and proportion of clay minerals, vegetation, and land-use (Gerrard, 1981). When water moves through soil, it displaces water previously retained in the soil pores. Water moves into and within soil under the influence of gravitational and capillary forces, the latter being due to attractive molecular forces between soil particles and water which yields very slow water movement (Baver, 1937). At low soil moisture, most water movement is due to



Precipitation (gross rainfall)	P	Horton overland flow	q_h
Channel precipitation	P_c	Saturated overland flow	q_s
Precipitation intensity	i	Return flow	q_r
Evapotranspiration	e_t	Pipe flow	t
Canopy interception loss	e_c	Pipe storage	T
Interception and canopy storage	I	Unsaturated throughflow	m_u
Stemflow and drip	s	Saturated throughflow	m_s
Litter flow	l	Soil-moisture storage	M
Litter interception loss	e_l	Seepage into bedrock	s_b
Litter storage	L	Interflow in bedrock	a
Evaporation	e	Aeration zone storage	A
Depression storage	R_P	Deep seepage	d
Detention storage	R_T	Baseflow	b
Infiltration	f	Groundwater storage	B

Figure 1.1. Components of the hillslope hydrological cycle.
(from Chorley, 1978)

capillarity and takes place in micropores. When soil moisture is between field capacity (soil-moisture content where excess water has drained) and saturation, most water movement is due to gravitational pull, and takes place in macropores. When the ability of the soil to intake water is not surpassed, the amount of water infiltrated is contingent upon the rainfall rate, and is called flux controlled infiltration. If the rainfall rate exceeds the infiltration rate, ponded, or profile-controlled infiltration occurs.

When the infiltration capacity of the soil is surpassed, surface ponding occurs and this ponded water moves downslope as surface flow or Horton overland flow (Horton, 1935). This surface flow rarely occurs as a uniform sheet of water and most of the water travels downslope in lateral concentrations. It is generally accepted that these lateral concentrations possess characteristics of sheet flow (Emmett, 1970). At a critical distance downslope overland flow becomes deep enough to cause sheer stress which can dislodge and move surface soil particles causing erosion to occur as rills. Cook (1946) presented a sequence of events that occurs with overland water flow on slopes as follows: a. A thin water layer forms on the surface and downslope surface flow begins; b. The flowing water gathers in surface depressions. c; When full these depressions overflow; d. Overland flow enters microchannels which coalesce to form rivulets which discharge into gullies; e. Along each microchannel, lateral inflow from the land surface takes place. Horton overland flow happens relatively instantaneously over a basin only if the basin is small and has homogeneous soil, soil moisture, rain interception, and infiltration conditions.

Also important, is the lateral downslope movement of water (throughflow) within soil layers (Freeze, 1972, 1974). In soils where there is a discontinuous decrease of hydraulic conductivity with depth, saturation may build up from the base of a soil horizon within which saturated throughflow may occur downslope (Chorley, 1978). Temporary zones of saturation above the groundwater surface have been noted by Burt and Butcher (1985). In this type of water flow soil physical properties and depth assume a large role (Hoover and Hursh, 1943). In coarse-textured soils, vertical flow dominates, while in fine textured soils there is resistance to vertical flow, initiating saturated throughflow. Of major importance is soil structure, especially in fine-textured soils or soil layers, where fissures, cracks, and channels replace textural voids as the main avenues of water flow. The effect of cracks and channels on water movement is enhanced if they penetrate different soil horizons, and lithologic discontinuities (Gerrard, 1981). Differing permeability's greatly enhance lateral downslope throughflow. Differences in soil horizons, dense layers, weathered and unweathered bedrock cause hydraulic discontinuities.

Early in a storm event, a saturated wedge forms at the slope base, and throughflow begins. This saturated throughflow increases as the saturated layer becomes thicker, intersecting the ground surface, initiating return flow (Dunne, 1978: Gerrard, 1981), causing saturated overland flow (Kirkby and Chorley, 1967; Kirkby, 1969; Calver et al., 1972; Chorley, 1978). This surface flow is supplemented by direct precipitation onto the saturated area. As the storm continues the saturated wedge increases upslope and the amount of saturated overland flow also increases.

Zaslavsky and Sinai (1977, 1981a, b, c) and Sinai et al. (1981) noted four forms of lateral throughflow (saturated and unsaturated) are induced by rainfall and infiltration:

1. Splash of rain drops lead to larger splash downhill and result in a net lateral flow.
2. Lateral flow is formed in a transition layer between the soil and the air due to its nonuniformity, anisotropy, and slope.
3. When the layers of a soil are slanted, lateral flow occurs. This occurs in many alluvial deposits, gemetically formed A and B horizons, and soil layers formed by cultivation.
4. Lateral flow will form in the unsaturated zone immediately above a sloped phreatic surface.

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These forms of lateral flow start almost immediately after the beginning of the rainfall, but may lag for an increasingly longer time after the rain at increasingly greater soil depths. The lateral flux component is proportional to the slope of the surface or to the slope of the soil layers. As a result, water will accumulate in concave parts of the landscape and diverge from convex positions.

Piping provides a macropore network for the quick transmission of throughflow water. Pipe networks are usually discontinuous and may discharge onto the same slope segment as the pipe inlet (Gilman and Newson, 1980). Beasley (1976) noted subsurface flow often began shortly after rainfall began even when there was neither saturation at the point of outflow nor high antecedent soil moisture and attributed this phenomena to interconnected channels through the soil formed by decayed roots and animal burrows. Soils most likely to produce pipes are peaty surface horizons and impermeable layers at shallow depth, loamy soils on a steep slope (Gerrard, 1981), and highly dispersive soil layers with a high exchangeable sodium percentage (Omodt et al., 1975). Eluviation in highly dispersive soils forms pipes by allowing the fine earth fraction to be removed progressively through the soil matrix. This is indicated by the deposition of clay and silt where the pipes emerge (Gerrard, 1981). Desiccation creates cracks that act as pipes in cohesive clay soils (Parker, 1964).

SOIL WATER BALANCE

Water in soils is either in a flowing or stored state. Soil retention storage relies on the concept of field capacity, the amount of water that a soil can permanently hold against the downward pull of gravity (Horton, 1933). Conversely, soil-detention storage consists of soil-water in excess of field capacity which is slowly draining through large, non-capillary pores (Fletcher, 1952: Hoover, 1962).

In general, the concept of soil water balance, as outlined by Rouse (1970) is that the change in stored soil water (dS) is the difference between input water (Iw) to the soil and output water from the soil (Ow) or;

$$dS = Iw - Ow.$$

Separating the input and output water into components, the following equation is obtained:

$$dS = P + Ro - Rf - ET - D$$

where the change in soil profile water content, dS, is the result of the input of precipitation, P, and surface and subsurface runon, Ro, minus surface and subsurface runoff, Rf, evapotranspiration, ET, and drainage from the profile, D. Since soil profile drainage is much more difficult to measure than the change in soil moisture content, the above equation can be rearranged to estimate drainage as follows:

$$D = P + Ro - Rf - dS - ET.$$

To determine ET, potential evapotranspiration (PET) may be estimated. There have been several methods developed to estimate PET, among which the Thornthwaite (1948), Penman (1948), and Priestley and Taylor (1972) methods are most widely accepted. Once PET is estimated, it is incorporated into the water balance equation as follows:

$$\text{in periods where } D > 0, \text{ and } AET = PET;$$

$$D = P + Ro - Rf - dS - PET:$$

$$\text{in periods where } D = 0, \text{ and } ET \leq PET;$$

$$ET = P + Ro - Rf - dS.$$

Many computer models have been developed to simulate hydrologic processes associated with water balance in the vadose zone (Baire et al., 1972; Molz and Remson, 1971; Parkes and O'Callaghan, 1980; Francis and Pidgeon, 1982; Belmans et al., 1983; Jones and Kiniry, 1986; Workman et al., 1990). Conceptually, mathematical computer models of soil-water balance have been developed using either a parametric or deterministic approach. Each model has strengths and weaknesses, depending on what the user needs the model for and what hydrologic circumstances the model is used to simulate.

RELATIONSHIPS OF SOIL DEVELOPMENT AND LANDSCAPE

The distribution of water on slopes has a substantial influence on the properties of soils, and water movement integrates soils existing on different parts of the landscape (Gerrard, 1981). This gives rise to the catina concept, first proposed by Milne (1935a, b). A catena is considered to be the interlocking of soils on the landscape. The catena concept has been use interchangeably with the toposequence concept, which relates morphologic changes (especially color) with relative elevation, and thus to water table depth and fluctuation. But catena is also a process-response concept. Not only do the soils of a catena differ morphologically, but differ as a result of erosion, transport and deposition of sediments, as well as leaching, translocation (vertically and laterally), of chemical and particulate matter in the soil (Hall, 1983). Thus, the processes of each soil member of a catena are related to every other soil member, and are continuously adjusting to the environmental changes of the landscape (Dan and Yaalon, 1964).

Moving water is the principal cause of movement of material overland and within sloping soils. The distribution of water and water movement are the primary reasons that different soils are found on a landscape composed of the same parent material (Hall, 1983).

Slope gradient and length are very important in regards to movement of water and materials in water on landscapes. As slope gradient increases, flow velocity of surface runoff increases, and the force of the overland flow increases exponentially (Zingg, 1940). Amemiya (1970) noted that as a given straight slope element increases in length, the flow velocity and volume of water that reach the lower portion is greater.

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The ability to erode increases as a function of increased water flow volume (Wischmeier, 1975).

As discussed previously, within a landscape, flowlines of water exist both on the surface and within the soil. These flowlines run straight only where the soil is homogeneous and the contour lines of a slope are parallel. Concave downslope contour lines (coves and headslopes) make for convergent flowlines, and convex downslope contour lines (spurs and noseslopes) make for divergent flowlines (Hall, 1983).

There are significant differences in water movement and erosion between convex, concave and straight portions of a slope (Acton, 1965; Gerrard, 1981; King et al., 1983). Water velocity and soil erosion increase on convex segments as slope steepness increases downslope (Meyer and Kramer, 1969). The opposite happens on concave slopes as water velocity and soil erosion decrease with gentler downslope angles.

The amount of water that flows over and through (vertically and laterally) soils effects the depth and morphology of the soil. Water that vertically percolates through the soil can leach salts, elements, and oxides in soil-solution as well as translocate silts and clays, which leads to development and deepening of the soil profile. Overland water flow causes erosion which removes material from sloping areas and deposits them on gentler areas downslope, causing thinner profiles on the slopes and thicker profiles in the depressions downslope. Lateral translocation downslope of silts and clays as well as salts and oxides and hydroxides of Al, Fe, Mn, and Si in throughflow water has also been observed (Glazovskaya, 1968; Huggett, 1976).

Much research has attempted to relate processes to the occurrence of soils on specific landscape positions (Acton, 1965; Beckett, 1968; Ruhe and Walker, 1968; Walker and Ruhe, 1968; Malo et al., 1974; Huggett, 1975; Conacher and Dalrymple, 1977; Davidson, 1977; Krikby, 1977; King et al., 1983). Ruhe (1960) developed the

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most widely used system for describing landscape units. These include the summit, shoulder, backslope, footslope, and toeslope. On summits, water movement in soils is predominantly vertical, except near the transition to the shoulder. Solum thickness is dependent upon soil permeability and amount and frequency of rainfall. As a result, the summit is a very stable element of the landscape (Hall, 1983). Shoulder positions are almost always convex. This increases surface runoff and decreases infiltration, resulting in a highly erosional and unstable surface with thin soil profiles. Lateral mass movement downslope of surface material (soil creep) may occur. Lateral throughflow may also be an important process within this position (Hall, 1983). Lateral transport of water and material (both surface and subsurface) is very important on and within the backslope position. Soil creep may also occur. If the backslope is relatively smooth, surface transport of material will be uniform. The soils of the backslope are thinner than the other hillslope elements except the shoulder. Footslopes are almost always concave, resulting in increased infiltration and deposition of material. Thickness of soil profiles vary, but tend to increase downslope. Toeslope positions are constructional in nature and thus unstable. Alluvial material from up valley and/or the adjacent footslopes are frequently being deposited on this position, resulting in very thick A horizons.

SOIL SPATIAL VARIABILITY AND GEOSTATISTICS

Soil variability consists of systematic and random components (Trangmar et al., 1985). Wilding and Drees (1983) describe systematic soil variation as a gradual or distinct change in soil properties as a function of landform, geomorphic elements and soil forming factors, and/or man induced management. Observed differences in soil properties that cannot be related to known causes is termed "random" variation. Systematic soil forming processes and landscape element position determine soil occurrence. As such, classical statistics may not be appropriate to analyze soil

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properties, which vary spatially. The theory of regionalized variables (Matheron, 1971), the basis for geostatistics, takes into account both systematic and random variation of spatially distributed variables.

Interpolation of spatially dependent variables was first developed by Krige (1966) to estimate gold content of ore deposits in the South African mining industry. Krige's procedures were expanded by Matheron (1971) into the theory of regionalized variables which forms the basis of techniques for estimation of spatially dependent variables. These techniques are known as geostatistics.

Geostatistics are founded on three concepts; regionalized variables, random functions, and stationarity. If a set of a measured property of individuals is characterized by some probability distribution law, then it is a random variable (z). Examples of random variables in soil research include percent clay, pH, organic matter content, and bulk density. If the value of the random variable is dependent on the position (x) it was sampled, it is a regionalized variable and its location can be used in statistical analysis. If an infinite set of random variables are considered with their sample locations, then the regionalized variable becomes a member of an infinite set of random variables for all locations within the considered region (Trangmar et al., 1985). Such a set is called a random function Z(x).

If the expected value of the random function Z(x) is the same in all locations in the considered region, then it has first-order stationary. Expressed statistically

$$E[Z(x)] = m = \text{mean}$$

and

$$E[Z(x)-Z(x+h)] = 0$$

where h is the vector of separation between sample positions, termed the lag (Figure 1.2) (Trangmar et al., 1985).

For all observation pairs separated by lag h, the intrinsic hypothesis requires the variance of the increment Z(x)-Z(x+h) be finite and independent of position within the

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Figure 1.2

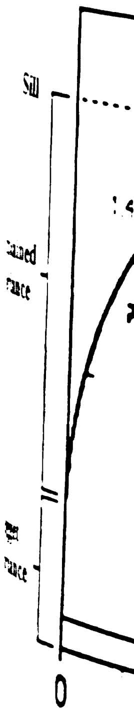

Figure 1.3

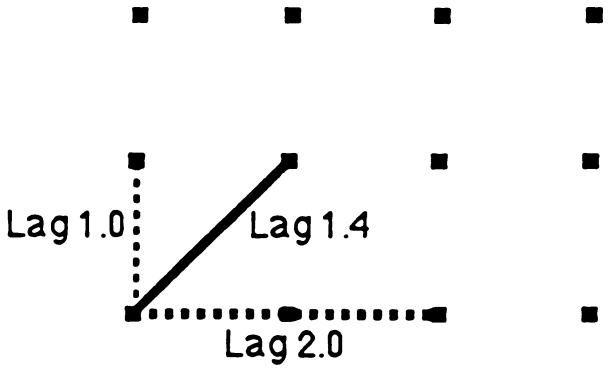

Figure 1.2. Portion of a hypothetical grid, illustrating semivariance computation for given lags. (from Johnson, 1990)

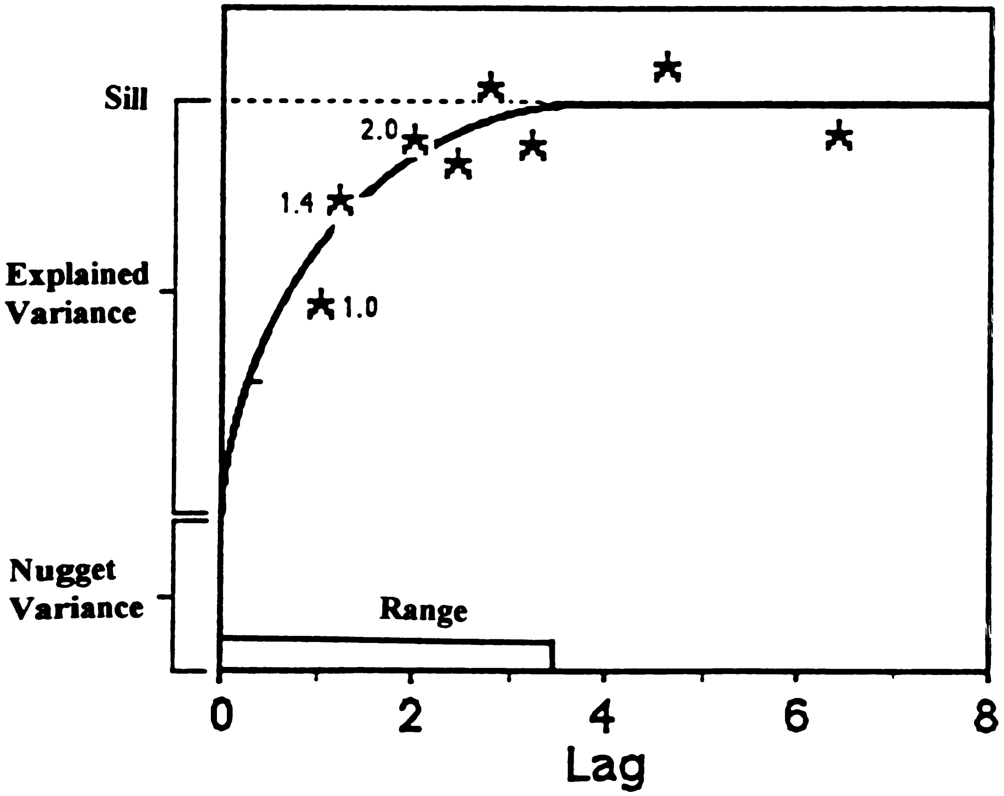

Figure 1.3. Hypothetical semivariogram. Numbers refer to lags. (from Johnson, 1990)

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$$VAR[Z(x)-Z(x-h)]=E[Z(x)-Z(x-h)]^2$$
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This describes the variance of the difference between pairs of observations, which when divided by two, yields a per-observation variance known as the semivariance statistic $\tau(h)$. The semivariance is a measure of the average similarity between points of a given lag distance apart. The more alike the measurements of the points are, the smaller the semivariance (Burgess and Webster, 1980a). Semivariance provides the basis for kriging and cokriging techniques, which are used for unbiased, optimal interpolation between known points of data (Burgess and Webster, 1980a). When the intrinsic hypothesis is assumed, the semivariance for a lag h distance between all observations separated by the lag is:

$$\tau(h)=1/2Nh\Sigma\ [Z(X)-Z(x+h)]^2$$

where there are Nh sample observations separated by lag h.

The plot of semivariance versus lag distance h is known as the semivariogram. The semivariogram consists of four basic parts; the sill, the range of spatial dependence (range), the nugget variance (nugget), and the structural or explained variance (Figure 1.3). The sill approximates the sample variance of classical statistics, and is the region of relatively constant semivariance. The range is the lag distance over which the variable exhibits spatial dependence, and is defined by the value at which the curve reaches the sill. The nugget is the y-intercept value of the semivariogram. Ideally, the semivariance at zero lag is zero, but often is not. The nugget represents unexplained or random variance, which is caused by sampling error, or variability which cannot be detected by the sampling scale used (Trangmar et al., 1985). The explained variance is the portion of the total variation correlated with distance.

A continuous increase in semivariance without an apparent sill or range indicates a broader regional trend and nonstationarity, thus not allowing for definition of a spatial

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variance. An absence of spatial structure in the semivariogram indicates either a lack of spatial dependence between sample values, or that the spatial structure cannot be determined at the sampling scale used (Trangmar et al., 1985).

Plotted semivariance points must be fitted to a mathematical model to produce statistics for kriging procedures. There exists no set mathematical procedure for fitting observed semivariograms (Webster, 1985). In general, the criteria for choosing a model are high correlation coefficient, small nugget, and a large range (Johnson, 1990).

There are two basic kriging procedures; simple point estimation, or punctual kriging, and average estimates for discrete areas, or block kriging. In punctual kriging, the estimated value of the regionalized variable z at location x is:

$$Z'(xo)=\sum^{n}LiZ(xi)$$

where $Z'(xo)$ = kriged estimate

$Z(xi)$ = sample value

Li = weight applied to sample value $Z(xi)$

n = number of neighboring samples used in interpolation

The kriged estimate for point P in Figure 1.4 is calculated by multiplying each sample value in the estimation neighborhood by its concomitant weight (Li), then sum the results for all sample locations in the neighborhood. The fact that near sample points carry much more weight than far samples (Figure 1.4) means that kriging is essentially a local estimation procedure (Webster, 1985). The configuration of sample points near the estimation point can modify the effect of distance on kriging. The effect of distant samples tend to be dampened by samples near the estimation point, and lone points have more weight than individual points found in clusters.

Soil properties are anisotropic if they do not vary in a similar manner in all directions. The effect of anisotropy can be seen in Figure 1.4. Variance is greatest in

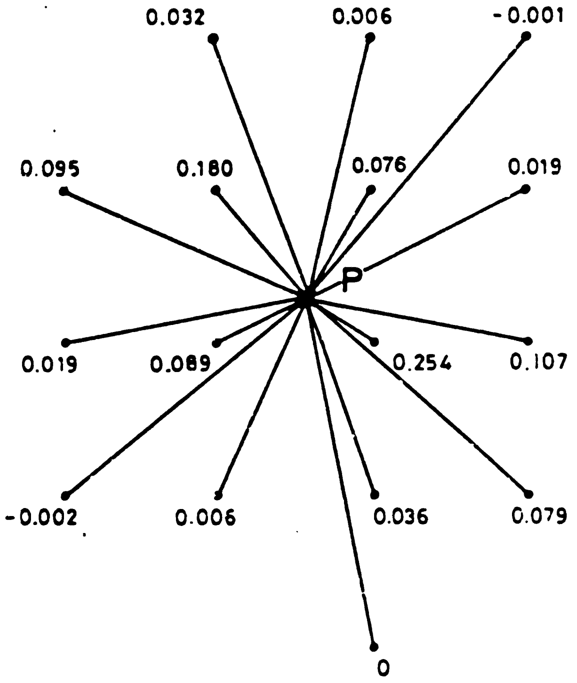

Figure 1.4. Weights for kriging point P.
(from Webster, 1985)

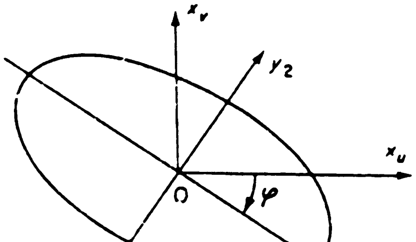

Figure 1.5. Geometric anisotropy about a sample.
(from Journel and Huijbregts, 1978)

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If a property varies the same in all directions, it is isotropic, and one semivariogram applies to all parts of the study region where a circular range of spatial dependence (h) occurs around each sample location. If the magnitude for variance of a property is at a distance h in one direction, and a distance kh in another direction for an equivalent variation, then the property varies anisotropically where an ellipsoidal range of spatial dependence, elongated in the direction of minimum variance, occurs (Journel and Huijbregts, 1978) (Figure 1.5). The anisotropy ratio k is a measure of the magnitude of directional differences in variation, and is calculated by dividing the explained variance by the range in the direction of greatest variation by the explained variance by the range perpendicular to it (Trangmar et al., 1985).

In the calculation of estimates, the only difference between punctual and block kriging is how the weighting coefficients are determined. An average semivariance between sample points and all points in a block is calculated for the determination of sample point weight (Trangmar et al., 1985). Block kriging has the effect of smoothing local discontinuities, which is desirable when the investigator is more interested in regional patterns than local detail.

The spatial distribution of a variable can be closely related to that of other variables affected by the same spatial process. Such properties are co-regionalized and are spatially dependent on each other (Trangmar et al.,1985). Cokriging uses two or more correlated random variables simultaneously in such a manner that the spatial information from each parameter aids in the estimation process. If a correlation exists between the two random variables then one method of improving the sampling efficiency is to increase the sampling of the covariable with respect to the under sampled (primary) variable. Using cokriging, the spatial information of the covariable

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is transferred to the primary through the cross-correlation function, thus improving the quality of the estimates of the primary variable (Yates and Warrick, 1987). Cokriging is most efficiently used where one variable may not have been sampled sufficiently (due to experimental difficulties, high costs, ect.) to provide enough estimates (Trangmar et al., 1985).

The co-regionalization of variables Z1 and Z2 is described by a cross-semivariogram:

$$\tau 12(h)=(2N(h))^{-1}\sum^{n}[Z1(xi)-Z1(xi+h)][Z2(xi)-Z2(xi+h)]$$

where N(h) is the number of pairs of variables separated by vector h. The cross-semivariogram is calculated using only the locations where both variables are measured. Unlike semivariances, cross-semivariances can be negative if the relationship between the primary and covariables are negative (Trangmar et al.,1985).

The primary variable is calculated as the weighted average of the observed values of the covariable and primary variable that occur in the estimation neighborhood at each kriged point:

$$Z'2(xo)=\sum^{n1}LiZ1(X1)+\sum^{n2}L2Z2(X2)$$

where L1 and L2 are the weights associated with Z1 and Z2, and n1 and n2 are the number of neighbors of Z1 and Z2 involved in estimating Z'2 at each xo location (Trangmar et al.,1985). The above equations can be extended to include additional covariables.

Kriging has been used to evaluate soil variability for soil delineation of map units (Burgess and Webster, 1980a, b; Webster and Burgess, 1980; McBratney and Webster, 1983; Ovalles and Collins, 1988; Di et al., 1989; Webster and Oliver, 1989; McBratney et al., 1991). Kriging has also been used to spatially quantify soil chemical properties (Yost et al., 1982; Samra et al., 1988), soil structural properties (Reinert, 1990), and soil hydraulic properties (Vieira et al., 1981; Van Kuilenberg et al., 1982; Russo and Bresler, 1982).

Yates and Warrick (1987) and Mulla (1988) used soil surface temperature with sand content and penetrometer resistance, respectively, as covariables to cokrig for soil water content. Nash et al. (1992) cokriged for vegetative cover using soil moisture as the covariable. Stein et al. (1988) used mean high water table as the covariable to estimate soil moisture deficit.

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CHAPTER 2

SPATIAL VARIABILITY OF SAND, SILT, AND CLAY CONTENT, AND HORIZON THICKNESS OF SOILS WITHIN A SLOPING LANDSCAPE

ABSTRACT

Spatial studies of soil properties have been primarily conducted on relatively level landscapes. This study determined the spatial relationships of selected important soil morphological properties within a sloping landscape. Soil profiles of Kalamazoo loam (fine-loamy, mixed, mesic, Typic Hapludalfs), from a 52 by 34 meter area with 4.25 by 4.00 meter grid cells on a sloping landscape (backslopes range from 4.6 to 5.6 %) at Kellogg Biological Station in southwest Michigan were described and sampled. Statistical and geostatistical analyses were performed on percent organic carbon of the Ap horizon, percent sand, silt, clay, and thickness (cm) of the Ap, Bt1, and 2Bt2 horizons, and amount of clay (kg) in the Bt1, 2Bt2, control-section, and soil profile. The range of spatial dependence for the soil properties varied from 6.4 to 26.1 meters. All soil properties, except the 2Bt2 horizon properties, exhibit anisotropy associated with slope direction. The Ap horizon of the lower backslope, footslope, and toeslope displayed greater mean thickness, percent silt and organic carbon, relative to the summit and upper backslope position Ap horizons. The Bt1 horizon and control-section displayed a greater mean percent silt and clay below the middle of the backslope. Solum thickness increased downslope from the upper backslope to the toeslope. These results indicate erosional and depositional processes may have affected the morphology of the Ap and Bt1 horizons. Differential glacio-fluvial sorting of material at each position of the landscape and water movement on and through the landscape likely caused the differences in soil profile morphology at different positions of the landscape.

INTRODUCTION

Topography plays a major role in processes that create soil variability within a landscape (Gerrard, 1981; Jenny, 1941; Ruhe, 1960). In order to understand how topography controls the distribution of soil properties within a landscape, the spatial relationships of these variables need to be examined. An increased knowledge of spatial variability of soil properties can enhance interpretation of soils and lead to a better understanding of the complex topographical-soil relationships.

Soil forming processes do not behave uniformly but vary with hillslope component (Hall, 1983; Ruhe, 1960). Soil thickness and particle-size distribution are highly related to slope position (Acton, 1965; King et al., 1983; Mermut et al., 1983; Miller et al., 1988). Soil thickness and particle size distribution effect water holding capacity, nutrient supply, and rooting depth. Hanna et al. (1982) found water content to be greatest in the backslope and footslope position soils, and least in the summit and shoulder position soils.

Geostatistics is a very useful approach to study spatial variability of soils (Trangmar et al., 1985; Webster, 1985). Although many studies involve spatial variability of soil physical properties on relatively level landscapes (Campbell, 1977, 1978; Burgess and Webster, 1980; Gajem et al., 1981; Vieira et al., 1981) there have been few spatial studies conducted on sloping landscapes (Miller et al., 1988).

It is the hypothesis of this study that landscape position controls soil formation (i.e. organic matter accumulation, formation of soil horizons and soil structure, and clay translocation) which effects soil morphological properties. The objective of this study was to characterize the spatial variability of selected important soil morphological properties within a sloping landscape of southwest Michigan.

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MATERIALS AND METHODS

Study Site

The study was conducted at the W.K. Kellogg Biological Station (KBS) in southwest Michigan. KBS is situated on a pitted outwash plain and the major soils found there are Kalamazoo Loam (Fine-loamy, mixed, mesic, Typic Hapludalfs) and Oshtemo Sandy Loam (Coarse-loamy, mixed, mesic, Typic Hapludalfs) (Figure 2.1). Both soils are well drained. A typical Kalamazoo soil profile from the study site has a loam Ap horizon, from 0 to 20 cm, a loam E horizon , from 20 to 25 cm, a clay loam Bt1 horizon, from 25 to 56 cm, a sandy loam 2Bt2 horizon, from 56 to 112 cm, and a 3E/Bt horizon of sand and loamy sand lamellae, from 112 to 150 cm. A typical Oshtemo soil profile from the study site has a sandy loam Ap horizon, from 0 to 18 cm, a sandy loam Bt1 horizon from 18 to 56 cm, and a 2E/Bt horizon of sand and loamy sand lamellae, from 56 to 150 cm. Both soils probably formed in glacio-fluvial outwash in which the parent material becomes coarser with depth. The area was deglaciated approximately 14,000 b.p. (Wayne and Zumberge, 1965).

The study site was located on a west facing slope with distinct summit, backslope (4.6% to 5.6% slopes), and toeslope components (Ruhe, 1960) (Figure 2.2). There is no distinct shoulder component to this landscape, as the upper portion of the backslope is linear, except near the transition to the summit. The location of the slope units are given in Table 2.1.

Table 2.1. Location of slope units at the study site.

Slope Position	Position east of west border of site ---Meters---	Width of slope position Meters
Summit	27.6 to 34.0	4.0
Upper Backslope	19.1 to 27.6	2.4
Lower Backslope	6.4 to 19.1	12.7
Footslope	4.0 to 6.4	8.5
Toeslope	0.0 to 4.0	6.4

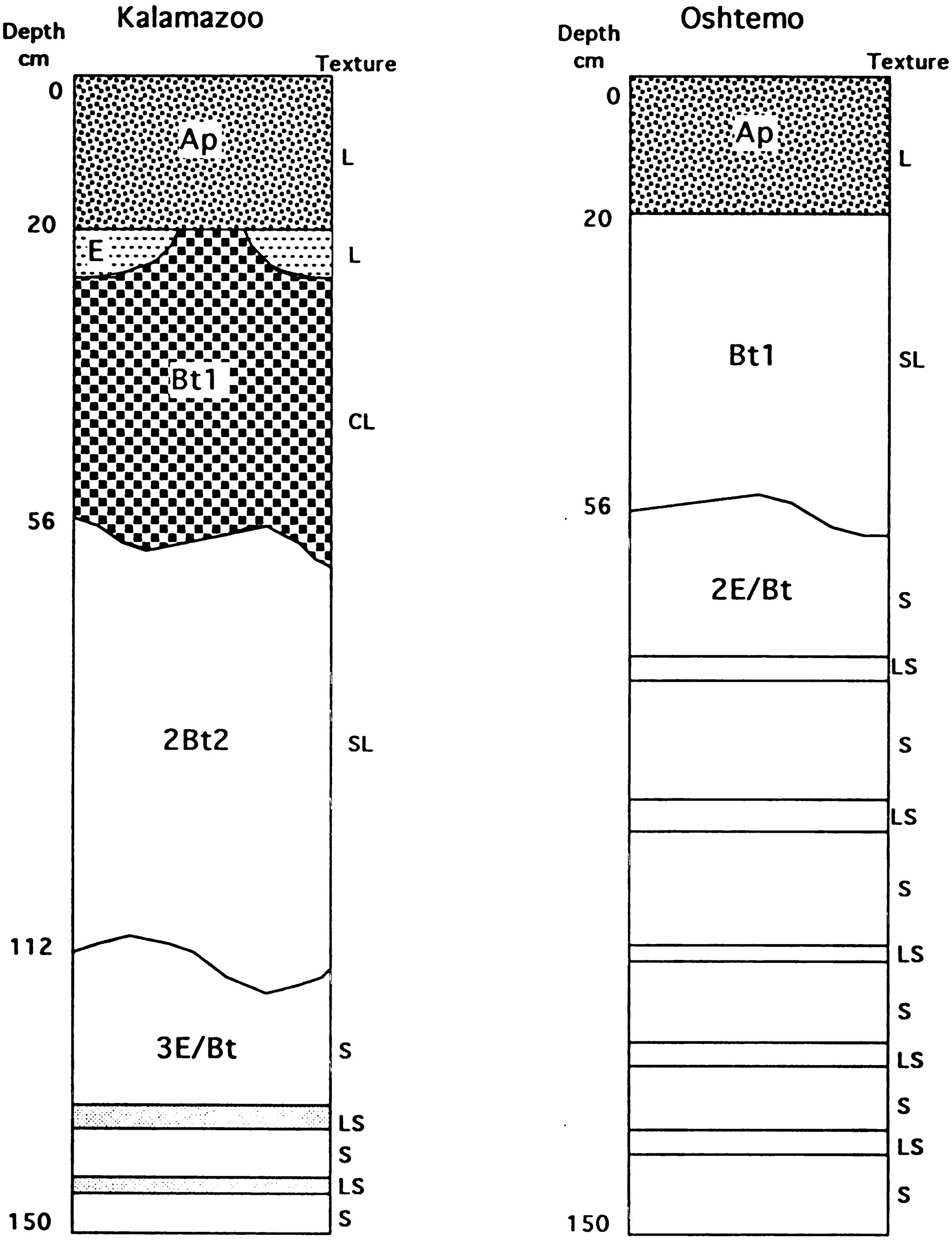
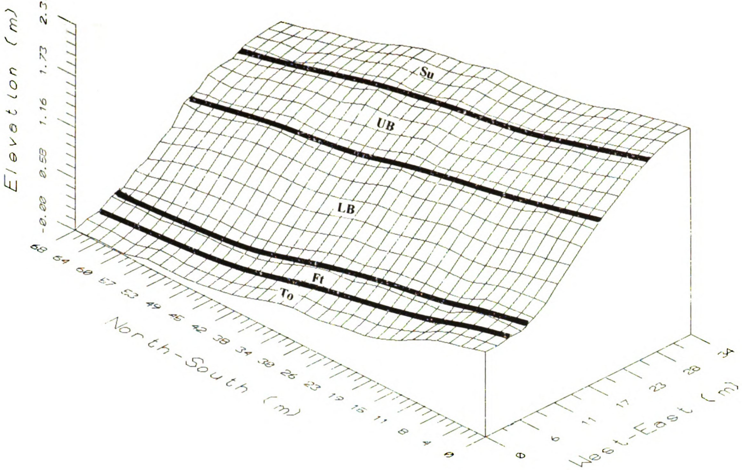


Figure 2.1. Typical Kalamazoo and Oshtemo soil profiles.



To = Toeslope, Ft = Footslope, LB = Lower Backslope, UB = Upper Backslope, Su = Summit

Figure 2.2 Study site surface 3 dimentional plot.

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A 34 meter by 68 meter rectangular grid of sampling points was established on the site, using a 4.25 meter (east-west) by 4 meter (north-south) grid cell. Grid points were located and flagged using a WILD Distomat and Theodolite (Total Station), and elevations were recorded for topographic map production. The raw survey data were converted to coordinate data using the WILDSOFT computer program (Wild Heerbrug Instruments, Inc., 1987). Soil descriptions and samples at each point were taken using a Giddings hydraulic probe mounted on a pickup truck. Additionally, soils were sampled at 2 meter intervals on the north and south boarders of the site. This made for a total of 180 soil profiles sampled. Soil profiles were described using standard procedures (Soil Survey Staff, 1984) and sampled to a depth of 150 cm, or to the base of the 2Bt2 horizon if it was deeper than 150 cm. Percent sand, silt, and clay, of the samples were determined by a hydrometer method (Grigal, 1973). The percent organic carbon of the Ap horizon samples were determined colormetrically by a routine organic matter method (Graham, 1948).

In order to delineate the Kalamazoo and Oshtemo soils on the landscape, a map of the control-section clay content, the average clay content of the upper 50 cm of the argillic horizon, or the entire argillic horizon if less than 50 cm thick (Soil Survey Staff, 1975), was generated for the study site (Figure 2.3) using geostatistical methods (Trangmar et al., 1985; Webster, 1985). The 18% clay line separates Kalamazoo soils which are classified as fine-loamy, from Oshtemo soils, which are classified as coarse-loamy. Most of the Oshtemo soils occur in the north 12 meters of the site.

Statistical Approach

In order to perform statistical analyses on a single sample population where topography alone regulates the major trends, the soil samples from the north 16 meters were eliminated from further examination (Figure 2.3), leaving 135 soil profiles for statistical analyses.

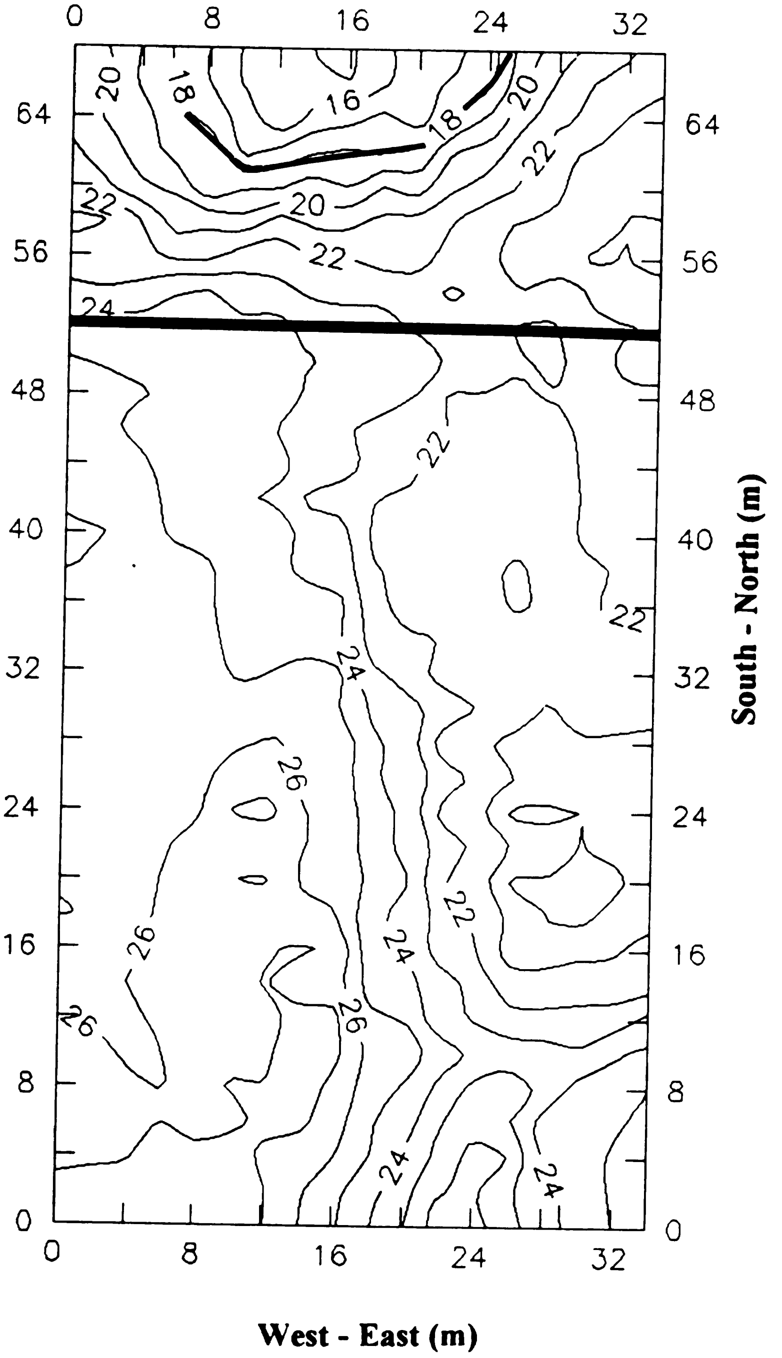

Figure 2.3. Control-section percent clay of the study site.

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Statistical analyses were performed on the percent organic carbon of the Ap horizon; percent sand, silt, and clay, of the Ap, Bt1, and 2Bt2 horizons; percent clay in the control-section; thickness of the Bt1, 2Bt2, and solum (the surface to the base of the 2Bt2 horizon in this study); and amount of clay (kg) in the Bt1, 2Bt2, control-section, and soil profile (0 to 150 cm). These variables were chosen for study because of there relationship to soil development and water holding capacity.

Each variable was first subjected to classical statistical analysis to obtain the mean, variance, standard deviation (SD), and coefficient of variation (CV) of each horizon. Mean and SD of the variables within each landscape position were calculated. A one-way ANOVA was performed on each variable for all five landscape positions to determine if the means of the variable were significantly different, and least significant difference (LSD) values were obtained to determine which means of the variable were significantly different. The degree of spatial variability for each variable was determined by geostatistical methods (Trangmar et al., 1985; Webster, 1985). A semivariogram for each property to ascertain the degree of spatial variability between neighboring observations, and a appropriate model was fit to the semivariogram. The semivariance is a measure of the average similarity between points of a given lag distance apart. The more alike the measurements of the points are, the smaller the semivariance (Burgess and Webster, 1980).

The plot of semivariance versus lag distance, h, is known as the semivariogram. The semivariogram consists of four basic parts; the sill, the range of spatial dependence (range), the nugget variance (nugget) and the explained variance (Figure 2.4). The sill approximates the sample variance, and is the region of relatively constant semivariance. The range is the distance over which the variable exhibits spatial dependence, and is defined by the value at which the curve reaches the sill. The nugget is the y-intercept value of the semivariogram. The nugget represents unexplained or random variance, which is caused by sampling error, or variability of

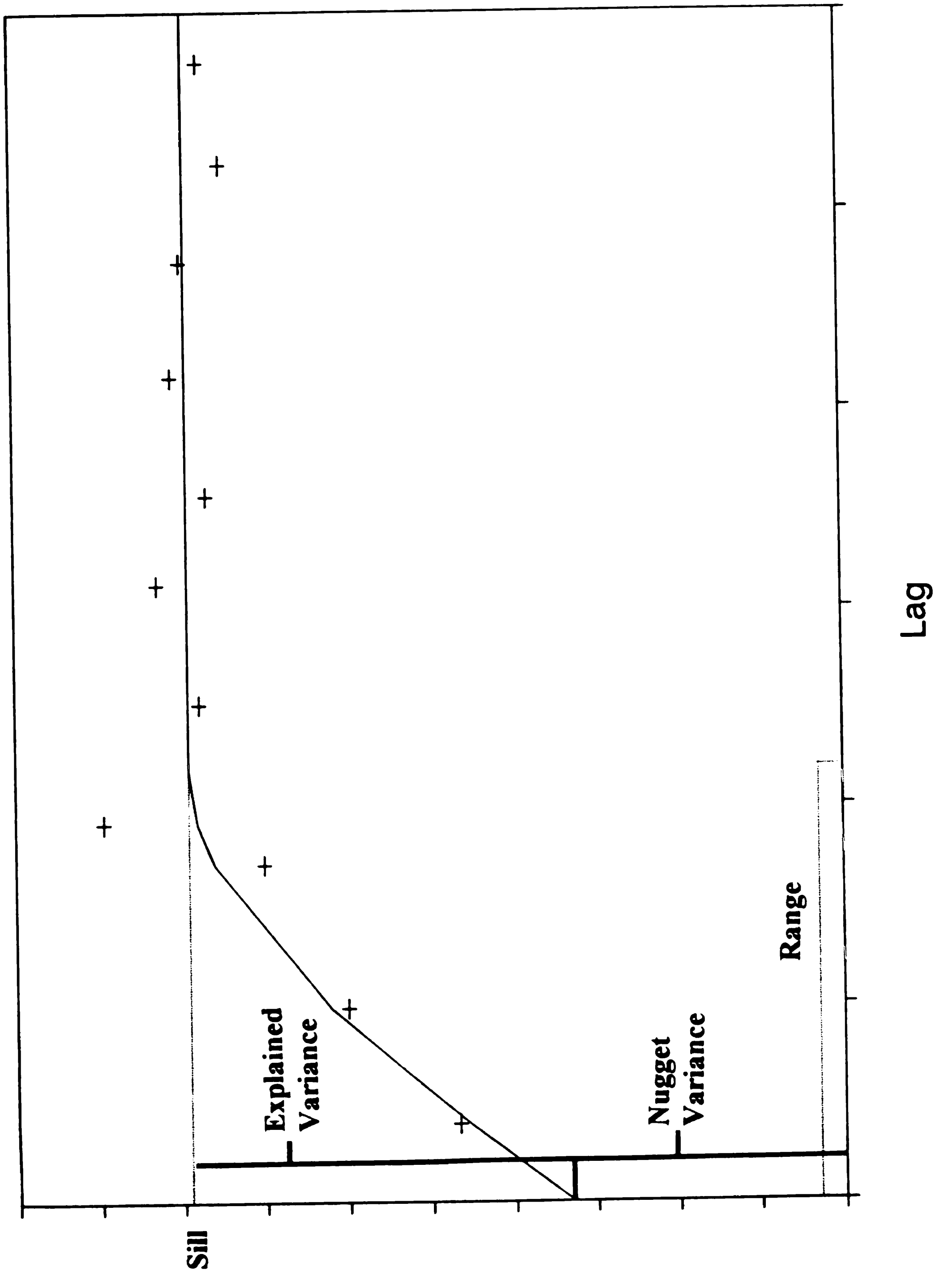


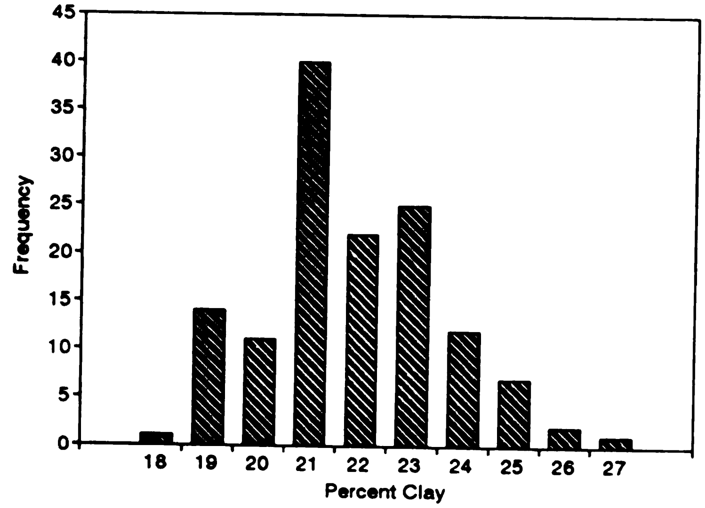
Figure 2.4. Hypothetical semivariogram.

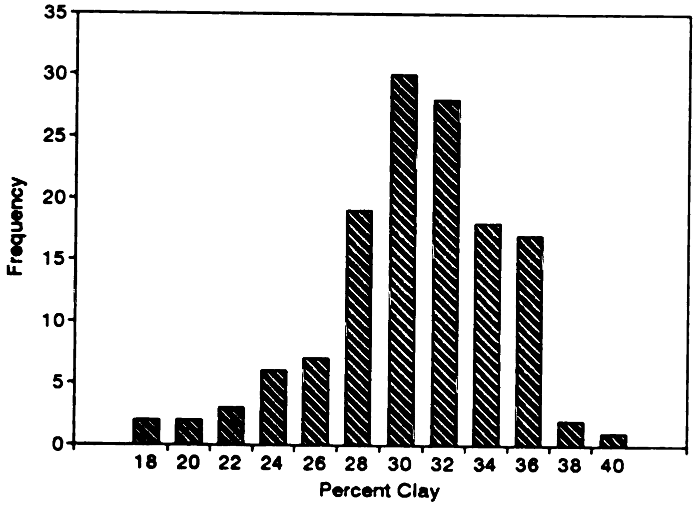
the variable which cannot be detected by the sampling scale used (Trangmar et al., 1985). The explained variance is the portion of the total variation correlated with distance.

Plotted semivariance points must be fitted to a mathematical model to produce statistics for kriging procedures. There exists no set mathematical procedure for fitting observed semivariograms (Webster, 1985). In general, the criteria for choosing a model are high correlation coefficient, small nugget, and a large range. Semivariance data in this study were fitted to exponential, spherical, linear, and gaussian models. Semivariance provides the basis for kriging and cokriging techniques, which are used for unbiased, optimal interpolation between known points of data (Burgess and Webster, 1980). Semivariograms and block kriging interpolation data for each variable were calculated using GEOPACK (Yates and Yates, 1989). Each property was block-kriged with the statistics generated by the chosen semivariogram model. A width of two meters was chosen for the block size, which defined 486 blocks within the study area. A maximum search radius of 62.13 meters was used, and the 16 nearest data points ("neighbors") were used for kriging. The generated block kriged data for each variable was gridded in SURFER (Golden Software, 1989). The gridded estimates were used to produce maps of the variables with SURFER.

RESULTS AND DISCUSSION

The distributions for the studied variables of the south 52 meters of the site , under visual inspection, were approximately normal (Figures 2.5 to 2.11) except for the amount of sand and silt in the 2Bt2 horizon, which were eliminated from geostatistical analysis. The descriptive statistics for the soil properties studied are given in Table 2.2. Johnson (1990) found similar mean, SD, and CV values for percent clay of the Bt1 (25.6, 4.5, and 17.6 %, respectively) and 2Bt2 (10.0, 3.0, and 30.0 %,


Ap Clay (%)


Bt1 Clay (%)

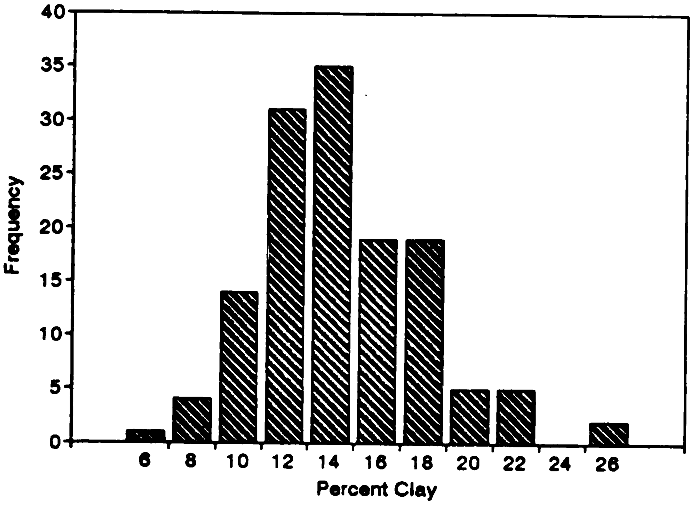

2Bt2 Clay (%)

Figure 2.5. Frequency of Ap, Bt1, and 2Bt2 horizon percent clay.

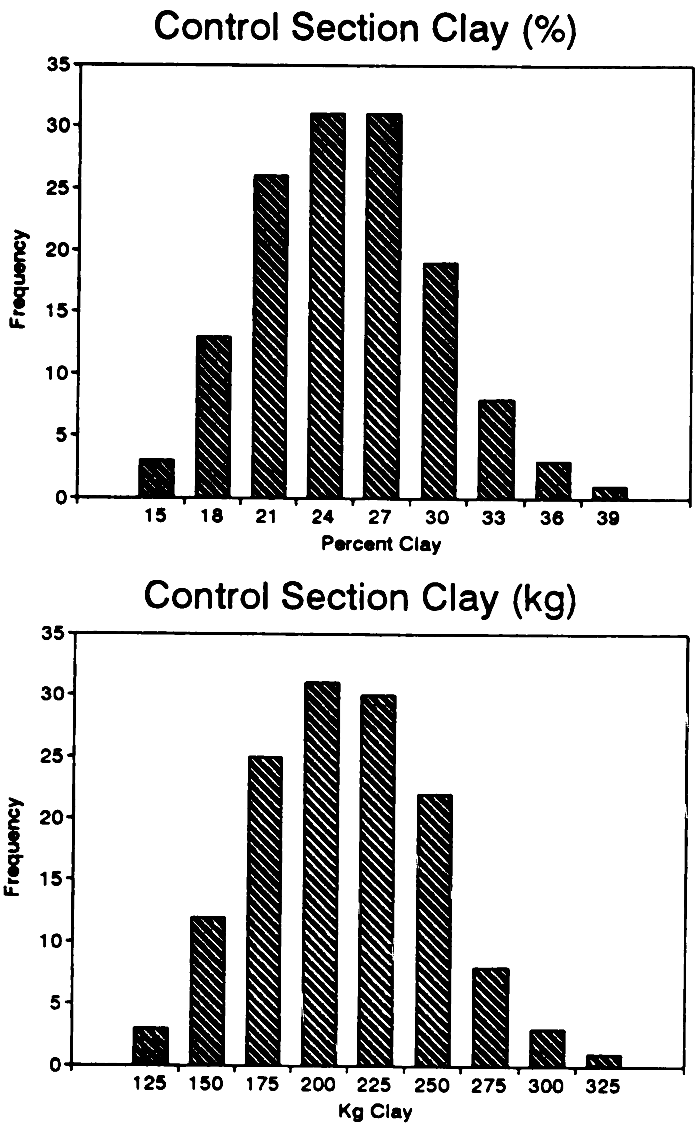


Figure 2.6. Frequency of control-section percent clay and clay mass.


Frequency

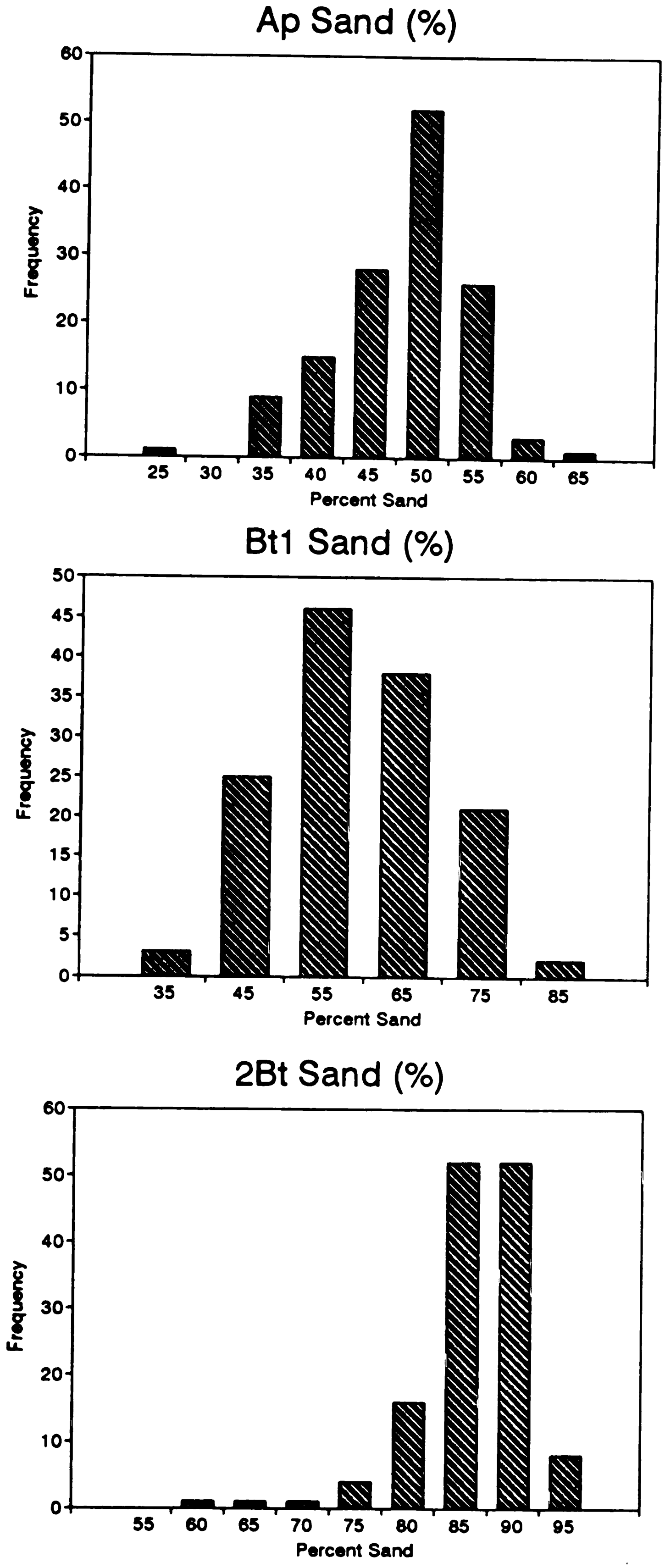


Figure 2.7. Frequency of Ap, Bt1, and 2Bt2 horizon percent sand.

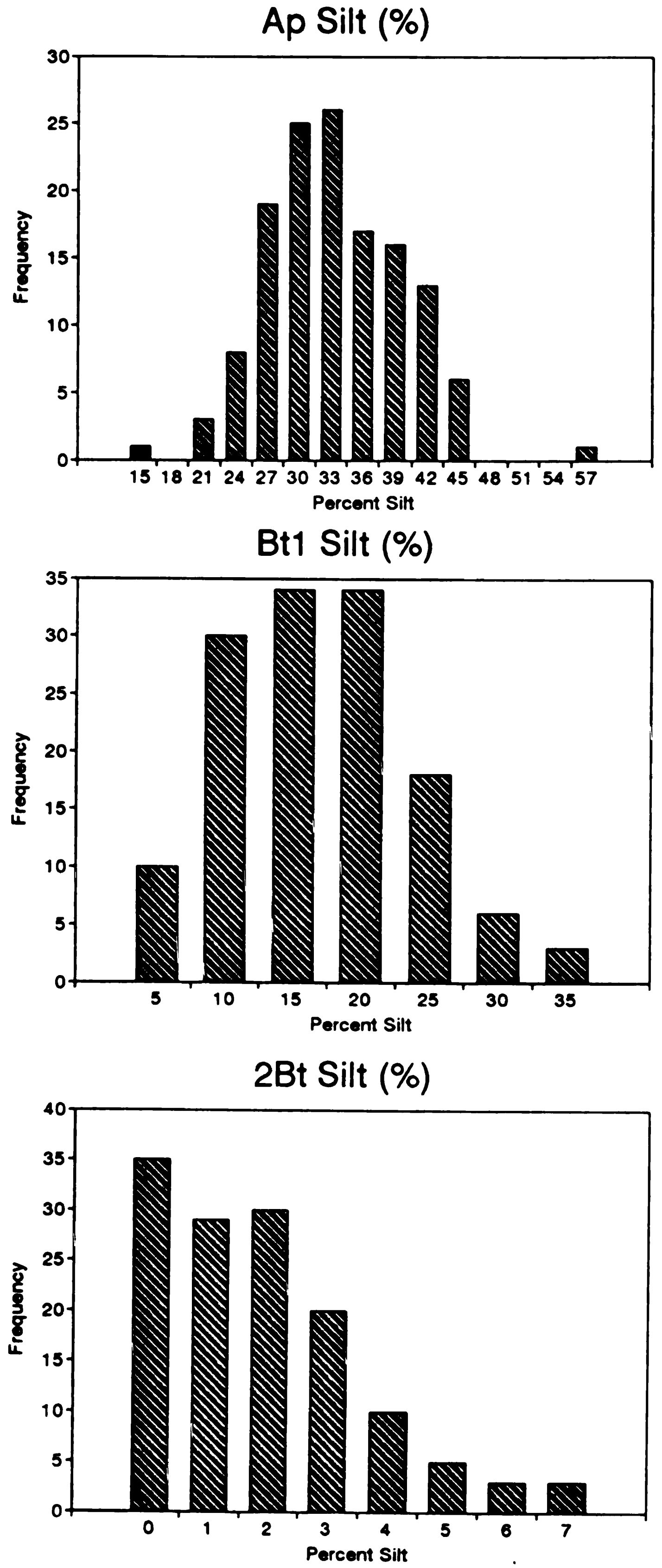
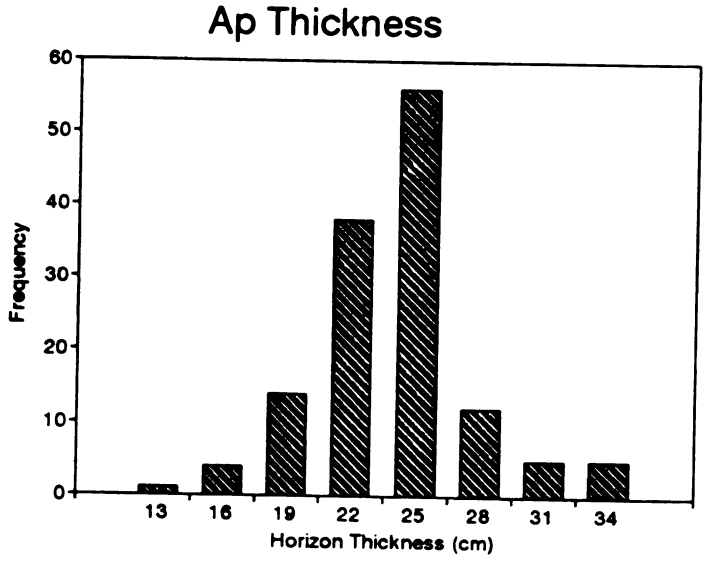
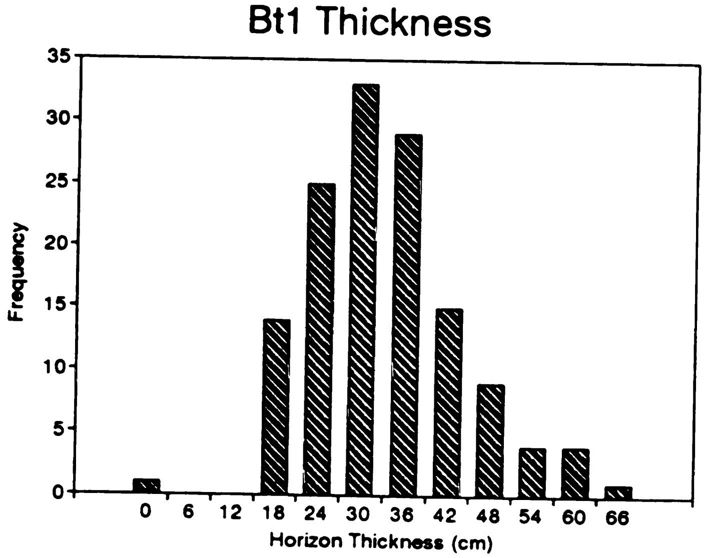


Figure 2.8. Frequency of Ap, Bt1, and 2Bt2 percent silt.





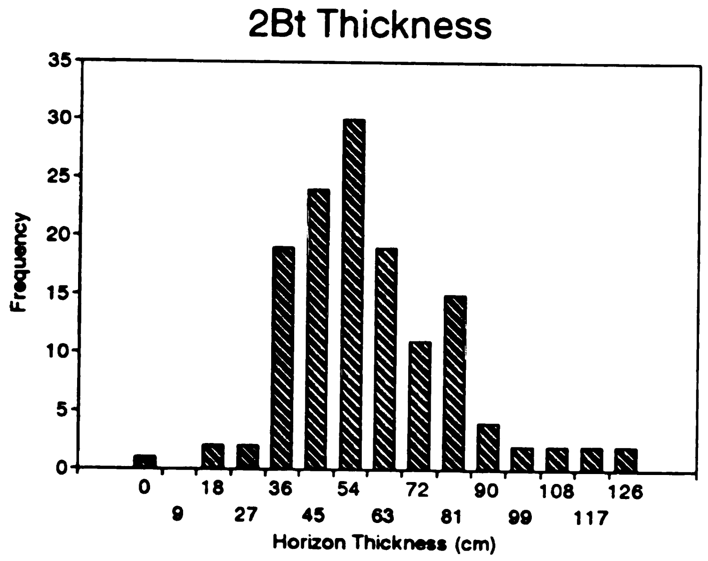
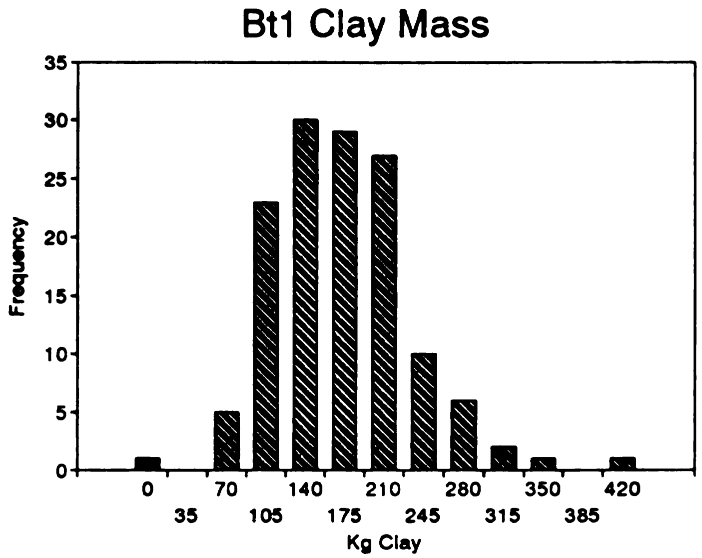
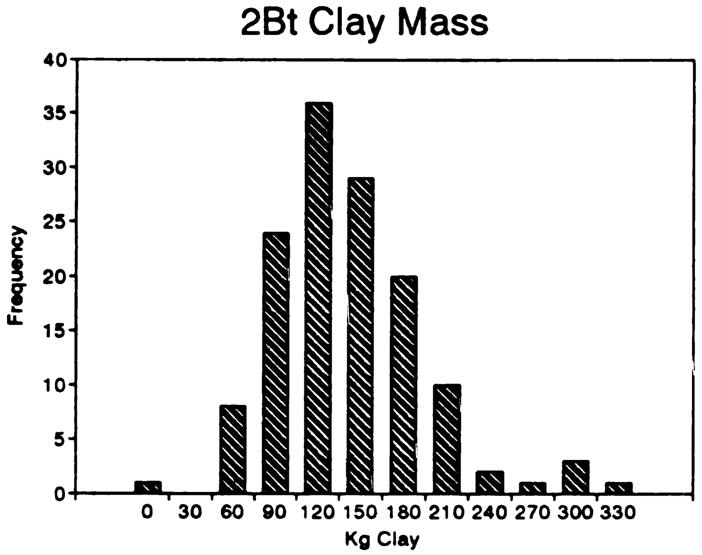


Figure 2.9. Frequency of Ap, Bt1, and 2Bt2 horizon thickness.


Bt1 Clay Mass


2Bt Clay Mass

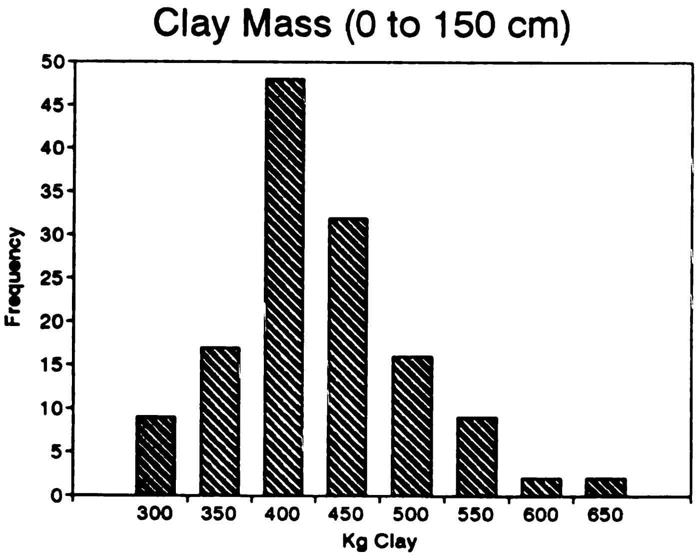

Clay Mass (0 to 150 cm)

Figure 2.10. Frequency of Bt1, 2Bt2, and soil profile clay mass.

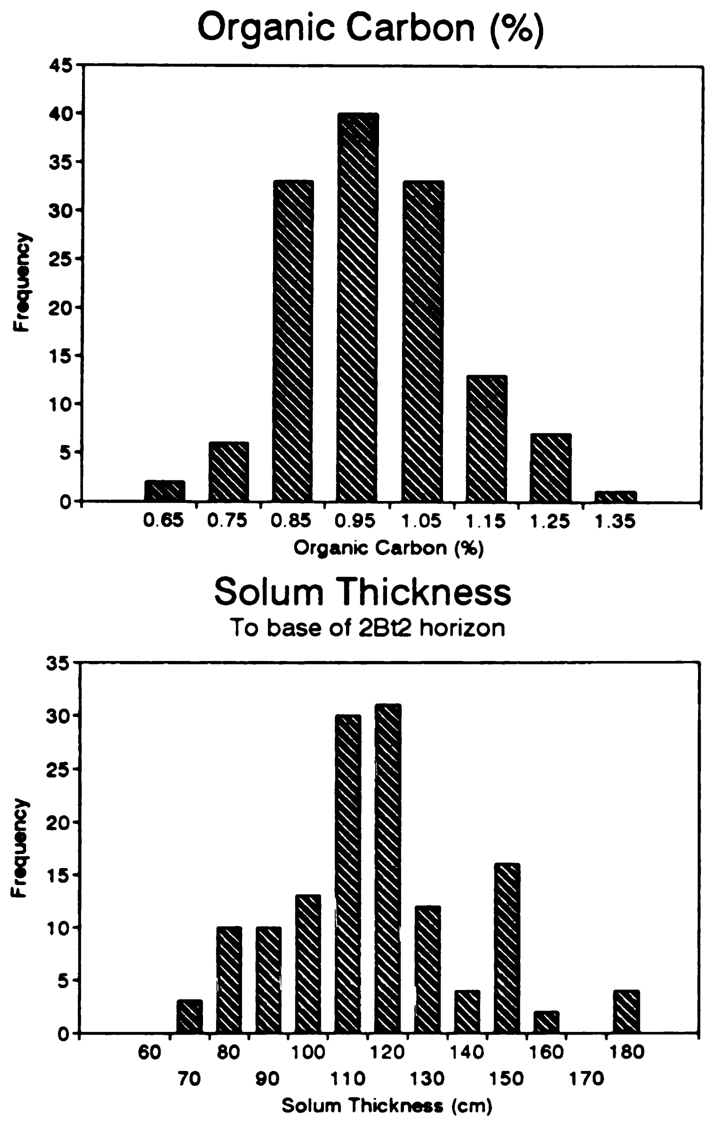


Figure 2.11. Frequency of Ap percent organic carbon and solum thickness.

Table 2.2. Descriptive statistics for variables determined in the field and laboratory.

Variable		Min.	Max.	Mean	Variance	SD	CV (%)
O.C. (%)	Ap	0.65	1.29	0.93	0.017	0.13	13.8
Clay (%)	Ap	18.0	27.0	21.8	3.1	1.8	8.1
	Bt1	0.0	39.0	29.9	22.4	4.7	15.7
	2Bt2	0.0	26.0	13.8	13.4	3.7	26.8
	Control Sec.	15.0	39.0	24.2	22.4	4.7	19.6
Sand (%)	Ap	25.0	65.0	45.9	38.4	6.2	13.5
	Bt1	27.0	79.0	55.2	102.4	10.2	18.4
	2Bt2	57.0	94.0	84.1	28.6	5.4	6.4
Silt (%)	Ap	13.0	55.0	32.2	40.2	6.4	19.7
	Bt1	1.0	34.0	14.8	47.7	6.9	46.9
	2Bt2	0.0	7.0	1.9	2.9	1.7	91.6
Thick. (cm)	Ap	13.0	33.0	22.6	15.8	4.0	17.6
	Bt1	0.0	63.0	30.9	112.8	10.7	34.5
	2Bt2	0.0	120.0	54.7	431.7	20.9	38.1
	Solum	69.0	173.0	113.3	550.5	23.5	20.8
Clay (kg in m^2 x m depth)							
	Bt1	0.0	405.4	155.4	3834.0	62.2	40.0
	2Bt2	0.0	326.0	123.4	2665.9	51.8	42.0
	Control Sec.	120.1	321.7	199.0	1524.1	39.2	19.7
	0 to 150 cm	275.8	633.9	405.2	5023.4	71.1	17.6

respectively) horizons on a relatively level landscape at KBS. Johnson also found similar means for control-section clay (20.4%) and Bt1 thickness (34.1 cm), but greater SD and CV values (6.0 and 29.9 percent for control-section clay content and 18.3 and 53.7 percent for Bt1 thickness) for these variables. The mean 2Bt2 thickness of Johnson's study was less (43.1 cm) while the SD and CV values were substantially greater (28.1 and 65.9 %). The greater SD and CV values of these variables in Johnson's study could be due to the larger study area (440 by 140 meters) and sample grid cells (20 by 20 meters). Also, Johnson's study had both Kalamazoo and Oshtemo soils in the data set, and exhibited a bimodal population, which may contribute to the greater SD and CV values of control-section clay content.

The descriptive statistics for the soil properties as a function of landscape position are given in Table 2.3. There is no significant difference ($\alpha = 0.05$) between the means of all the slope positions for the 2Bt2 thickness and 2Bt2 amount of clay (kg), therefore LSD values were not calculated for those variables. Organic carbon displayed a small but steady increase from the upper backslope to the toeslope soils. Ovalles and Collins (1986) and Miller et al. (1988) found a similar trend from the summit to backslope soils and the shoulder to the toeslope soils, respectively. The summit and upper backslope position Ap horizons have significantly less O.C. than do those of the footslope and toeslope positions. The lower backslope position Ap horizons have significantly less O.C. than those of the toeslope positions. This may reflect the greater amount of water which enters the soils on the lower portions of the landscape via surface and subsurface run-on from upslope and throughflow (Rosek and Crum, 1994). The mean percent sand in the Ap horizon of the toeslope position is significantly less than in Ap horizons of upslope positions. The percent sand in the Bt1 horizon of the lower backslope, footslope, and toeslope positions are significantly lower than the Bt1 horizon of the upper backslope position. The 2Bt2 horizon of the upper backslope had significantly more sand than the 2Bt2 horizon of the footslope

Table 2.1 Descriptive statistics as a function of slope position for selected soil properties

Table 2.3. Descriptive statistics as a function of slope position for selected soil properties.

Variable		Summit n = 29		Upper Backslope n = 31		Lower Backslope n = 45		Footslope n = 15		Toeslope n = 15			
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	Fstat.	LSD
O.C. (%)	Ap	0.87a	0.11	0.88a	0.08	0.92a	0.11	1.03b	0.12	1.10b	0.12	16.30*	0.11
Clay (%)	Ap	22.1abc	1.9	22.5bc	1.4	21.1ab	1.7	20.7a	1.3	23.1c	1.3	8.53*	1.5
	Bt1	28.6ab	4.5	26.6a	3.8	32.4c	2.6	31.7bc	2.4	31.5bc	3.0	16.48*	3.6
	2Bt2	13.3ab	2.2	11.6a	3.2	14.3ab	2.9	15.0b	3.1	14.8b	3.8	5.42*	2.8
Control Section		23.2ab	5.5	20.4a	4.1	26.5b	3.3	24.1ab	3.0	26.9b	4.1	12.13*	4.1
Sand (%)	Ap	46.5ab	6.7	50.1b	3.6	47.2ab	4.5	42.8a	3.2	35.4c	2.6	28.94*	5.4
	Bt1	59.2ac	10.3	64.5a	7.8	49.2b	6.6	49.4b	7.4	51.0bc	7.0	21.87*	8.8
	2Bt2	84.7ab	3.4	87.1ab	4.0	84.0ab	3.7	81.5a	8.0	82.0a	5.1	5.26*	4.2
Silt (%)	Ap	31.4ab	7.2	27.4a	3.8	31.7ab	4.8	36.5bc	3.1	41.5c	2.1	24.33*	5.5
	Bt1	12.1ab	6.9	9.0a	5.7	18.3c	5.1	18.9c	5.6	17.5bc	4.6	16.81*	6.0
	2Bt2	1.9ab	2.0	1.4a	1.5	1.8ab	1.3	2.2ab	2.2	3.2b	1.8	2.95*	1.5
Thick (cm)	Ap	21.0a	2.3	20.9a	3.2	21.8a	3.3	25.9b	3.5	28.5b	3.3	23.02*	3.5
	Bt1	31.6ab	11.8	27.1a	12.0	32.5ab	7.7	27.7ab	9.3	36.7b	11.6	2.87*	9.2
	2Bt2	60.0	21.5	59.5	30.4	50.9	13.9	49.4	12.3	51.1	17.1	1.65	
	Solum	113.3ab	24.2	107.5a	27.2	109.9a	18.6	117.6ab	19.5	131.3b	24.4	3.22*	20.9
Clay (kg in m^2 x depth)													
	Bt1	151.3ab	78.5	123.0ab	51.2	175.0ab	45.8	144.0ab	42.5	190.7b	64.1	5.32*	53.1
	2Bt2	134.8	39.4	121.9	76.2	121.9	42.8	121.1	35.8	120.0	43.1	0.38	
Control Section		191.2ab	45.4	167.2a	33.4	218.4b	27.2	199.3ab	24.2	221.6b	33.7	12.71*	34.0
	0 to 150 cm	385.6ab	62.8	349.1a	56.5	420.7bc	62.6	444.7bc	60.0	472.8c	51.5	14.73*	61.8

* Significant at $\alpha = 0.05$, F critical = 2.44.

a, b, and c represent significant differences between positions for a variable.

and toeslope positions. The trend of percent sand to decrease downslope could be due to glacio-fluvial sorting of the parent material at the time of deposition. This trend in the Ap horizon could also be due to erosion, where the silt fraction is transported downslope, increasing the proportion of sand in the summit and backslope soils and decreasing the proportion of sand in the toeslope soils.

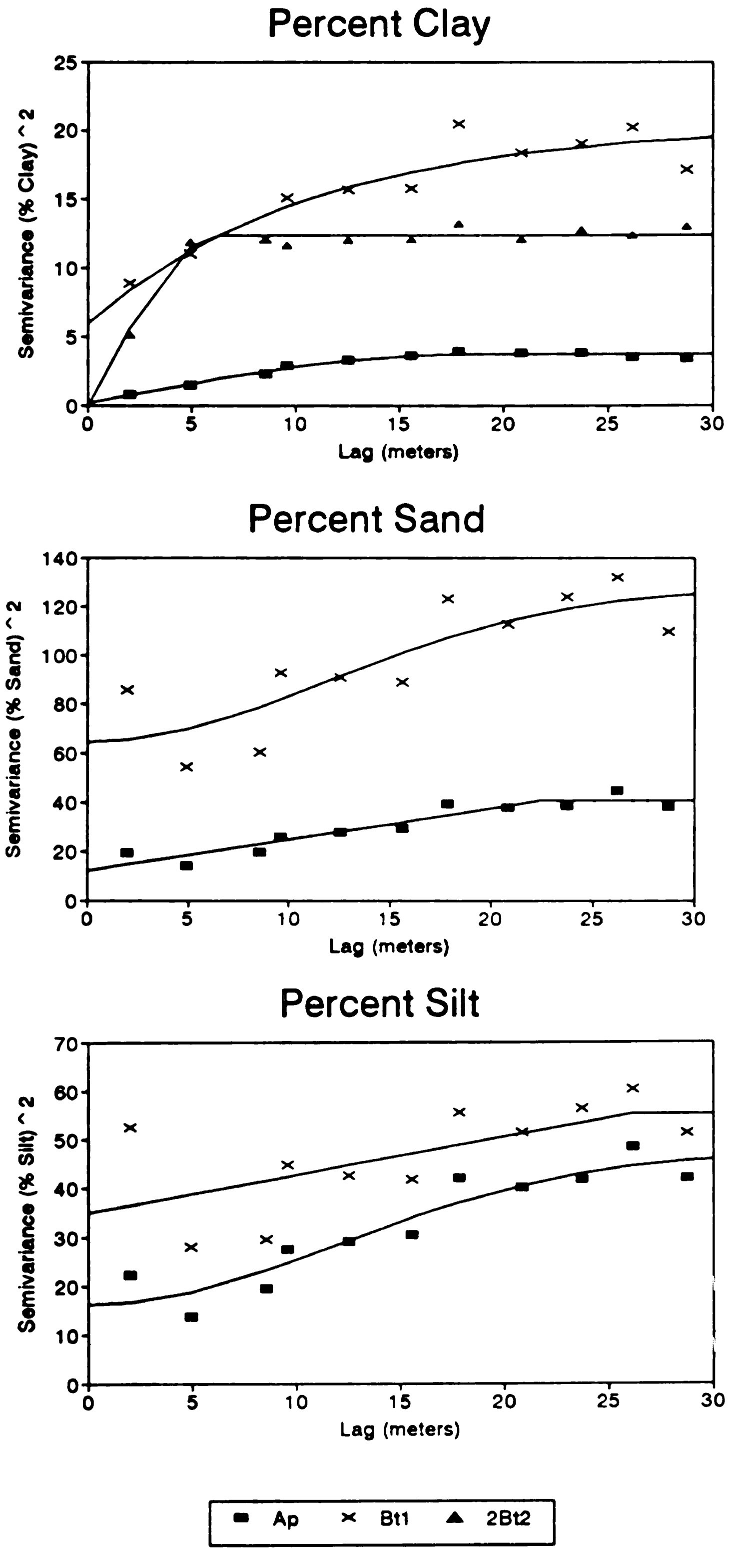
The trend of percent silt of the Ap, Bt1, and 2Bt2 horizon, with landscape position, is to increase downslope. The toeslope position Ap horizons have significantly more silt than Ap horizons upslope of the footslope position. The Bt1 horizon of the summit and upper backslope have significantly less silt than the Bt1 horizons of downslope positions. The 2Bt2 horizon of the upper backslope position had significantly less silt than of the toeslope position. This is further indication that differential glacio-fluvial sorting occurred at deposition. Also, there is evidence of erosion and transportation of the silt fraction, which is the most highly erodible fraction (Hjulstrom, 1939), from the soils of the summit and upper backslope positions to the footslope and toeslope.

There are statistically different means of Ap percent clay, but the differences are small, and the significance is most likely due, in part, to the low CV (8.1 %) of this variable. The mean percent clay of the Bt1 horizon of the upper backslope position is significantly less than mean percent clay of downslope positions. The summit position mean percent clay of the Bt1 horizon is significantly less than the lower backslope Bt1 mean percent clay. The mean percent clay of the Bt1 horizon is least in the upper backslope position, greatest in the lower backslope, footslope, and toeslope positions, with the summit mean clay percent between the upper backslope and lower slope positions. The mean percent clay of the 2Bt2 horizon and control-section of the upper backslope position is significantly less than the footslope and toeslope, and lower backslope and toeslope positions, respectively. The percent clay in the argillic horizon of this landscape appears to decrease from the summit position to the upper backslope position and increase downslope. Malo et al. (1974) found a similar pattern of percent clay in the solum of a toposequence within a glacial till plain of North Dakota (the shoulder position of their study is analogous to the upper backslope position of this study).

The Ap horizon of the footslope and toeslope positions is significantly thicker than the Ap horizon thickness of the upslope positions. This is further evidence that erosion and transport from the upper backslope to the footslope and toeslope positions has taken place. The Bt1 horizon of the toeslope horizon is significantly thicker than the upper backslope Bt1. There are no significant differences in 2Bt2 horizon thickness associated with landscape position. The mean solum thickness decreases from the summit to the backslope positions, and then increases downslope. The toeslope position mean solum thickness is significantly greater than the upper and lower backslope solum thickness. The greater solum thickness of the footslope and toeslope positions is due to a thicker Ap horizon, the presence of an E horizon in most soil profiles (Appendix 1), and a thicker Bt1 horizon. King et al. (1983) noted solum thickness increases greatly below the point downslope where the slope becomes concave. In this study, the slope becomes concave at the backslope-footslope juncture. The trend in Bt1 and solum thickness may be due to water moving from the upper backslope position via overland flow and subsurface lateral downslope throughflow of water to the footslope and toeslope soils (Rosek and Crum, 1994), increasing the amount of leaching and translocation of clay in the footslope and toeslope soils. This is indicated by the presence of E horizons in the footslope and toeslope positions.

The mean amount of clay (kg) in the Bt1, control-section, and soil profile (0 to 150 cm) decreases from the summit to the upper backslope, and then increases downslope, with the footslope position having slightly less clay in the Bt1 and control-section than the lower backslope. The mean amount of clay in the Bt1 horizon of the toeslope position is significantly greater than in the upper backslope position. The mean amount of clay in the control-section of the upper backslope is significantly less than the lower backslope and toeslope positions. The mean amount of clay from 0 to 150 cm in the upper backslope position is significantly less than in the downslope positions. The mean amount of clay from 0 to 150 cm in the summit position is significantly less than in the toeslope position. The trends of the mean amount of clay as a function of landscape position noted above are probably due to both differential glacio-fluvial sorting which may have occurred between the landscape positions at deposition, and pedogenic clay translocation. Water moving from the backslope via overland flow and subsurface downslope lateral throughflow could transport clay to the soils downslope. Glazovskaya (1968) observed lateral subsurface translocation of silt and clay in throughflow water. Overland flow from upslope can also transport clay, which can infiltrate into the soils of the lower backslope.

The semivariograms for the soil properties are presented in Figures 2.12 to 2.14. The spatial dependence of the soil properties are summarized in Table 2.4. The "explained" variation (that portion of the total variation correlated with distance) ranged from 27.7 to 100 percent. The "unexplained" variation is attributable to the nugget variance. The range of spatial dependence values were adequately large to provide for valid block kriging within the 4.25 by 4.00 meter grid cells. All variables except the 2Bt2 horizon properties exhibited significant east-west anisotropy (Journel and Huijbregts, 1978). This is expected since the slope components are aligned in the north-south direction, and the greater amount of variability should occur up/down slope. The absence of anisotropy for the 2Bt2 horizon variables indicate these processes affecting these variables are acting somewhat independent of landscape position. Fewer significant differences among the 2Bt2 variables occur than for other soil layers (Table 2.3). Miller et al.(1988) found Ap percent sand, silt, clay, silt + very



Percent Clay

Percent Sand

Percent Silt

Figure 2.12. Semivariograms for Ap and Bt1 percent clay, sand, and silt; and 2Bt2 percent sand and silt.

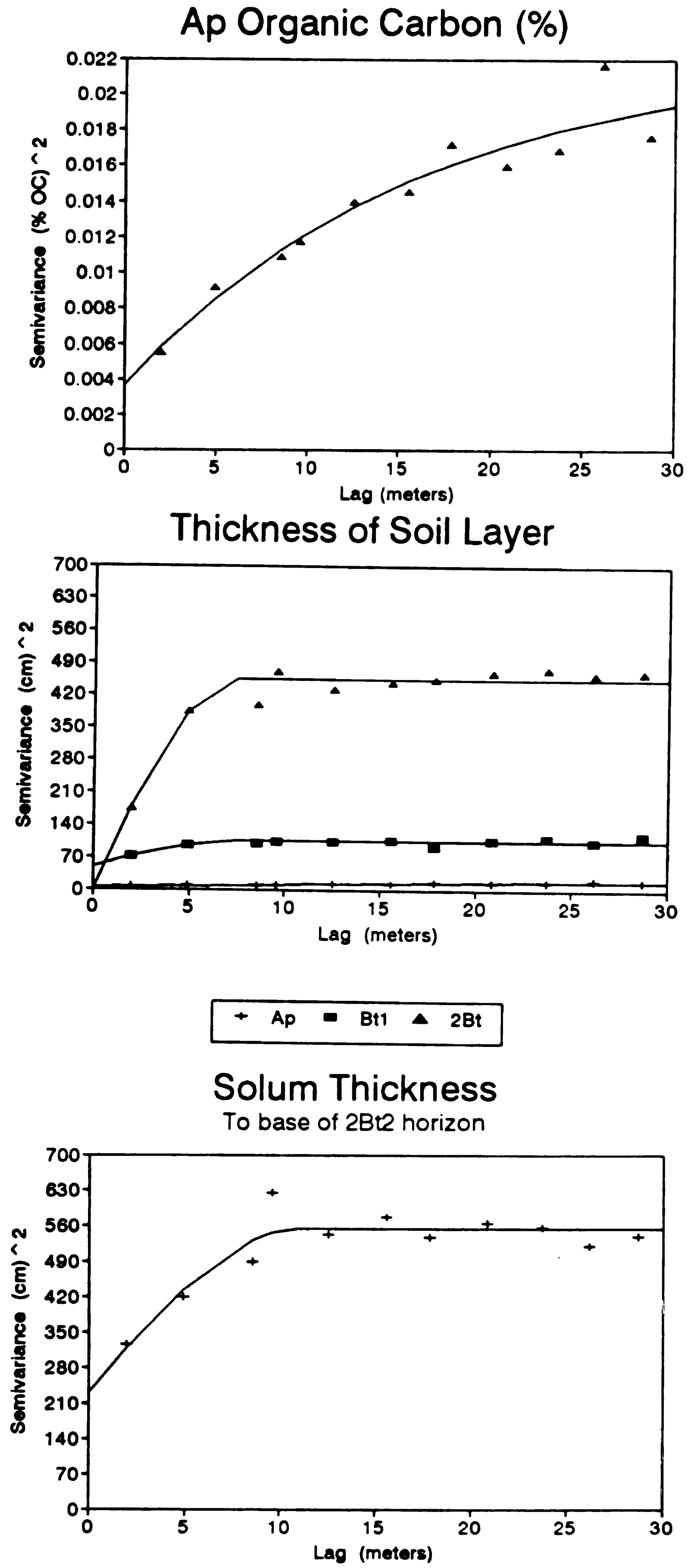
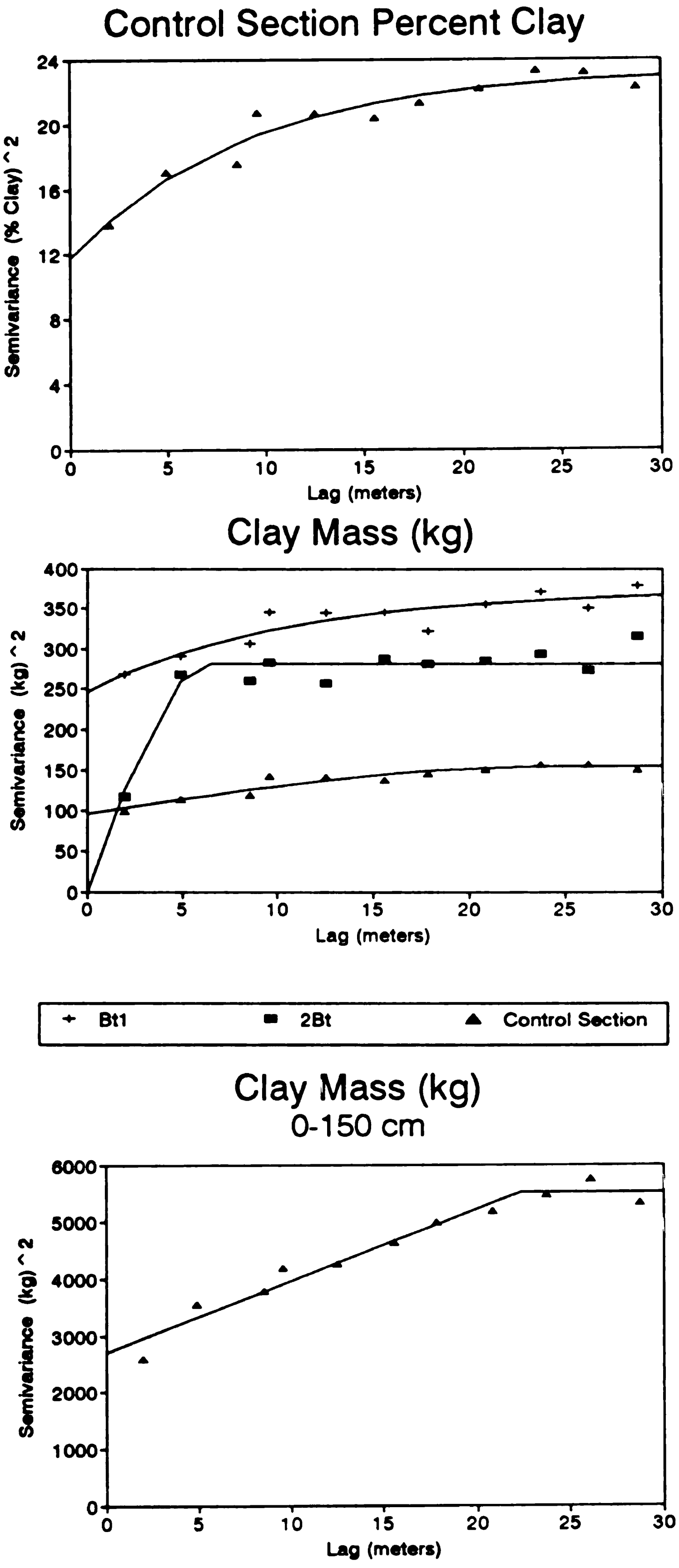


Figure 2.13. Semivariograms for Ap percent organic carbon; Ap, Bt1, 2Bt2, and solum thickness.



Control Section Percent Clay

Clay Mass (kg)

Clay Mass (kg)
0-150 cm

Figure 2.14. Semivariograms for control-section percent clay, Bt1, 2Bt2, control-section, and soil profile clay mass.

Table 2.4 Semivariance statistics for soil properties.

Property	*Model*	*Nugget Variance*	*Sill*	Variance Explained	Corr. Coeff.	Range	Anisotropy Ratio

Table 2.4. Semivariance statistics for soil properties.

Property	Model	Nugget Variance	Sill	Variance Explained	Corr. Coeff.	Range	Anisotropy Ratio East-West
				(%)	r	(m)	
O.C. (%)^2	Expon.	0.0036	0.0224	83.8	0.96	16.4	2.43
Clay (%)^2 Ap	Spherical	0.13	3.71	96.4	0.99	18.1	1.62
Bt1	Expon.	5.94	20.39	70.8	0.93	10.8	2.25
2Bt2	Spherical	0.00	12.38	100	0.98	6.4	1.00
Control Sec.	Expon.	11.75	23.36	49.7	0.96	9.1	2.26
Sand (%)^2 Ap	Linear	12.15	40.62	70.1	0.94	22.4	1.31
Bt1	Gaussian	64.44	127.63	49.5	0.85	16.8	2.69
Silt (%)^2 Ap	Gaussian	16.25	47.38	65.7	0.94	17.0	1.97
Bt1	Linear	34.94	55.28	36.8	0.65	26.1	2.54
Thick (cm)^2 Ap	Linear	4.78	18.56	74.2	0.96	23.1	1.85
Bt1	Spherical	48.50	105.16	53.9	0.86	7.6	2.22
2Bt2	Spherical	0.00	454.11	100	0.97	7.5	1.00
Solum	Spherical	230.24	554.08	58.4	0.92	11.0	2.37
Clay (kg in m^2 x m depth)^2							
Bt1	Expon.	2467.7	3735.7	33.9	0.91	10.4	1.52
2Bt2	Spherical	0.00	2824.2	100	0.95	6.5	1.00
Control Sec.	Spherical	961.4	1548.8	37.9	0.95	24.1	2.06
0 to 150 cm	Linear	2697.5	5524.2	51.2	0.98	22.4	3.60

fine sand, organic carbon, and thickness to be isotropic for soils on a sloping landscape.

Johnson (1990) found a similar nugget and sill (3.7 and 19.0 (% clay)^2) of the Bt1 clay content for a relatively level landscape at KBS, though the range of spatial dependence (22.9 meters) is more than twice that of this study. Johnson found little spatial dependence for the 2Bt2 clay content. Johnson found the Bt1 and 2Bt2 thickness (cm) exhibited substantially greater sill (315.9 and 837.2 cm^2) and range (11.7 and 27.5 meters) values than those of this study. The nugget value in Johnson's study for the Bt1 thickness was much lower (0.0 cm^2), while much higher for the 2Bt2 thickness (125.6 cm^2). The greater range of spatial dependencies Johnson found were most likely due to the level landscape and larger sample grid cells (20 by 20 meters) of that study. Reinert (1990) found the range of spatial dependence for Ap bulk density, porosity, and saturated hydraulic conductivity was from 10.2 to 43.2 meters on a relatively level landscape at KBS. All ranges of the soil properties were greater than the width of the footslope and toeslope positions that were sampled, and most ranges were greater than the width of the portion of the summit position that was sampled.

Maps of the soil properties for the south 52 meters of the site, generated by kriging, are presented in Figures 2.15 to 2.31. The kriged estimation maps indicate a progressive downslope increase in Ap percent organic carbon, percent clay in the Bt1 and control-section, percent silt in the Ap and Bt1, thickness of the Ap, and amount of clay (kg) in the Bt1, control-section, and soil profile from 0 to 150 cm. These variables decrease from the summit to lower backslope in the south 12 to 16 meters of the site. Kriged estimation maps of Ap and Bt1 percent sand (Figures 2.20 and 2.21) indicate a progressive downslope decrease, except the south 12 to 16 meters, where percent sand increases from the summit to the upper backslope. Most of the increase in Ap percent organic carbon, silt, and thickness (cm), and decrease in Ap percent silt, occurs at the toeslope, footslope, and lower backslope positions. This indicates

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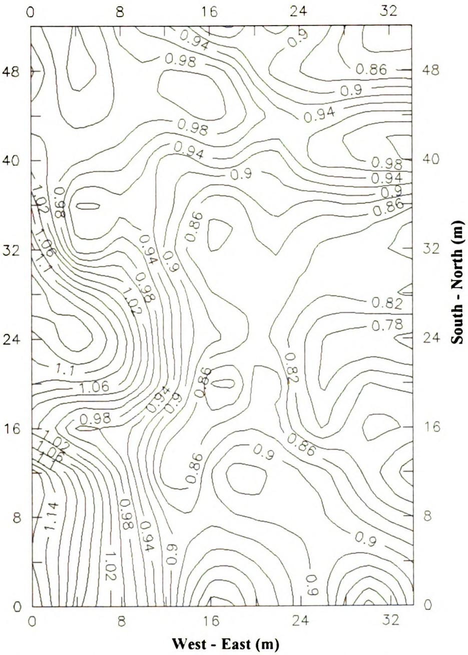

Figure 2.15. Block-kriged map of Ap horizon percent organic carbon.

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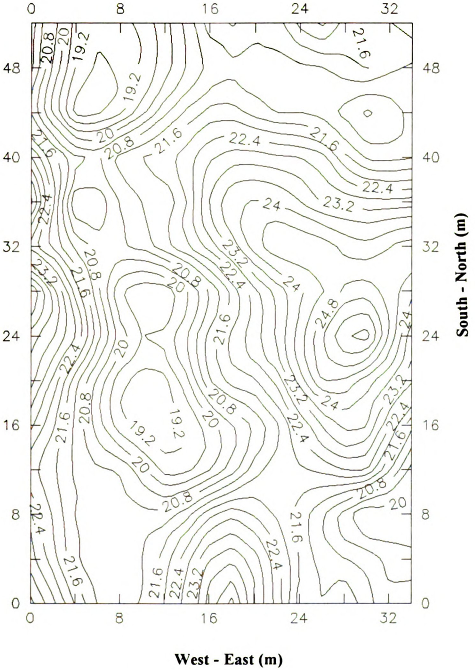

Figure 2.16. Block-kriged map of Ap horizon percent clay.


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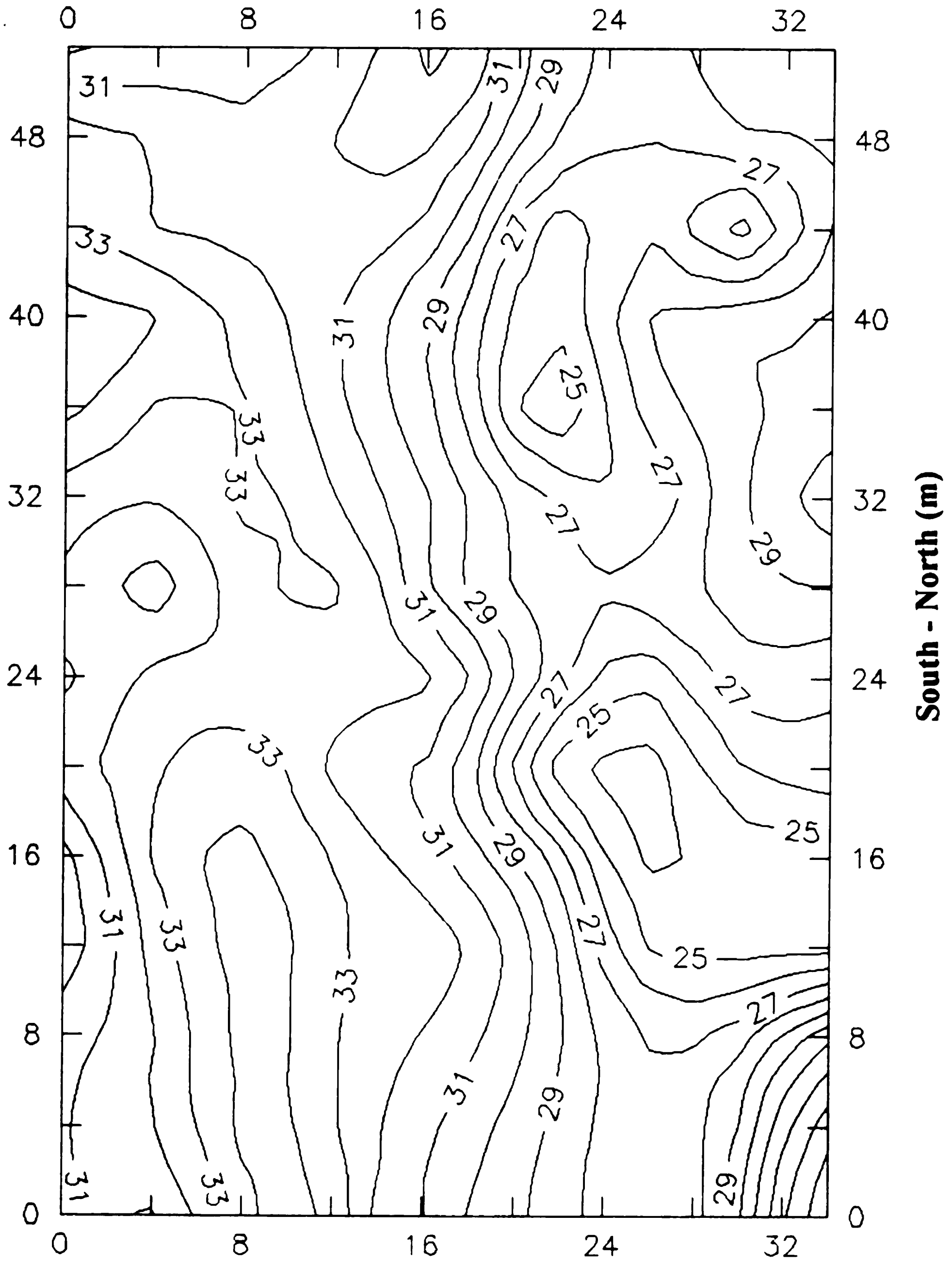

West - East (m)

Figure 2.17. Block-kriged map of Bt1 horizon percent clay.

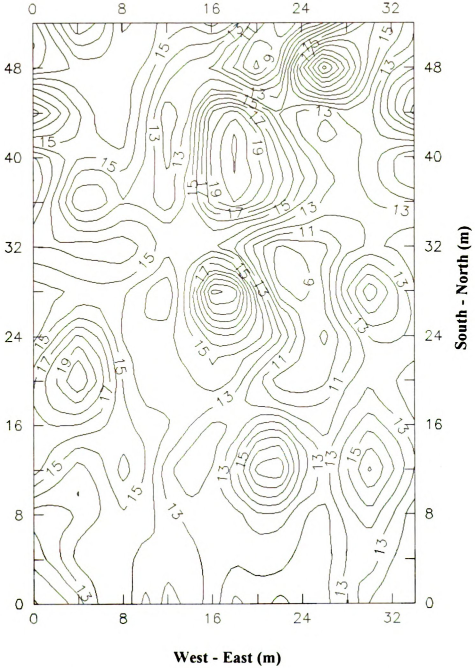

Figure 2.18. Block-kriged map of 2Bt2 horizon percent clay.


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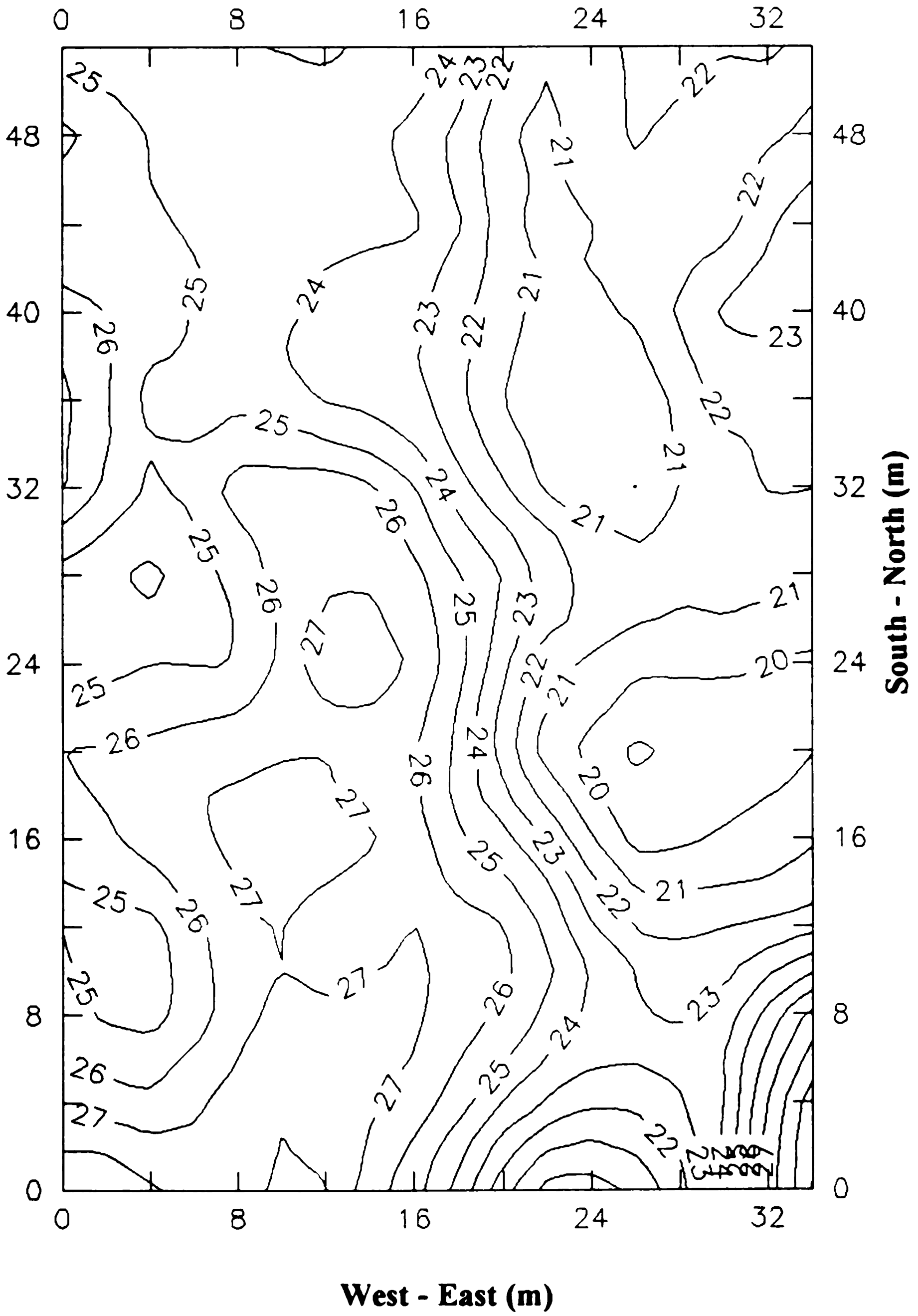

Figure 2.19. Block-kriged map of control-section percent clay.


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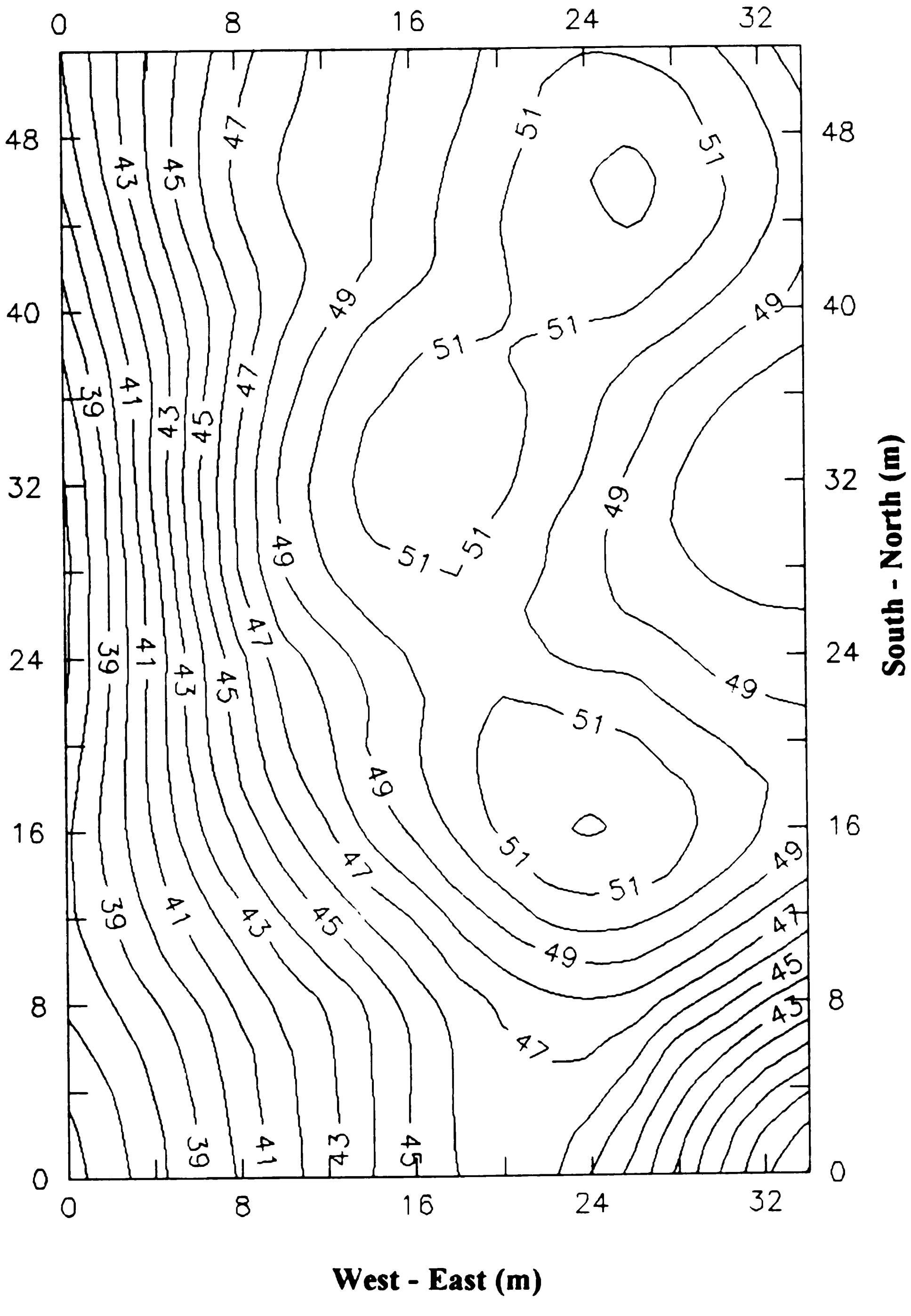
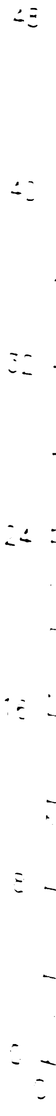


Figure 2.20. Block-kriged map of Ap horizon percent sand.



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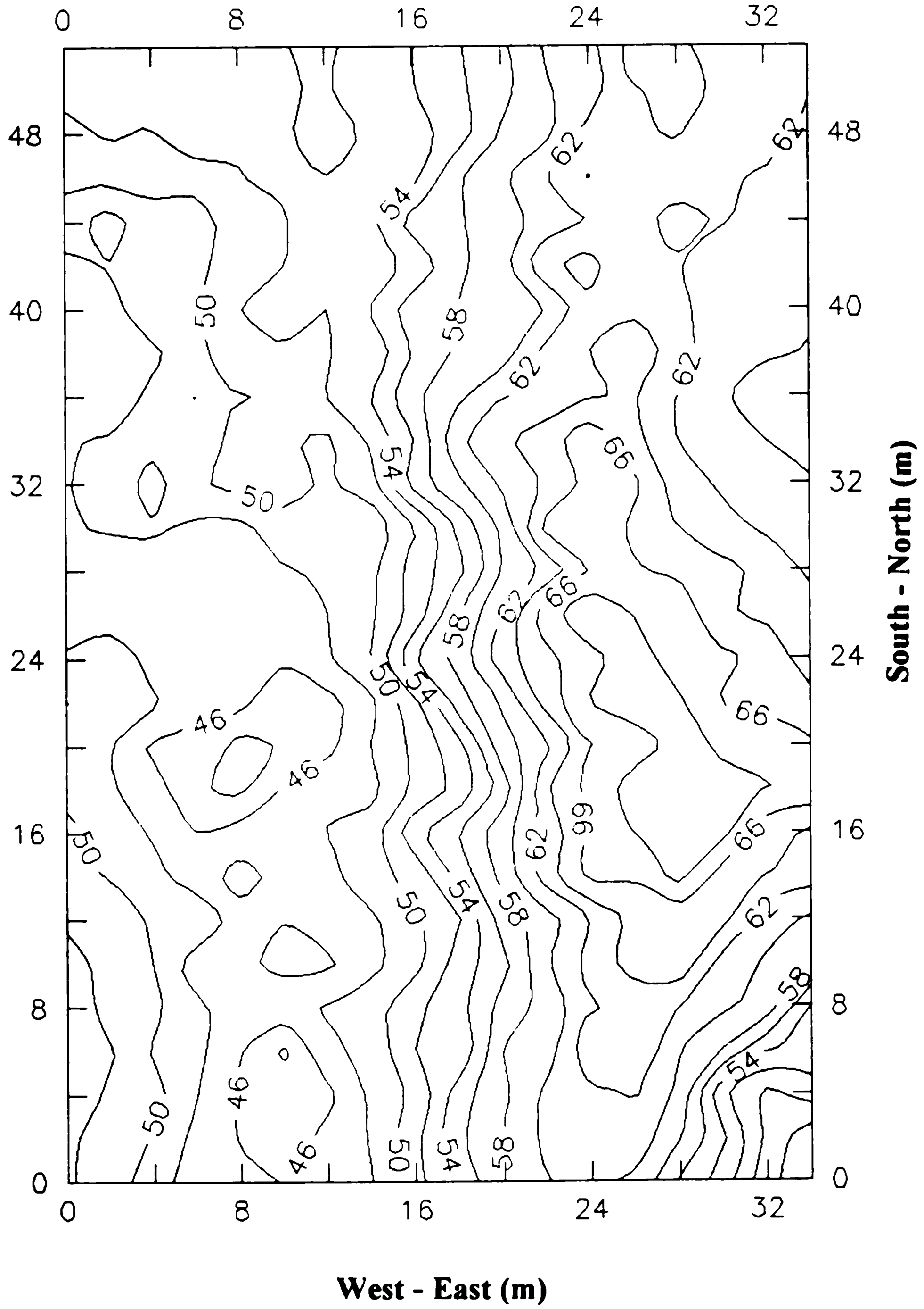
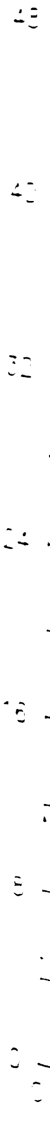


Figure 2.21. Block-kriged map of Bt1 horizon percent sand.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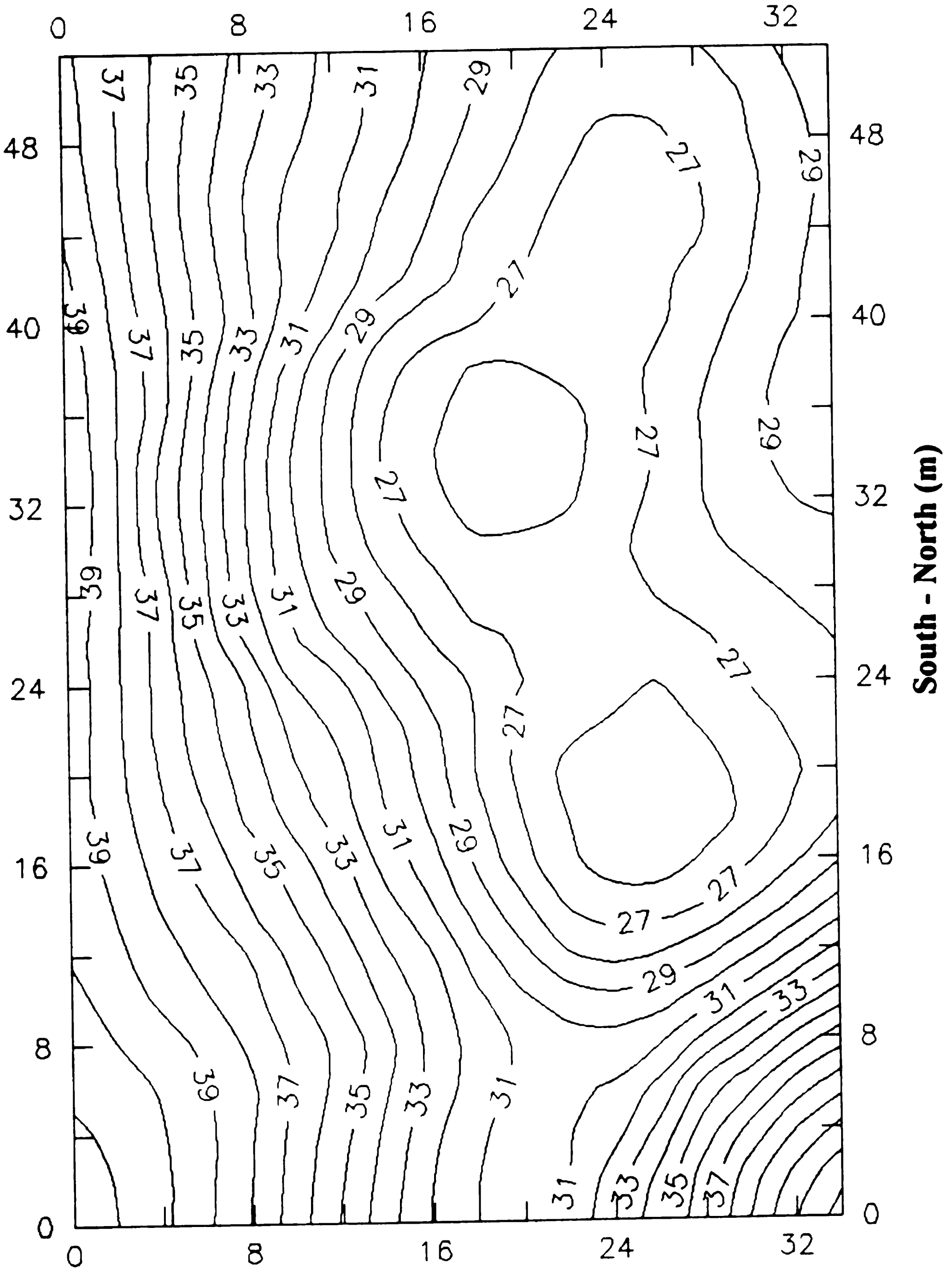

Figure 2.22. Block-kriged map of Ap horizon percent silt.

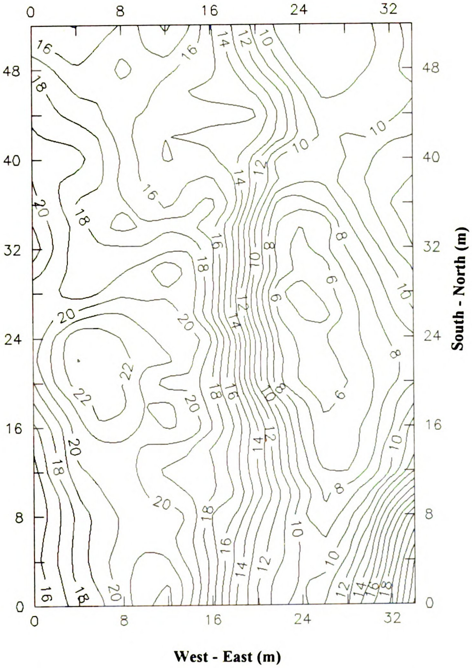

Figure 2.23. Block-kriged map of Bt1 horizon percent silt.

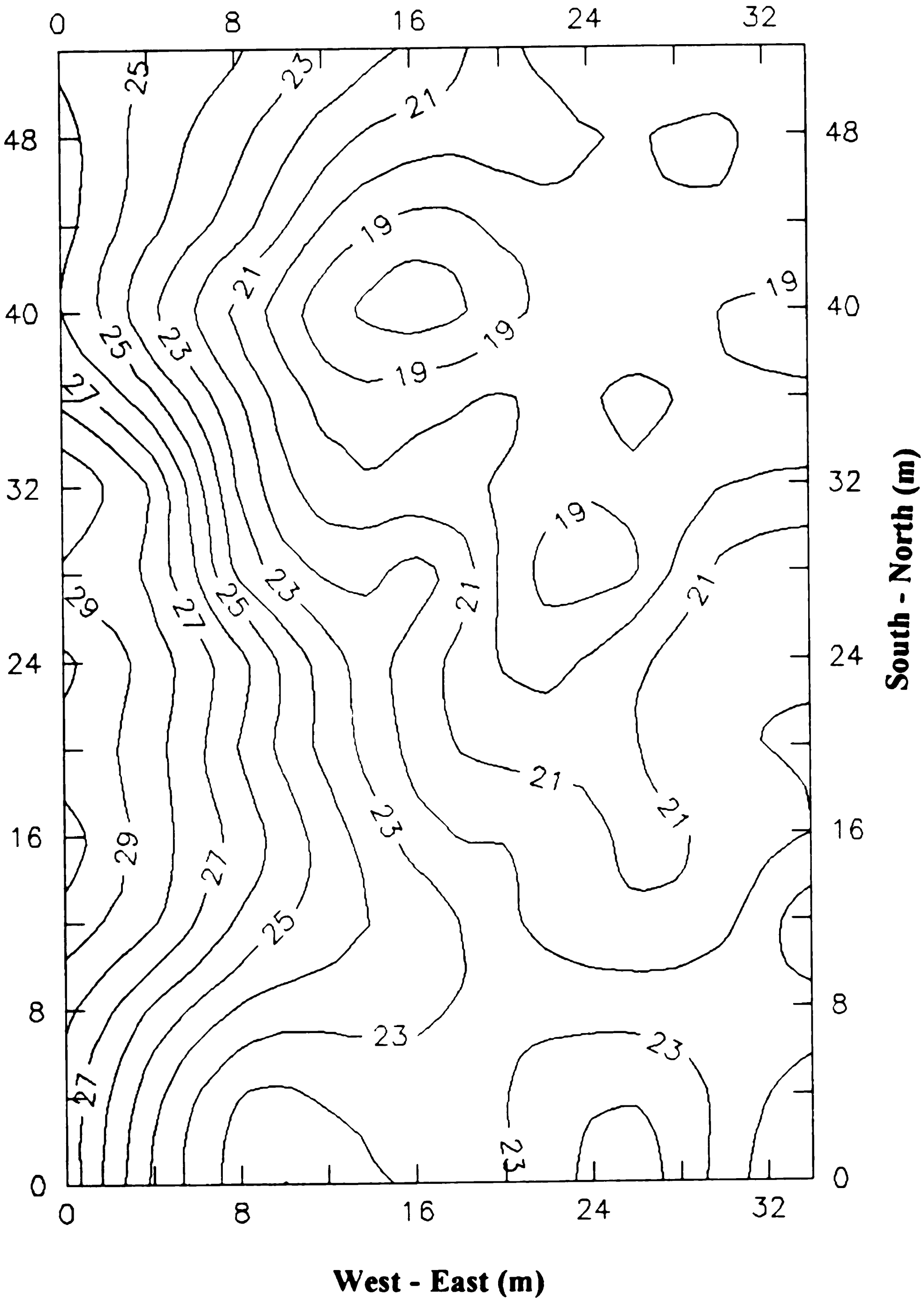

Figure 2.24. Block-kriged map of Ap horizon thickness.

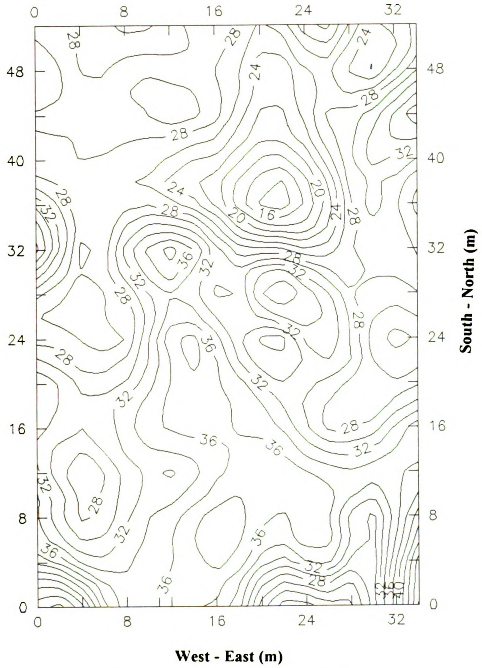

Figure 2.25. Block-kriged map of Bt1 horizon thickness.

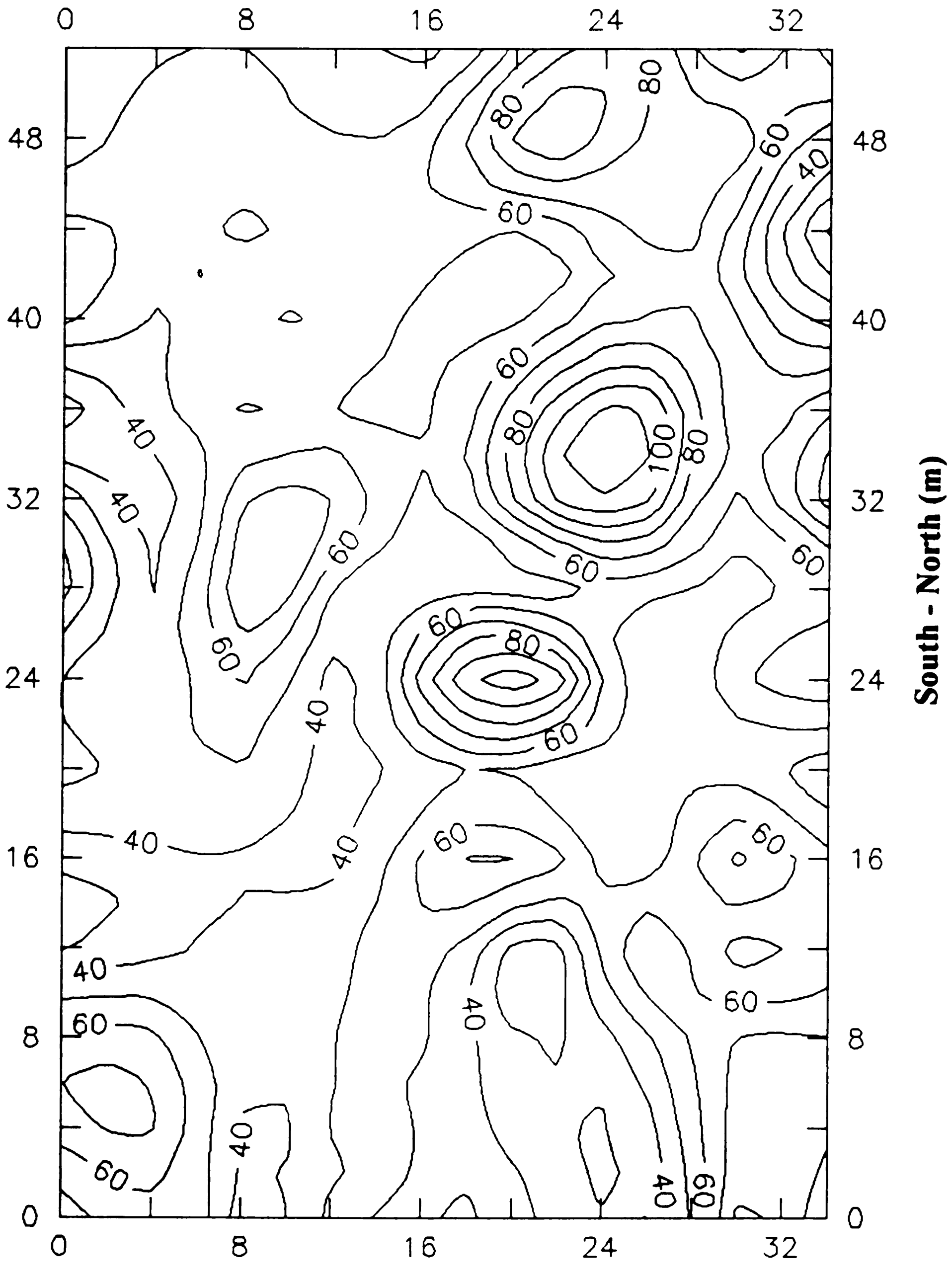

Figure 2.26. Block-kriged map of 2Bt2 horizon thickness.

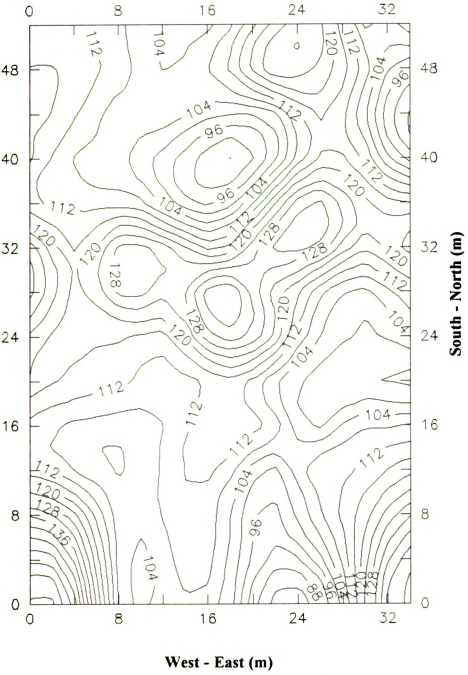

Figure 2.27. Block-kriged map of solum thickness.

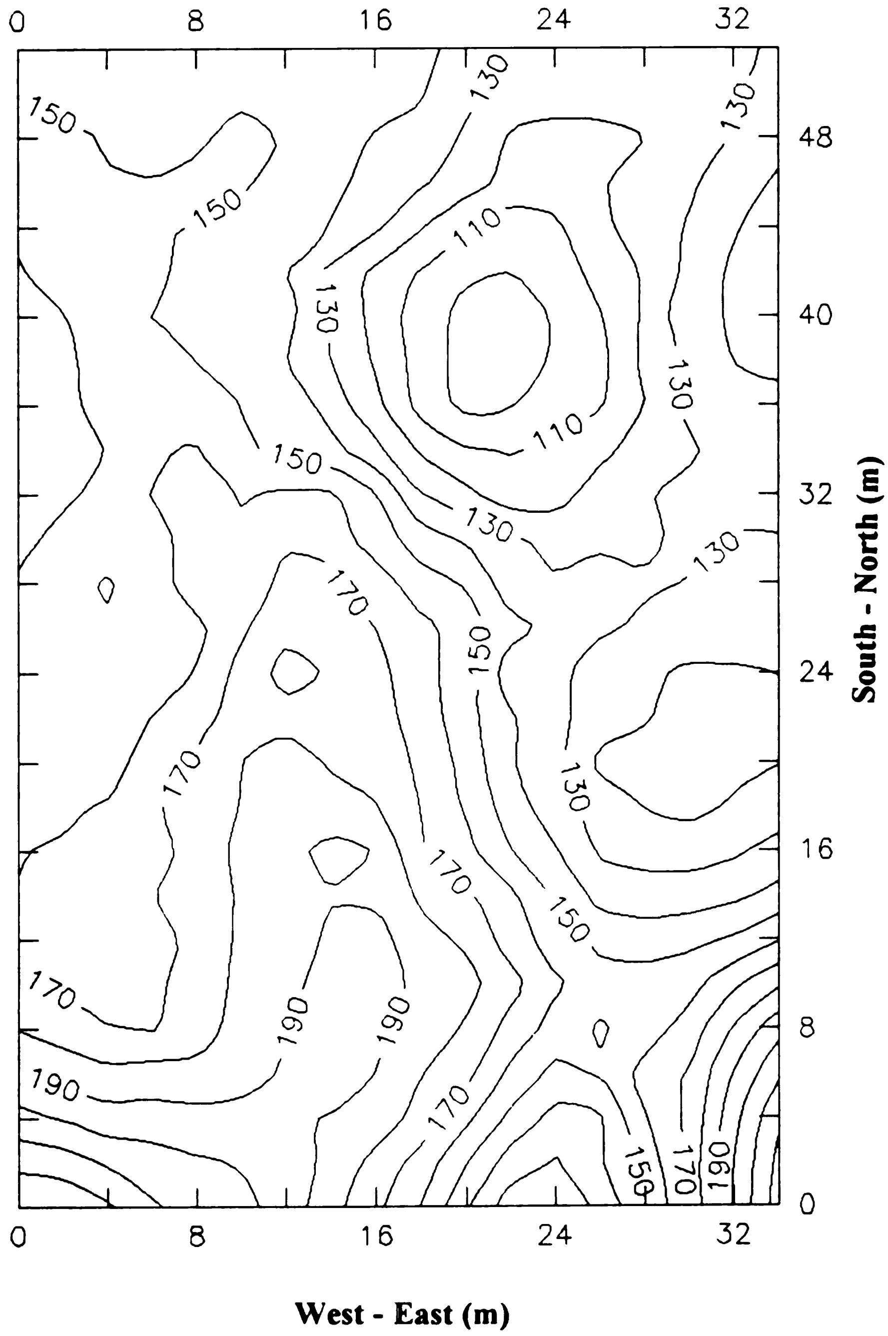

Figure 2.28. Block-kriged map of Bt1 horizon clay mass.


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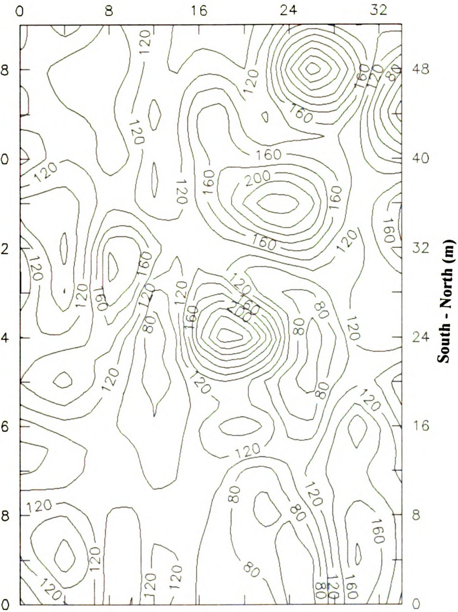


Figure 2.29. Block-kriged map of 2Bt2 horizon clay mass.

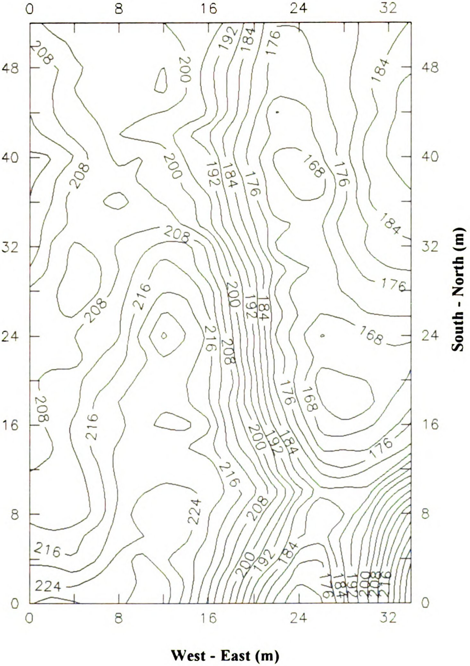
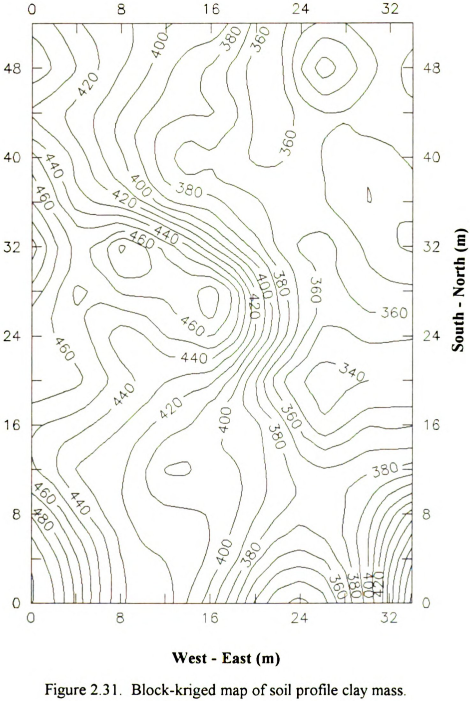


Figure 2.30. Block-kriged map of control-section clay mass.



West - East (m)

Figure 2.31. Block-kriged map of soil profile clay mass.

deposition of Ap material via overland flow from upslope may be significant, increasing the Ap thickness and amount of organic carbon and silt at the lower backslope, footslope, and toeslope positions relative to the upper backslope and summit positions. Most of the increase in Bt1 percent clay and decrease of Bt1 percent sand occurs at the middle of the backslope. This may be due to glacio-fluvial sorting of material differentially, above and below the middle of the backslope at deposition; and/or increased infiltration of water at the middle of the backslope and downslope via overland flow and subsurface lateral downslope throughflow from upslope, which could increase the amount of clay translocated to the Bt1 of the lower portion of this landscape.

In the north 36 to 42 meters of the site that was studied, clay content decreased downslope. Since the summit portion of the study site is near the transition to the backslope, surface and subsurface lateral downslope movement of water may be occurring (Hall, 1983), causing reduced leaching and clay translocation. Incorporation of the Bt1 into the Ap of the upper backslope (no E horizons exist in the upper backslope position soils, Appendix 1), could have increased the clay percentage of Ap horizon at that position. Increased wetting and drying cycles may have contributed to the upper backslope Bt1 having a greater clay content than the summit. Hall (1983) noted summit soils have less distinct horizonation, and thicker and more continuous cutans occur on ped surfaces of backslope than summit argillic horizons.

The 2Bt2 horizon thickness and amount of clay (kg), and solum thickness did not vary with depth (Figures 2.26, 2.27, and 2.29). In the center and north portions of the site, there appear to be "funnels" for preferential water flow, as indicated by relatively deep solum depths in irregular circular patterns on the backslope (Figures 2.26 and 2.27). This is also expressed with a greater amount of clay in the 2Bt2 horizon (Figure 2.29). Mokma and Doolittle (1993) observed the common occurrence of "funnels" expressed in soil profile segments of southwest Michigan.

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Clay

C
Sand (

Silt (%

Thick (c

Clay (kg)

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The pooled block estimation variances of the kriged soil properties are given in Table 2.5. The kriging estimation variances display either a repetitive spatial pattern, which is characteristic of grid sampling, as shown by the estimation variance of Ap clay content in Figure 2.32; or a relatively smooth spatial pattern where the variance is much greater at the edges and corners of the field, where less variable data is available for kriging, as shown by the estimation variance of Ap silt content in Figure 2.33. The south border of the site has much lower estimation variances (Figures 2.32 and 2.33) backslope at deposition; and/or increased infiltration of water at the middle of the backslope and downslope via overland flow and subsurface lateral downslope because the 2 meter sample spacing was much closer than the 4.25 meters for the rest of the kriged portion of the site.

Table 2.5. Pooled estimation variance of block kriging.

Property		Pooled Estimation Variance
O.C. (%)^2		0.0021
Clay (%)^2	Ap	0.33
	Bt1	2.70
	2Bt2	3.07
	Control Sec.	3.37
Sand (%)^2	Ap	2.01
	Bt1	2.81
Silt (%)^2	Ap	2.01
	Bt1	2.40
Thick (cm)^2	Ap	1.59
	Bt1	25.30
	2Bt2	85.68
	Solum	19.31
Clay (kg)^2	Bt1	395.04
	2Bt2	513.00
	Control Sec.	60.95
	0 to 150 cm	679.73

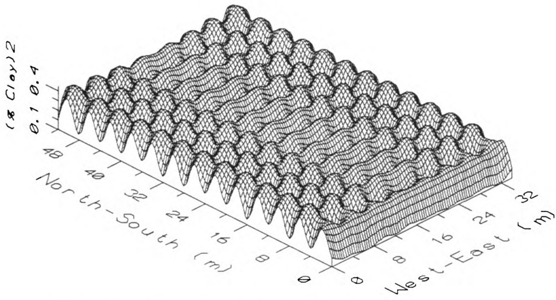

Figure 2.32. Estimation variance of Ap horizon percent clay.

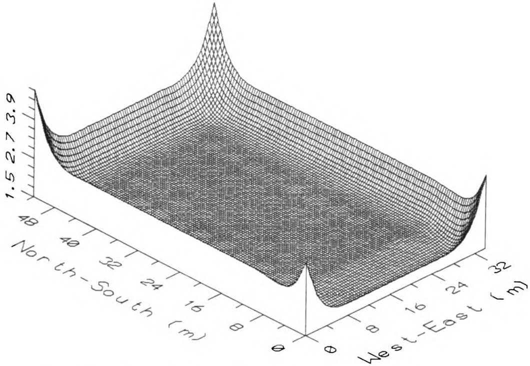

Figure 2.33. Estimation variance of Ap horizon percent silt.

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SUMMARY AND CONCLUSIONS

The soil properties of a sloping landscape were shown to be spatially dependent. Only the 2Bt2 horizon soil properties did not display significant anisotropy.

The results of the analyses of the soil variables indicate soil morphology is, in part, a function of landscape position. Three processes which may have or are occurring within this landscape probably cause differences in soil morphology at each landscape position. Depositional processes at the lower backslope, footslope, and toeslope may contribute to thicker Ap horizons with more silt and less sand from the lower backslope downslope, relative to the summit and upper backslope position soils. Differential glacio-fluvial sorting of material at deposition may, in part, be responsible for the greater percent silt and clay in the soils below the middle of the backslope than the soils upslope. Overland flow and subsurface lateral downslope throughflow of water may be contributing to greater solum thickness and percent clay in the Bt1 horizon below the middle of the backslope by increasing the amount leaching and clay translocation that occurs at these positions. Overland flow and subsurface lateral downslope thoughflow from the upper backslope can carry clay to downslope, where it can be incorporated into the soils upon infiltration. Evidence of preferential water flow occuring within the study area is expressed morphologically by deep, circular funnel shaped soil profiles found within various parts of the landscape.

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CHAPTER 3

SOIL WATER BALANCE AND GEOSTATISTICAL ESTIMATION OF STORED SOIL WATER WITHIN A SLOPING LANDSCAPE

ABSTRACT

The amount of stored water available for crop use in a particular soil of a sloping landscape is in part determined by landscape position. This study was conducted to estimate water balance that occurs in soil within each slope position of the landscape, and determine the minimum data set required to geostatistically estimate stored soil water on a sloping landscape with a backslope gradient of 4.6 to 5.6%. Two transects of 18 neutron probe access tubes, at 2 meter intervals, were established on a sloping topography of Kalamazoo loam (fine-loamy, mixed, mesic, Typic Hapludalfs) and Oshtemo sandy loam (coarse-loamy, mixed, mesic, Typic Hapludalfs). Volumetric water content of the soil was monitored approximately weekly in the spring, summer, and autumn of 1990 and 1991 at 15, 30, 60, 90, 120, and 150 cm by neutron attenuation. Water balance was quantified for the summit, upper backslope, lower backslope, and footslope-toeslope positions of each access tube transect. The CERES Maize model was used to estimate potential evapotranspiration and surface and subsurface runoff at each position of the landscape. Soil samples from a 48 by 34 meter grid, with a 4.25 by 4.00 meter grid density, between the access tube transects were used in geostatistical estimation of stored soil water within the landscape. Water content of each sample point was estimated with CERES Maize for August 6 and October 17, 1991 Selected stored soil water (mm per 150 cm soil depth) sample locations were removed from the data sets, and then kriged and cokriged the data points. Semivariograms and cross-semivariograms for the entire data set were used to estimate stored soil water (mm per 150 cm soil depth). The amount of soil water per

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150 cm soil depth throughout the study period was least within the upper backslope position, moderate within the summit and lower backslope positions, and greatest within the footslope-toeslope position, which was at or near field capacity throughout the study period. Cokriging estimation of stored soil water, using the mm of soil water per 150 cm soil depth at field capacity as the auxiliary variable, reduced the required sample distance to 44 meters in the direction parallel to the contour of the slope.

INTRODUCTION

Water content in soils of sloping landscapes is controlled by elements that are both external and internal to the soil-landscape system (Gerrard, 1981). External factors include rainfall duration and intensity. Internal factors are determined by soil physical properties such as soil texture and structure, amount and type of vegetation, and topographic properties such as slope form and angle, and positional properties such as relative height and distance from the base of the slope.

Stored soil water is an important source of plant available water for crop production on well drained soils of southwest Michigan. When fertility, growing season, and management practices are sufficient, the ability of a soil to produce crops can be limited by the capacity of the soil to supply and store water (Leeper et al., 1974). The amount of stored water available for crop use in a particular soil of a sloping landscape is influenced by it's position on the landscape (Franzmeier et al., 1969; Hanna et al., 1982). Therefore, crop management practices and soil-moisture simulation models should take slope position into account.

The use of changes in stored soil water content to estimate actual evapotranspiration and drainage is well established (Hall and Heaven, 1970; Rouse, 1970; Day et al, 1978; Mc Gowan and Williams, 1980a, b, c; Francis and Pidgeon, 1982a, b; Maule and Chanasyk, 1987). In sloping landscapes where surface and subsurface runoff may be significant, the water balance equation is as follows:

$$D = P + Ro - Rf - dS - ET.$$

where drainage of water from the soil profile (D) is the result of the inputs of precipitation (P) and surface and subsurface run-on from upslope (Ro) minus surface and subsurface runoff (Rf), change in soil water content (dS), and evapotranspiration, (ET). To determine ET, the amount of water that has been removed from the soil by evaporation and transpiring plants during the time period in question, potential evapotranspiration (PET) must be estimated. Several methods have been developed to estimate PET, among which the Thornthwaite (1948), Penman (1948), and Priestley and Taylor (1972) methods are widely accepted. Once PET is estimated, it is incorporated into the water balance equation as follows:

$$D > 0 \text{ if:}$$

$$PET < P + Ro - Rf - dS;$$

$$\text{and}$$

$$D = P + Ro - Rf - dS - PET:$$

$$D = 0, \text{ if;}$$

$$PET \geq P + Ro - Rf - dS;$$

$$\text{and}$$

$$Et = P + Ro - Rf - dS;$$

$$\text{where } Ro = Rf \text{ from upslope.}$$

In a sloping landscape, these equations can be used for the soils within each position of the landscape.

Geostatistical methods using spatial correlation (i.e., the semivariogram) and kriging estimation have been used to characterize soil-water properties (Burgess and Webster, 1980a, b; Webster and Burgess, 1980; Burgess et al., 1980; Russo and Bresler, 1981, 1982; Sisson and Wierenga, 1981; Vieira et al., 1981; Van Kuilenburg et al., 1982;

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Vauclin et al., 1983; Byers and Stephens, 1983; McBratney and Webster, 1983; Morkoc et al., 1985). Estimation of the amount of soil water using the amount of soil water of samples near the estimation points (kriging) is useful when a sufficiently large number of samples are taken within the landscape in question.

If the spatial relationships between soil and landscape properties (i.e., clay content, landscape position, etc.) and soil water content can be established, then those soil and landscape properties can be used to estimate soil water content over time, using cokriging. The spatial distribution of a variable can be closely related to that of other variables affected by the same spatial process. Such properties are co-regionalized and are spatially dependent on each other (Trangmar et al., 1985). Cokriging uses two or more correlated random variables simultaneously in such a manner that the spatial information from each parameter aids in the estimation process. If a correlation exists between the two random variables then one method of improving the sampling efficiency is to increase the sampling of the covariable with respect to the under sampled (primary) variable. Using cokriging, the spatial information of the covariable is transferred to the primary through the cross-correlation function, thus improving the quality of the estimates of the primary variable (Yates and Warrick, 1987). Cokriging is most efficiently used where one variable may not have been sampled sufficiently (due to experimental difficulties, high costs, etc.) to provide enough estimates (Trangmar et al., 1985). Unlike semivariances, cross-semivariances can be negative if the relationship between the primary and covariables are negative (Trangmar et al., 1985). Since cokriging requires a known cross-correlation function, there must be a large number of locations where both functions are sampled (Yates and Warrick, 1987). Vauclin et al. (1983) used sand content to improve the estimation of plant available water content. Yates and Warrick (1987) used ordinary kriging and cokriging in the analysis of surface soil water contents on a level landscape using bare surface temperature and sand content as auxiliary functions. Mulla (1988) used

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surface temperature and penetrometer resistance as auxiliary variables in the cokriging estimation process of soil-water content of two transects located within a sloping landscape.

Two objectives were investigatedin this study: (1), computer model the amount of surface and subsurface runoff and run-on using soil physical properties, precipitation and other climatic data, changes in the amount of stored soil water, and simulated crop growth, and calculate water balance that occurs in the soils at each slope component within the landscape of the study site: (2) estimate stored soil water within a sloping landscape with a minimum data set using geostatistics (kriging and cokriging).

MATERIALS AND METHODS

Study Area

The study was conducted at the W. K. Kellogg Biological Station (KBS) in southwest Michigan (latitude 42°25' N, longitude 85°25' W). The average annual temperature is 9.9°C, with January the coldest month at -4.0°C, and July the warmest month at 22.8°C. The mean annual precipitation is 874 mm with 58 % occurring during April through September (Austin, 1979).

KBS is situated on a pitted outwash plain. The study site is located where a small north-south valley dissects a level plain. The valley floor tilts downslope north to an outlet opening to a larger valley. The valley is approximately 4.4 meters deep and from 90 to 140 meters wide. The study was conducted on the east side of the valley where the slope of the backslope position ranged from 4.6 % to 5.6 %. The backslope on the west side of the valley ranged form 8 % to 10 %. The study site consisted of distinct summit, backslope, footslope, and toeslope components (Ruhe, 1960) (Figure 3.1). There is no distinct shoulder component to this landscape, as the upper portion of the backslope is linear, except near the transition to the summit. The dominant soils on this landscape are Kalamazoo Loam (Fine-loamy, mixed, mesic, Typic Hapludalfs)

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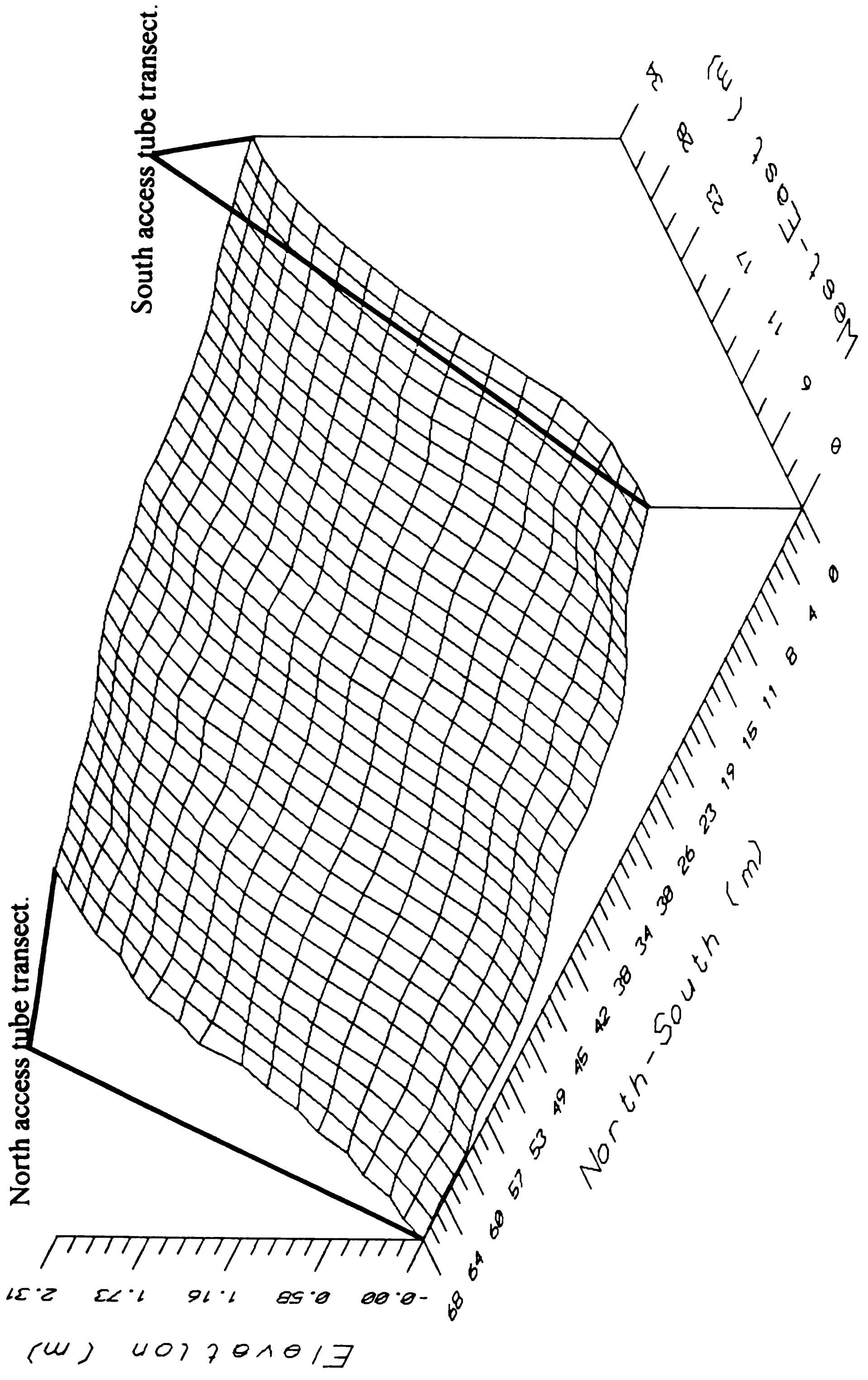

Figure 3.1. Study site surface 3 dimensional plot.

and Oshtemo Sandy Loam (Coarse-loamy, mixed, mesic, Typic Hapludalfs) (Figure 3.2). Both soils are formed in loamy material overlying sand and gravel. Because of the presence of stratified sand and gravel from the lower soil profile to the contact with glacial till, which is approximately 15 meters below the surface, as indicated by well logs from the area, both Kalamazoo and Oshtemo soils, which are well drained, are found on all positions of the landscape, including the toeslope. A typical Kalamazoo soil profile from the study site has a loam Ap horizon, from 0 to 23 cm, a loam E horizon, from 23 to 31 cm, a clay loam Bt1 horizon, from 31 to 59 cm, a sandy loam 2Bt2 horizon, from 59 to 112 cm, and a 3E/Bt horizon of sand and loamy sand lamellae, from 112 to 150 cm. A typical Oshtemo soil profile from the study site has a sandy loam Ap horizon, from 0 to 18 cm, a sandy loam Bt1 horizon from 18 to 56 cm, and a 2E/Bt horizon of sand and loamy sand lamellae, from 56 to 150 cm.

Stored Soil Water Sampling and Analysis

Two east-west transects of neutron probe access tubes, 68 meters apart, were established within the site (Figure 3.1). The south transect is dominated by Kalamazoo soils, as are the summit and toeslope soils of the north transect. The backslope of the north transect is dominated by Oshtemo soils. Eighteen access tubes were installed at two meter intervals down each transect of the hillslope. Soil moisture was measured approximately weekly from mid April through mid November, 1990, and from early April through mid October, 1991. The site, which is part of a cultivated field, was left idle with glyphosate herbicide applied to prevent weed growth in 1990, and was planted to corn under conventional tillage in 1991. Soil water content was monitored, by neutron attenuation, at 30 cm intervals to a depth of 150 cm. In 1991 a 15 cm reading was added to more accurately determine near surface soil water content. Three neutron probe calibration curves were prepared by the field calibration method outlined by Campbell Pacific Nuclear (1984), one for the fine-

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Figure 3.2

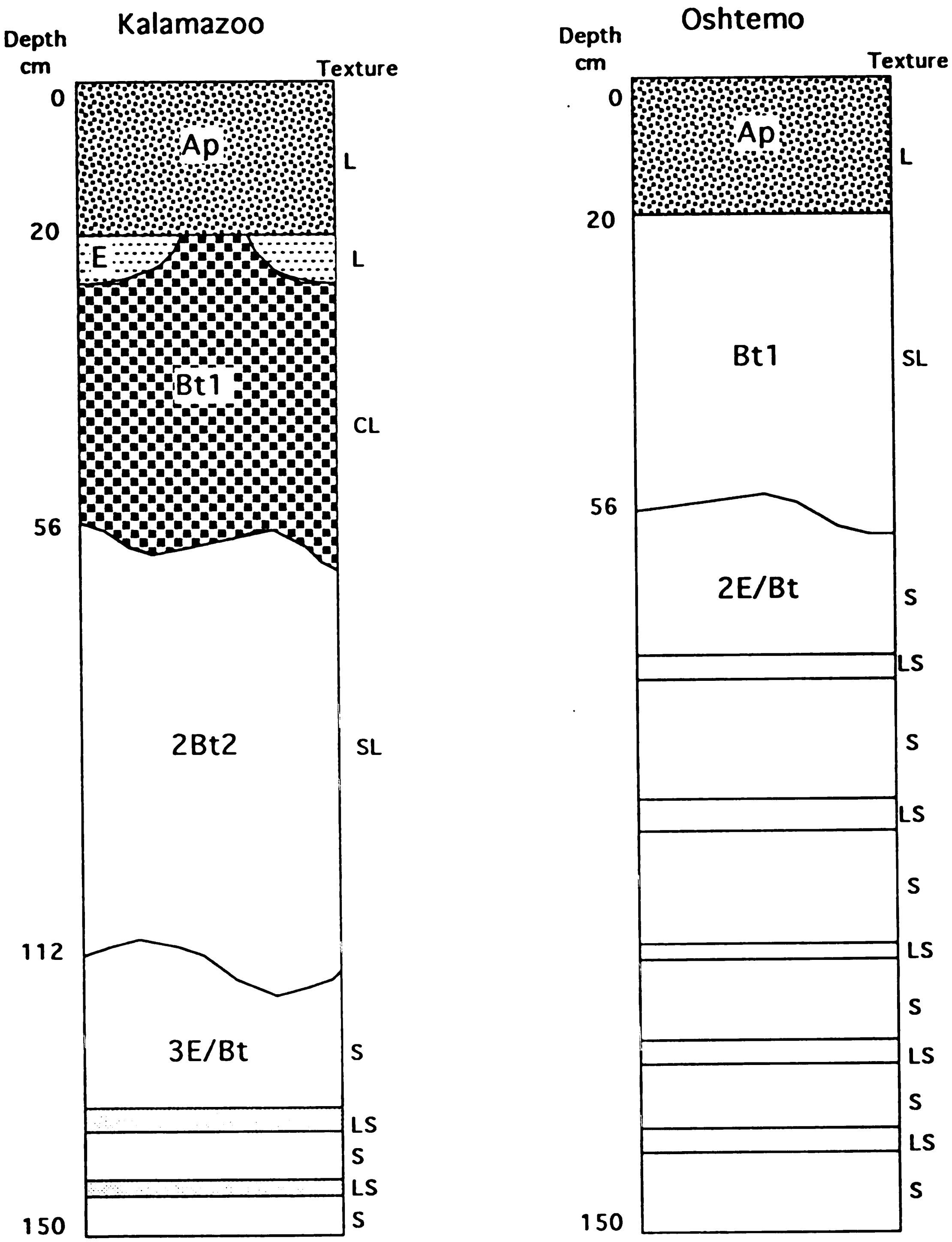

Figure 3.2. Typical Kalamazoo and Oshtemo soil profiles.

loamy Ap and Bt1 horizons of the Kalamazoo soil, a second for the coarse-loamy Ap and Bt1 horizons of the Oshtemo soil and 2Bt2 horizon of the Kalamazoo soil, and a third for the sandy E/Bt horizon of both soils. The curves were developed by averaging the volumetric moisture content and count ratio data for each of the fine-loamy, coarse-loamy, and sandy portions of all the access tubes.

The CERES Maize (version 2.1) (Jones et al., 1986) crop growth model was used to obtain values for runoff, run-on, and potential evapotranspiration (PET). CERES Maize uses the Priestley and Taylor (1972) model to estimate PET, and the Soil Conservation Service Runoff Curve Number method to estimate runoff (Soil Conservation Service, 1972).

Simulation accuracy of CERES Maize was evaluated by statistically comparing model estimates with mm soil water per 150 cm soil, averaged by slope position. Four combinations of statistical criteria were used to asses the simulation ability of CERES (Addiscott and Whitmore, 1987; Jabro et al., 1994). The association between simulated and measured values was determined from the correlation coefficient (r). The average deviation of the simulated and measured values was determined by calculating the mean difference (Md):

$$\mathrm{Md} = \Sigma(\mathrm{S}-\mathrm{U})/\mathrm{n}$$

where S is the simulated value, U is the measured value, and n is the number of observations. Positive Md values indicate overestimated simulation, and negative values indicate underestimated simulation values. A t-test was used to determine whether Md was significantly different from zero. The deviation of the simulated values from observed values, reported on an observed mean basis was determined by the root mean square error (RMSE):

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$$RMS = ((\Sigma(S-U)^2/n)^{0.5} \text{ X } (100/\bar{U})$$

where $\bar{U}$ is the measured mean. Lower RMSE values suggest greater simulation accuracy than higher values (Jabro et al., 1994).

Grid Sampling and Analysis

A 34 by 60 meter rectangular grid of sample points was established between the access tube transects, using a 4.25 (east-west) by 4.00 meter (north-south) grid cell (Figure 3.3). Grid points were located and flagged using a WILD Distomat and Theodolite (Total Station), and elevations were recorded for topographic map production. The raw survey data were converted to coordinate data using the WILDSOFT computer program (Wild Heerbrug Instruments, Inc., 1987). Soil sampling at each point was accomplished using a Giddings hydraulic probe mounted on a pickup truck. This made for a total of 180 soil profiles sampled including the access tube transects. Soil profiles of the access tube cores and grid were described using standard procedures (Soil Survey Staff, 1984) and sampled to a depth of 150 cm, or to the base of the 2Bt2 horizon if it was deeper than 150 cm. Percent sand, silt, and clay, of the samples were determined by the hydrometer method (Grigal, 1973).

A total of 117 soil profiles were used in the geostatistical estimation of soil water. Because the north 12 meters of the site consist mostly of Oshtemo soils, the north 16 meters of the site were eliminated from the study. This allowed study of a single soil population, where only topography causes major trends. The south access tube transect was also eliminated from this procedure because the access tubes are 2 meters apart while the grid profiles are 4.25 meters apart.

Two soil moisture sampling dates, August 6 and October 17, 1991, were selected for geostatistical estimation of soil water on the landscape. The mm soil water per 150

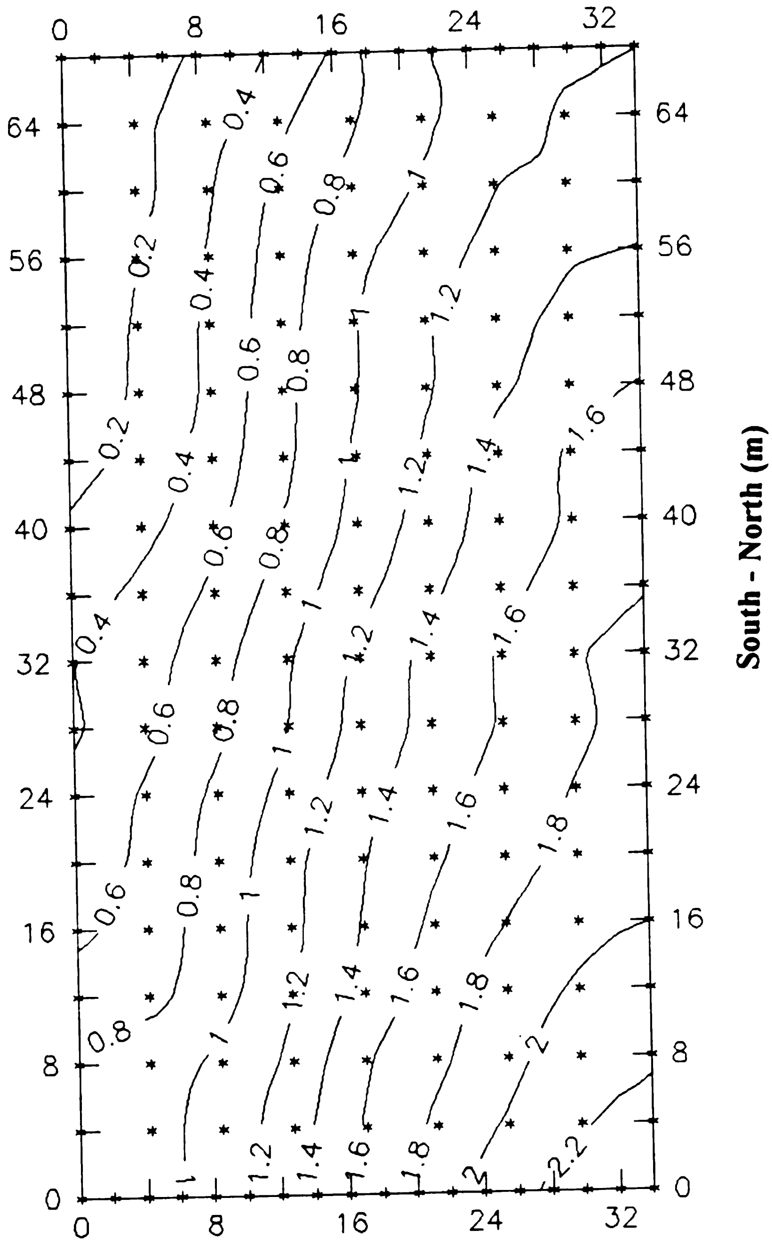

Figure 3.3 Topography (relative meters) of the study site with sample point locations.

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cm soil depth of all soil profiles from the sample grid of the south 52 meters of the site were simulated with CERES Maize (version 2.1) (Jones et al., 1986) based on the simulation techniques for the access tube transects. The east two soil profiles of each row (34 and 29.75 meters from the west edge of the site) are located on the summit, and mm soil water per 150 cm soil depth was simulated for Hydrologic Condition B soils (Soil Conservation Service, 1972) on 0% to 2% slopes. The two soil profiles of each row (25.5 meters and 21.25 meters from the west edge of the site) are located on the upper backslope, and mm soil water per 150 cm soil was simulated for Hydrologic Condition C soils on 5% to 6% slopes. The three soil profiles of each row (17, 12.75, and 8.5 meters from the west edge of the site) were found on the lower backslope and mm soil water per 150 cm soil depth was simulated for Hydrologic Condition B soils on 0% to 2% slopes. The two farthest west soil profiles of each row (0 and 4.25 meters from the west edge of the study site) were found on the footslope or toeslope, and mm soil water per 150 cm soil depth was simulated for Hydrologic Condition B soils on 0% to 2% slopes with the addition of 608.7 mm of surface and subusrface run-on water from both the east and west backslopes. Field capacity water content of the access tube transect soils was determined from soil-water contents 2 to 3 days after rain events in April, 1990 and 1991 (Hall and Heaven, 1979). Field capacity water content of the grid soil profiles was determined from texture (Ritchie and Crum, 1989). The total mm soil water per 150 cm soil of all soil profiles at -15 bar was estimated from texture (Soil Survey Staff, 1991).

Semivariograms were developed for mm soil water per 150 cm soil depth at field capacity and for August 6 and October 17, 1991, using all soil profiles from the the transect and grid of the south 52 meters of the site. Cross-semivariograms of mm soil water for August 6 and October 17 by field capacity mm soil water per 150 cm soil depth were also developed. CERES estimates of total mm soil water were successively removed from selected rows in the North-South and East-West directions and geostatistical procedures, kriging and cokriging, were used to estimate total mm soil water at locations where data points were removed from the data set until the estimation procedure could no longer produce values that were significantly close to the CERES values. In the cokriging procedure, total mm soil water per 150 cm soil depth at field capacity was used as the auxiliary variable. All geostatistical analyses were performed using the semivariograms and cross-semivariograms of the entire data set of the south 52 meters of the site. Since mm soil water was estimated at specific points on the landscape, punctual kriging and cokrignig was used. Soil water estimates were derived using a maximum of 16 nearest neighbors for both the primary and auxiliary variables. Semivariograms and geostatistical interpolation data were calculated using GEOPACK (Yates and Yates, 1989). All semivariograms and cross-semivariograms were validated using the jackknifing method (Vauclin et al., 1983; Russo, 1984).

RESULTS AND DISCUSSION

Slope Position and Soil-Water Content

The neutron probe access tube transects were divided into summit, upper backslope, lower backslope, and footslope-toeslope components based on slope position (Figures 3.4 and 3.5) and the average total mm soil water per 150 cm soil at each access tube. The mm soil water per 150 cm soil depth of each access tube within each slope position was averaged in order to simulate mean mm soil water per 150 cm soil depth and calculate the average water balance of the slope unit. Soil water data from three and five access tubes of the south and north access tube transects, respectively, were not averaged into the slope component soil water data because there locations (Figures 3.4 and 3.5) and soil moisture data indicated they were transitional between slope components.


South Transect
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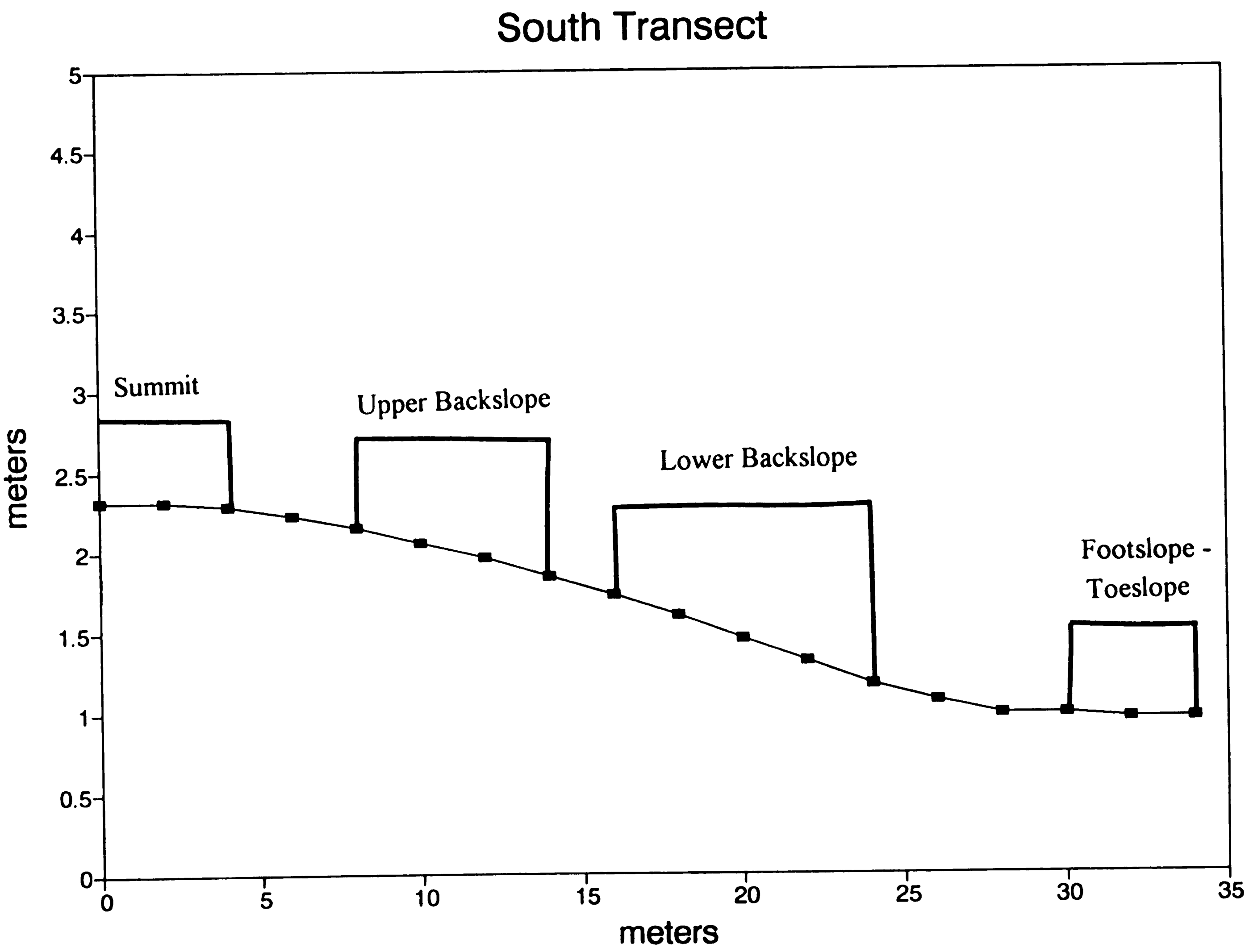

Figure 3.4. Slope profile of the south transect, showing the location of each neutron probe access tube.

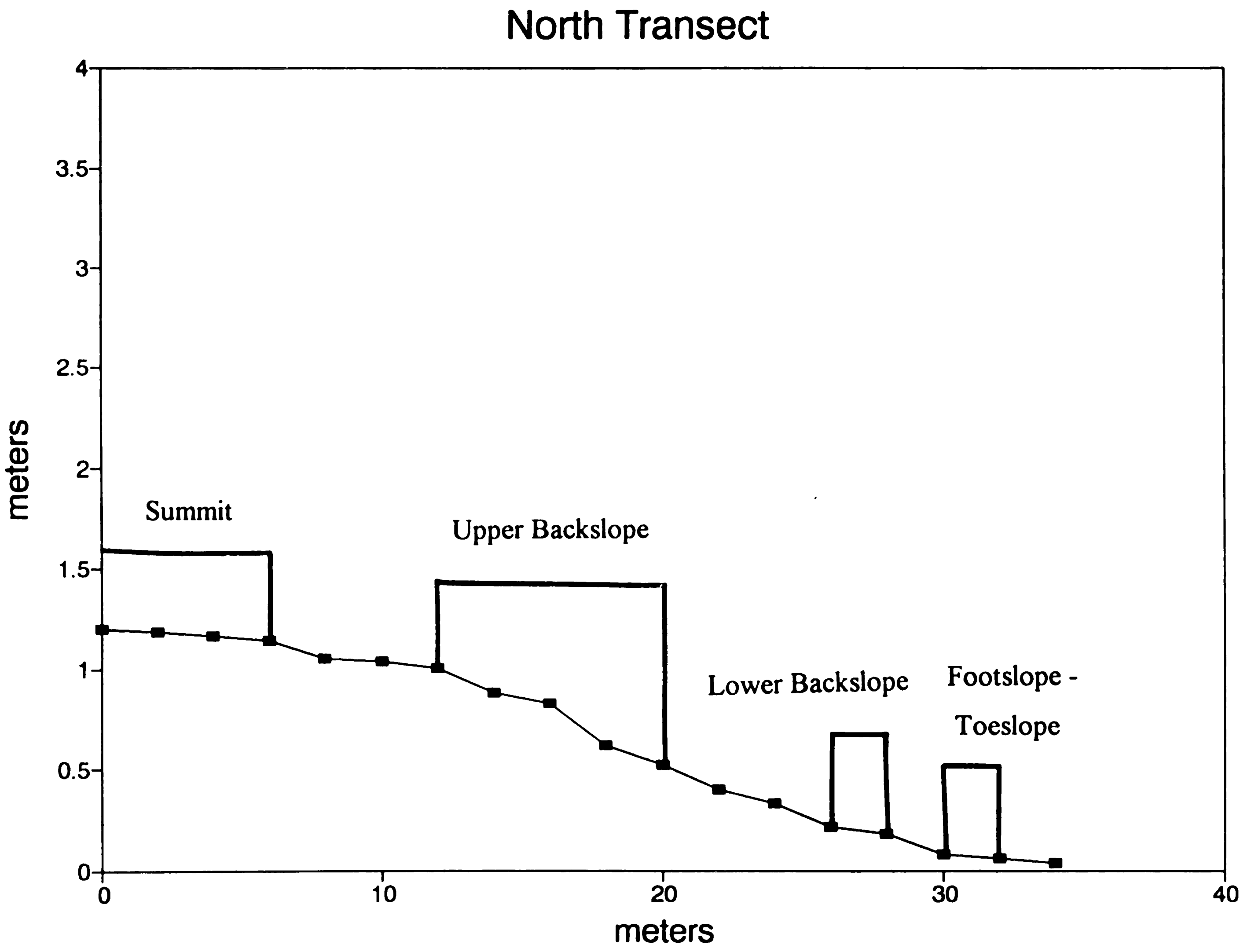

Figure 3.5. Slope profile of the north transect, showing the location of each neutron probe access tube.

The average maximum amount of water that can be held in the soil from 0 to 150 cm after drainage (field capacity) for each landscape position of both transects is given in Table 3.1. This table suggests the footslope and toeslope positions can hold the most water, while the upper backslopes hold the least.

Rainfall and average daily temperature data for the 1990 and 1991 study periods are presented in Figures 3.6 and 3.7. The mm soil water per 150 cm soil depth varied appreciably with slope position of each transect for 1990 and 1991 (Figures 3.6, 3.7, 3.8, and 3.9). In soils of all positions of both transects, the greatest amount of soil water existed in April and May, and October and November of 1990 and fluctuated widely from June through August (Figures 3.8 and 3.9). During the 1991 study period, the greater amount of soil water, for all soils, existed in April and October, and the least amount occurred in late July and early August (Figures 3.10 and 3.11). The reason, in part, for the differences in mm soil water for these two years was that in 1990 the study site was fallow, and no transpiration to remove soil water occurred, while in 1991 the site was planted to corn, with transpiration occurring during the growing season. In both 1990 and 1991 the mm soil water per 150 cm soil depth for

Table 3.1 Average soil profile water retention (0 to 150 cm) at field capacity for each landscape position.

Transect	Topographic Position	Soil	Water Content mm
South	Summit	Kalamazoo	282
	Upper Backslope	Kalamazoo	216
	Lower Backslope	Kalamazoo	288
	Footslope-Toeslope	Kalamazoo	343
North	Summit	Kalamazoo	207
	Upper Backslope	Oshtemo	194
	Lower Backslope	Oshtemo	250
	Footslope-Toeslope	Kalamazoo	374

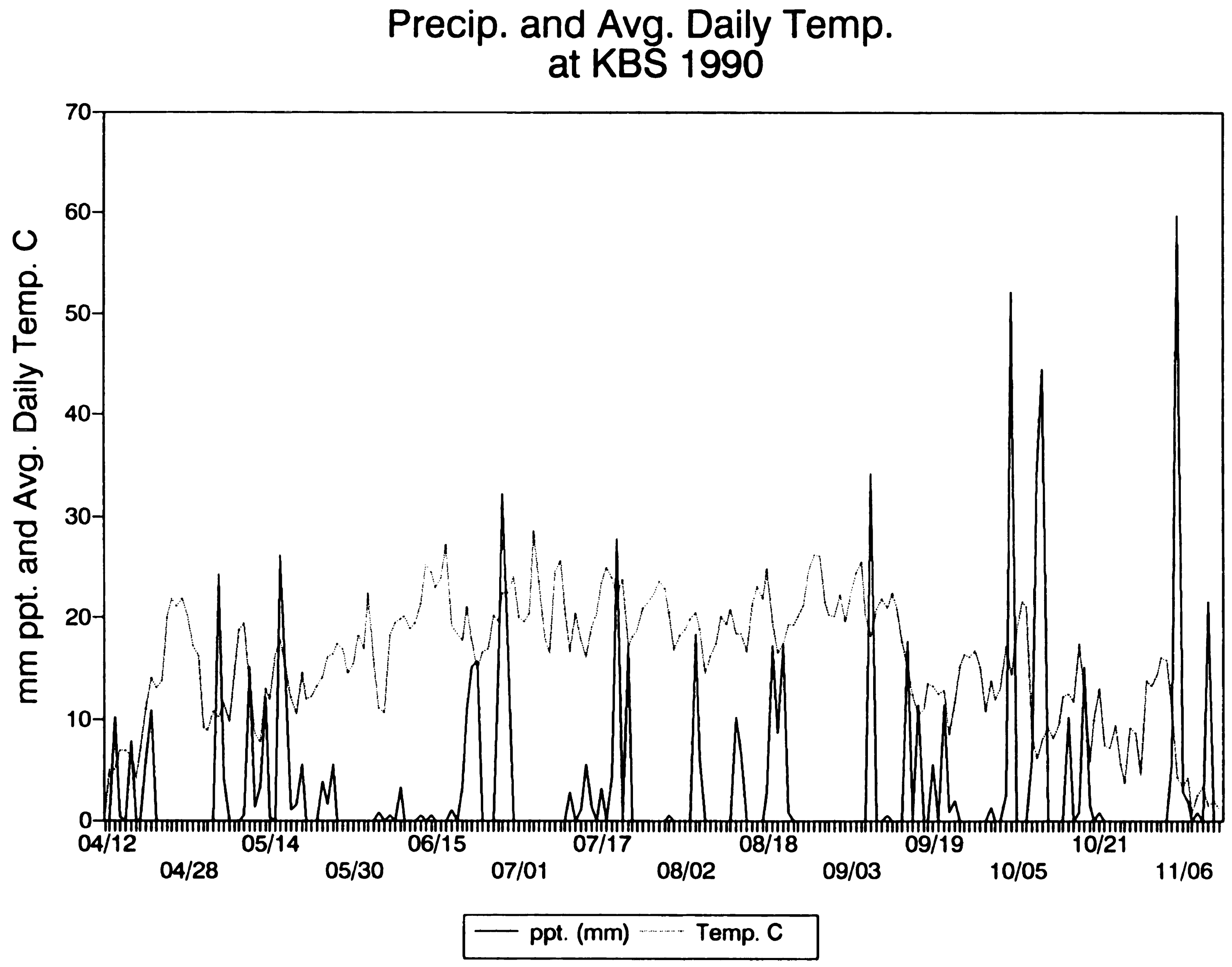

Figure 3.6. Precipitation and average daily temperature for the 1990 field study period.

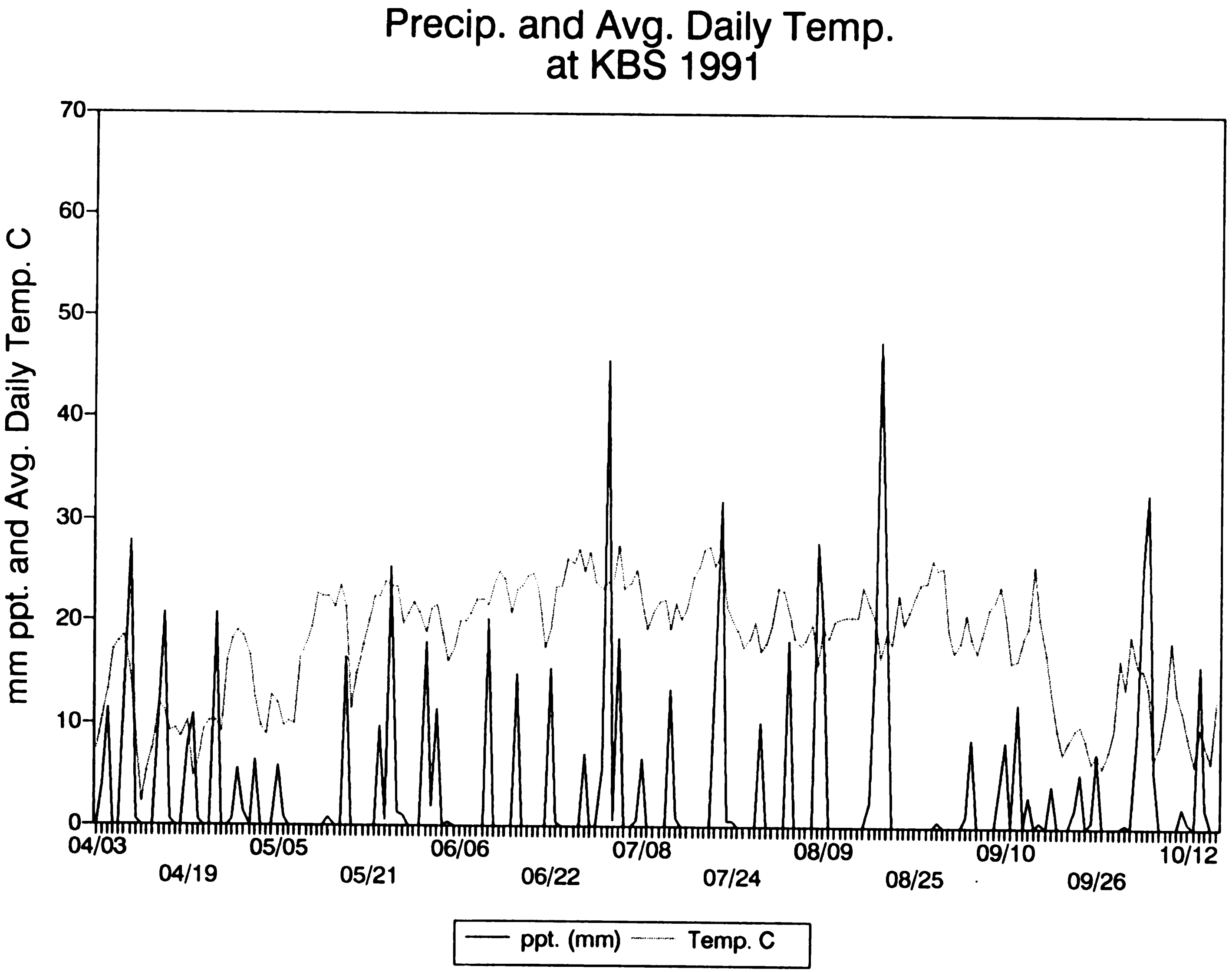

Figure 3.7. Precipitation and average daily temperature for the 1991 field study period.

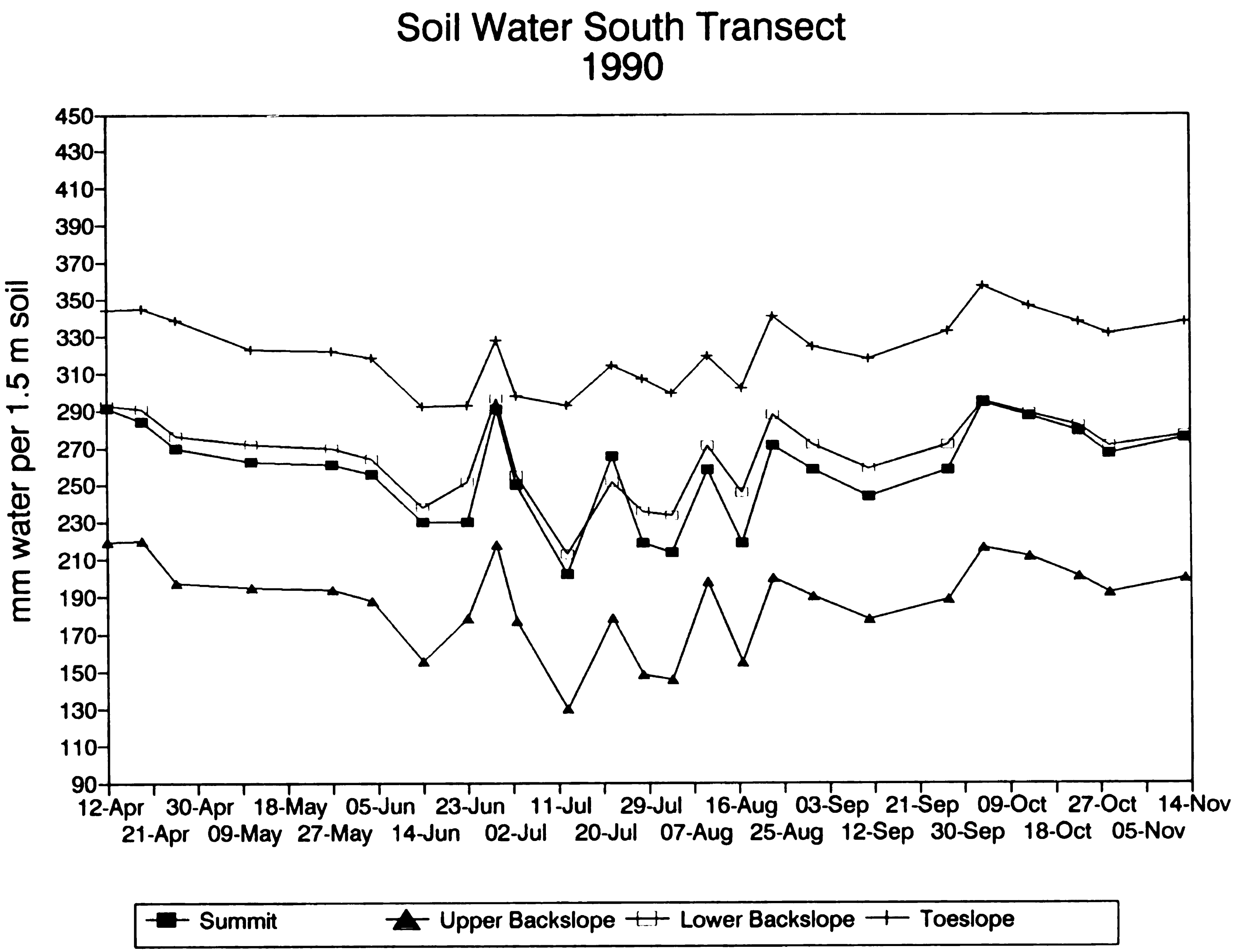

Figure 3.8. Average total soil water of the south transect for 1990.

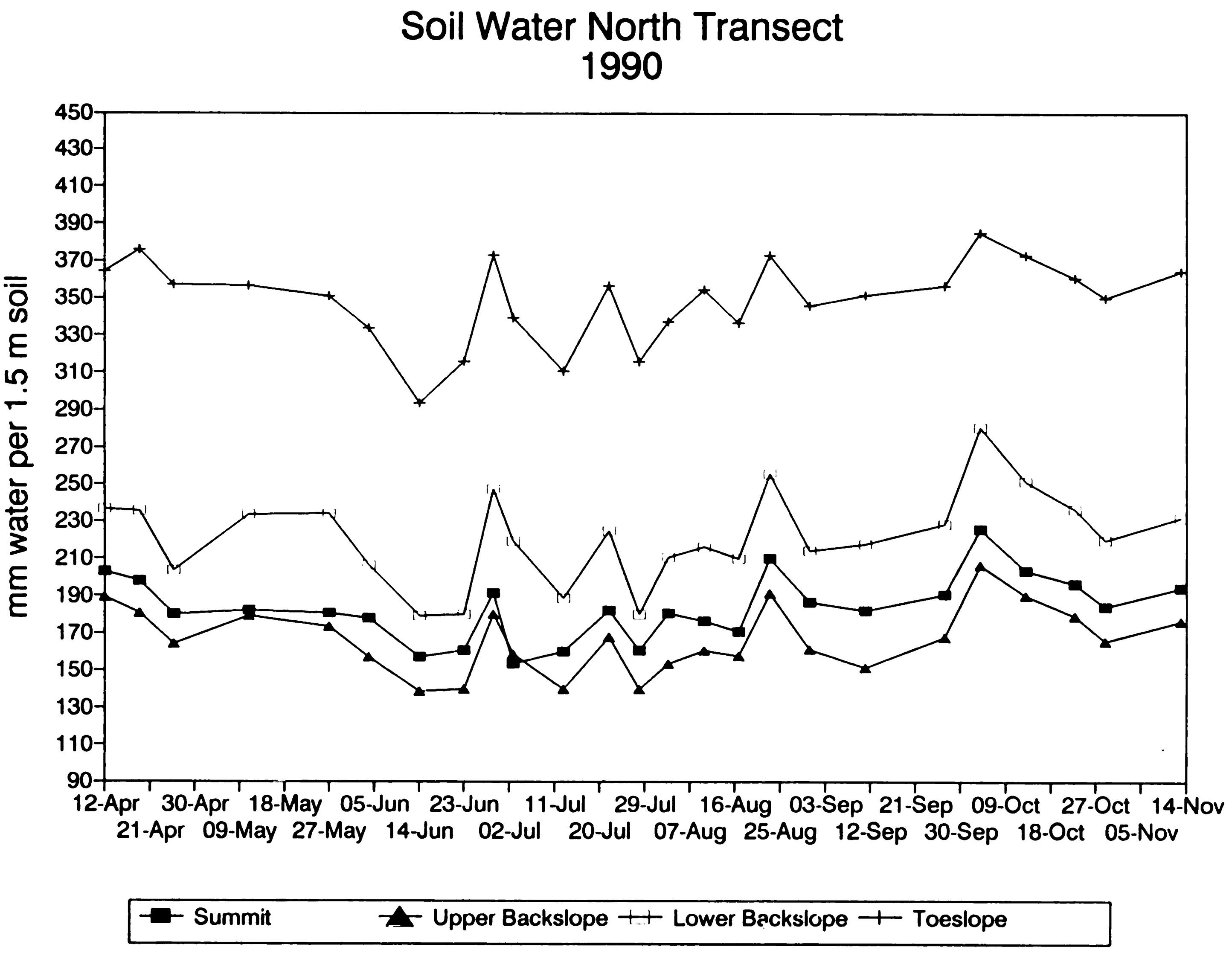

Figure 3.9. Average total soil water of the north transect for 1990.

Soil Water South Tra

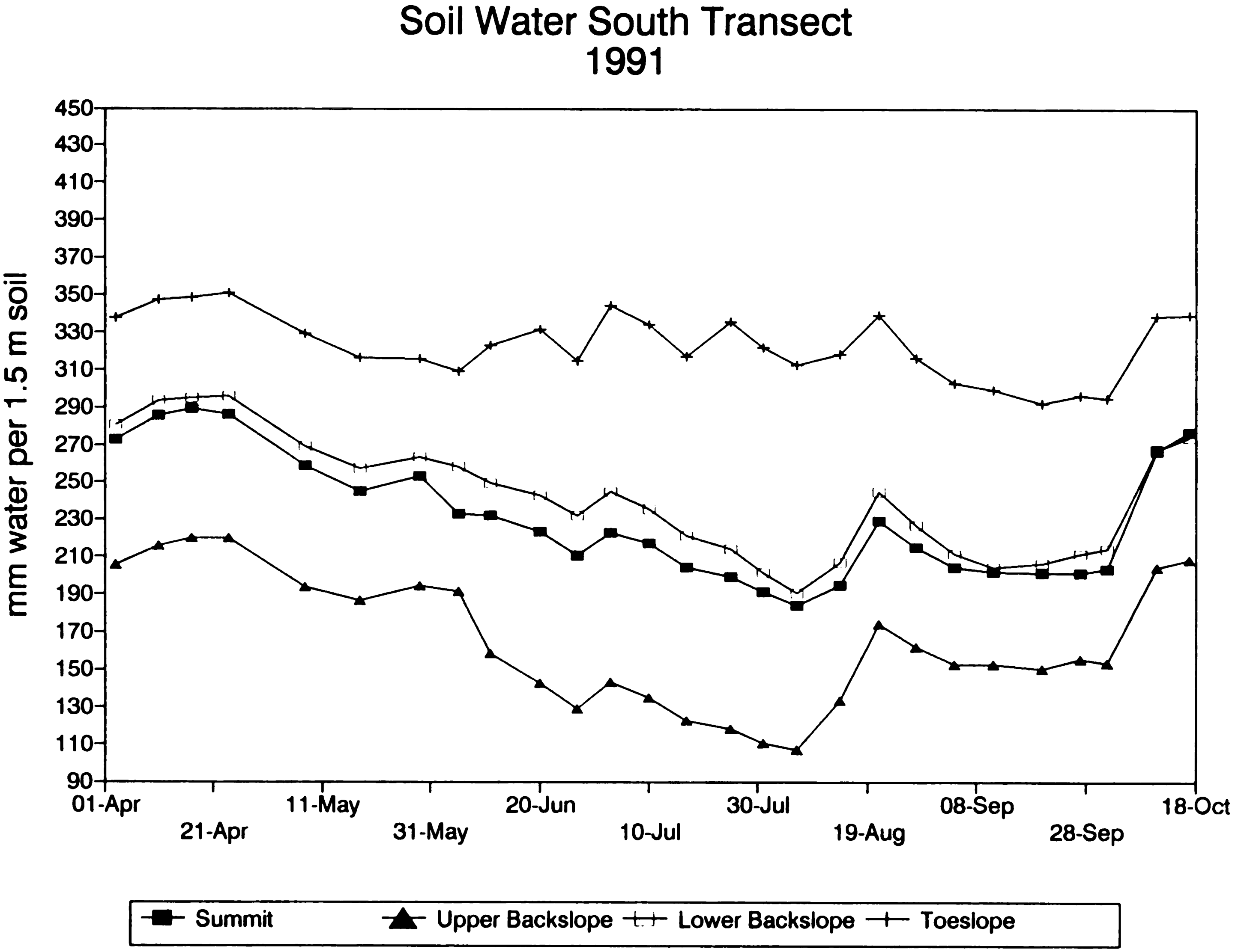

Figure 3.10. Average total soil water of the south transect for 1991.

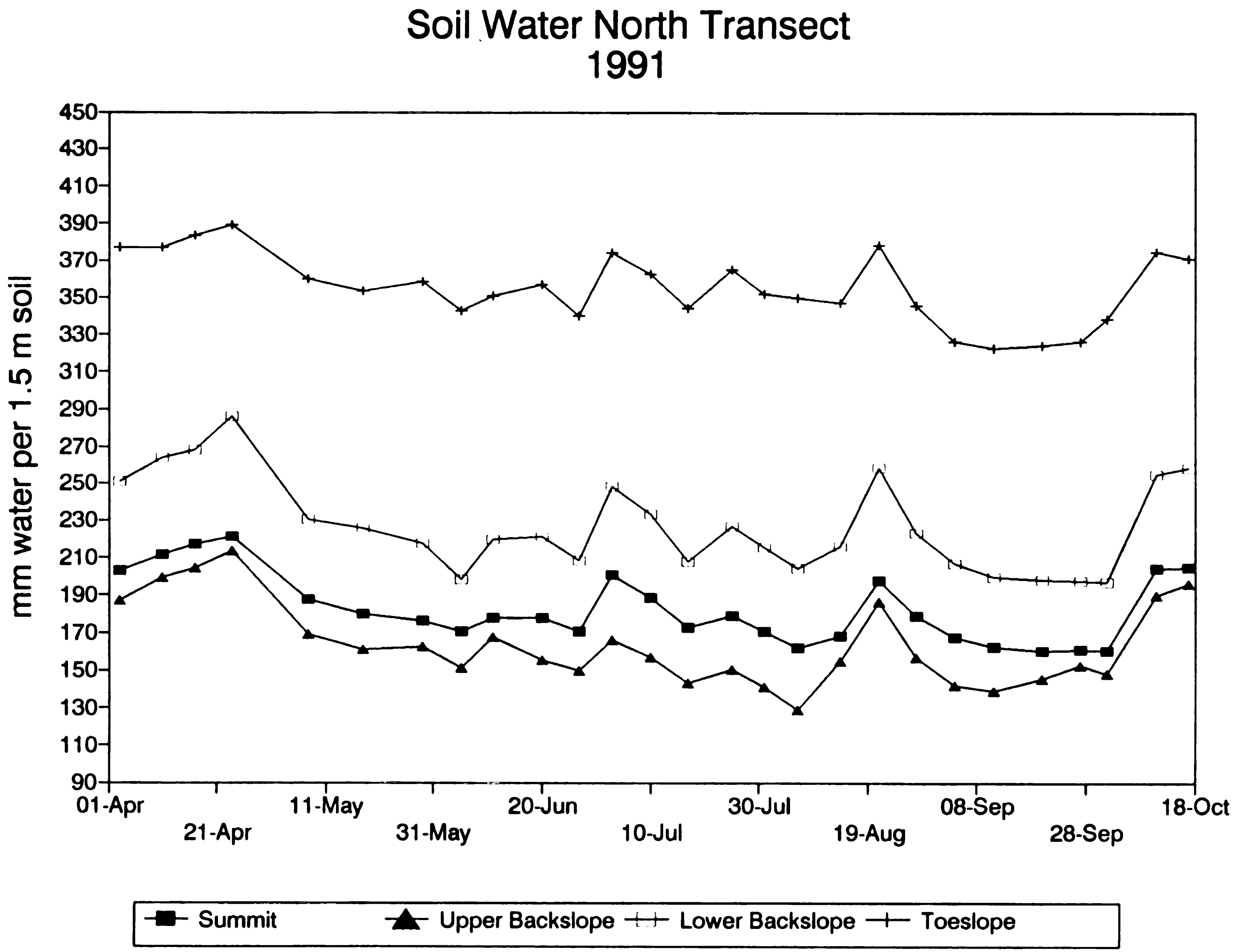

Figure 3.11. Average total soil water of the north transect for 1991.

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Table 3.2 Changes in Runoff Curve Numbers.

Transect	Topographic Position	Original Runoff Curve Number	Runoff Curve Number Used in Simulation
South	Summit	75.92	75.92
	Upper Backslope	86.4	95.04*
	Lower Backslope	86.4	75.92*
	Footslope-Toeslope	75.92	75.92
North	Summit	75.92	75.92
	Upper Backslope	86.4	95.04*
	Lower Backslope	86.4	75.92*
	Footslope-Toeslope	75.92	75.92
	Opposite Backslope	89.64	98.28*

* Changed Runoff Curve Number

the footslope and toeslope positions was the greatest of all positions, and did not vary as widely as the mm soil water of the other positions. In fact, the footslope and toeslope soils were at or near field capacity most of the year due to the large input of water from the backslopes east and west of the toeslope. The lowest mm soil water per 150 cm soil depth occurred in the upper backslope positions, which was well below field capacity during the growing season in 1991. The mm soil water per 150 cm soil depth of the summit and lower backslope positions were between the footslope-toeslope and upper backslope mm soil water. The mm soil water per 150 cm soil depth of the summit and lower backslope of the south transect were similar (as was water retention at field capacity), and both were somewhat below field capacity during the growing season. The greater mm soil water in the footslope-toeslope and lower backslope positions may be due to runoff and subsurface lateral downslope movement of water, or throughflow (Hoover and Hursh, 1943; Chorley, 1978; Gerrard, 1981; Burt and Butcher, 1985; Daniels and Hamer, 1992), from the summit

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and upper backslope positions. Throughflow may occur in the Kalamazoo soil because as percent clay increases from the Ap to Bt1 horizon, the hydraulic conductivity may decrease (Daniels and Hammer, 1992). Water may accumulate above the Bt1 horizon during periods of high infiltration, and flow laterally downslope. In their studies of soil water content in sloping landscapes, Bhargava et al. (1976) and Hanna et al. (1982) found the amount of stored soil to be greatest in the backslope and footslope position soils, and least in the summit and shoulder position soils.

Soil Water Balance

In order to obtain estimated values of potential evapotranspiration, surface and subsurface runoff and run-on, the CERES Maize computer model (version 2.1) was used to simulate these parameters for each slope position of both transects. The model was first used to simulate soil water conditions for each slope position, except toeslopes. It was assumed that if simulated volumetric moisture content (VMC) values of each soil layer for each slope position were close to the average soil layer content from the access tube transects, then the runoff estimates obtained from CERES were probably valid. Since the slope gradient of the summit position is similar (0 to 2%) both toward the west and north (Figure 3.3), it is difficult to determine where surface and subsurface runoff from the summit position moves. Therefore, runoff from the summit position was not added to water entering the upper backslope position. Changes to the inputs were necessary to make CERES estimates similar to field measured values. First, since the VMC values of the lower backslope soil layers were similar to those of the summit soil layers, it was assumed that overland plus subsurface throughflow from the upper backslope soils to the lower backslope soils equaled runoff plus subsurface throughflow from the lower backslope soils to the toeslope soils. Therefore, the Runoff Curve Numbers of the lower backslope soils were changed to be the same values as the summit soils, and runoff from the upper

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backslope was not added to precipitation. Second, since field VMC values still did not compare well with CERES VMC estimates, the Runoff Curve Numbers were determined for Hydrologic Condition C soils (clay loam textures) instead of Hydrologic Condition B soils (loam and sandy loam textures) (Table 3.2). Also, field capacity soil moisture input was modified (Tables 3.3 and 3.4), until CERES VMC estimates were as close to field VMC values. Next, overland flow plus subsurface throughflow from the backslope soils to the toeslope soils was estimated as follows. Since there is a hillslope (backslope = 8 % to 10 %) to the west, which converges with the toeslope of the study site, the runoff from this backslope was simulated and combined with the simulated runoff values from the upper backslope of the study site to obtain estimated values for water flow to the toeslope. Soil profile data of the upper backslope of the north transect was used as CERES input for simulating runoff from the backslope opposite the study site because both slope positions have similar soil profiles. The toeslope soils of each transect were then simulated for VMC by adding runoff from the study site upper backslope and the opposite backslope to precipitation. Simulated VMC values for the toeslope soils of both the south and north transects were similar to field data only after runoff from the backslopes were simulated using Hydrologic Condition C soil values for the backslopes. Simulated mm soil water per 150 cm soil estimates are presented in Figures 3.12, 3.13, 3.14, and 3.15.

Statistical assessment of the simulation accuracy of CERES to estimate mm soil water per 150 cm soil is summarized in Table 3.5. The Md values are all small except for the 1990 toeslope positions, which are moderately overestimated. The RMSE values are low compared to those reported by Jabro et al. (1994) using Br- simulation models. Their RMSE values ranged from 14 to 51 percent. The r values for 1991 were higher than those of 1990. This might be expected since CERES was developed as a corn growth model. All Md values were not statistically different from zero at the

Table 3.3 Changes in average field capacity volumetric moisture content for the south transect.

Position	Depth (cm)	Field capacity volumetric moisture	Field capacity volumetric moisture used in simulation
Summit	0-21	0.259	0.259
	21-45	0.280	0.307
	45-69	0.222	0.199
	69-107	0.152	0.130
	107-145	0.119	0.100
	145-150	0.097	0.080
Upper Backslope	0-25	0.253	0.257
	25-44	0.250	0.274
	44-77	0.131	0.100
	77-101	0.080	0.070
	101-125	0.093	0.070
	125-150	0.082	0.070
Lower Backslope	0-23	0.265	0.265
	23-58	0.283	0.296
	58-83	0.181	0.150
	83-108	0.128	0.110
	108-129	0.123	0.105
	129-150	0.120	0.095
Footslope-Toeslope	0-26	0.280	0.287
	26-44	0.292	0.267
	44-63	0.281	0.286
	63-100	0.207	0.181
	100-125	0.181	0.165
	125-150	0.169	0.150

Table 3.4. Changes in average field capacity volumetric moisture content for the north transect.

Position	Depth (cm)	Field Capacity Moisture Conent	Field Capacity used in simulation
Summit	0-16	0.237	0.243
	16-36	0.223	0.257
	36-55	0.180	0.154
	55-84	0.101	0.075
	84-117	0.094	0.075
	117-150	0.092	0.075
Upper Backslope	0-15	0.169	0.184
	15-46	0.146	0.130
	46-76	0.130	0.111
	76-106	0.134	0.111
	106-128	0.099	0.073
	128-150	0.100	0.073
Lower Backslope	0-20	0.213	0.216
	20-30	0.188	0.216
	30-61	0.151	0.121
	61-92	0.174	0.173
	92-124	0.135	0.115
	124-150	0.180	0.170
Footslope-Toeslope	0-20	0.282	0.254
	20-30	0.26	0.268
	30-61	0.293	0.289
	61-92	0.222	0.190
	92-124	0.213	0.148
	124-150	0.237	0.225

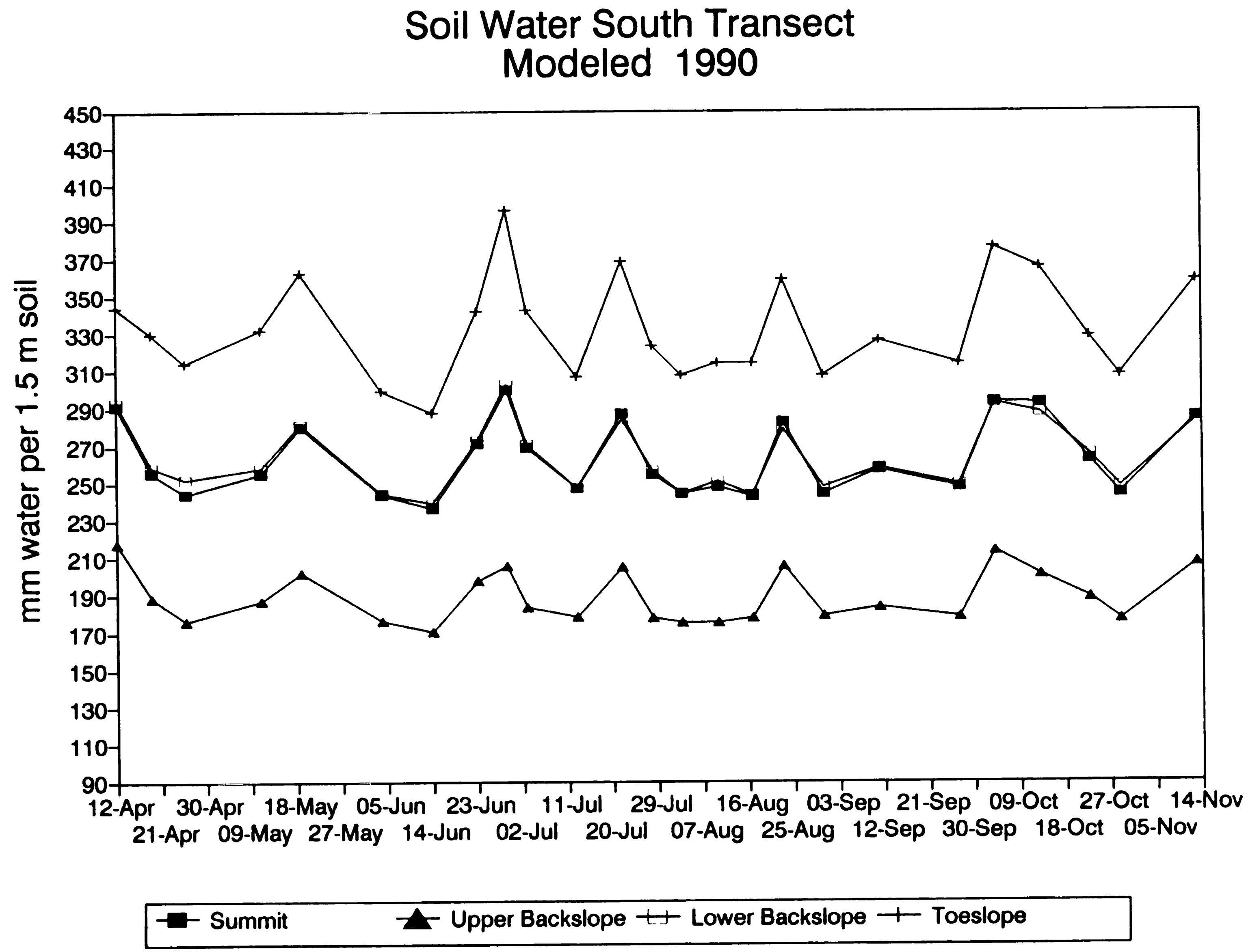

Figure 3.12. Simulated total soil water of the south transect for 1990.

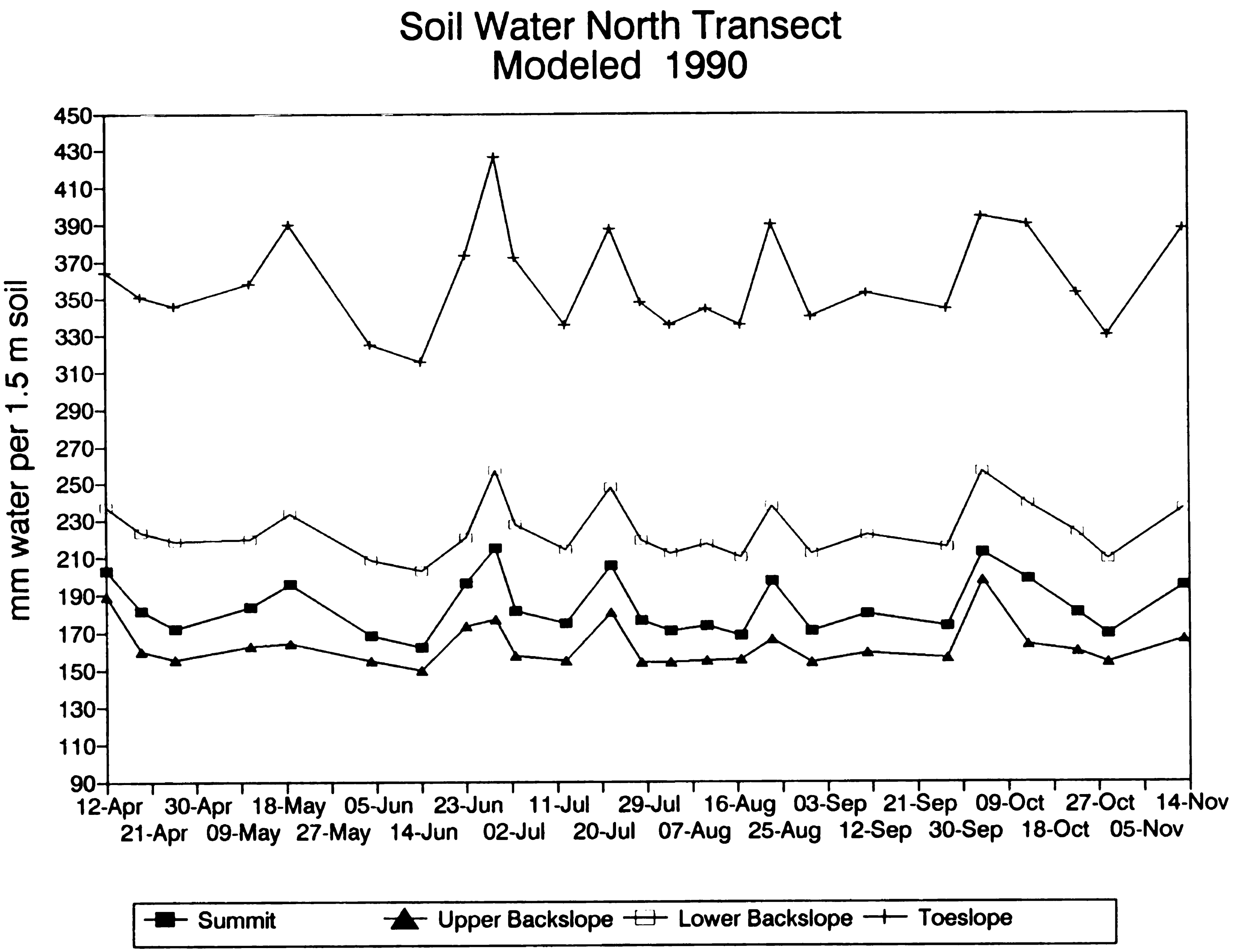

Figure 3.13. Simulated total soil water of the north transect for 1990.

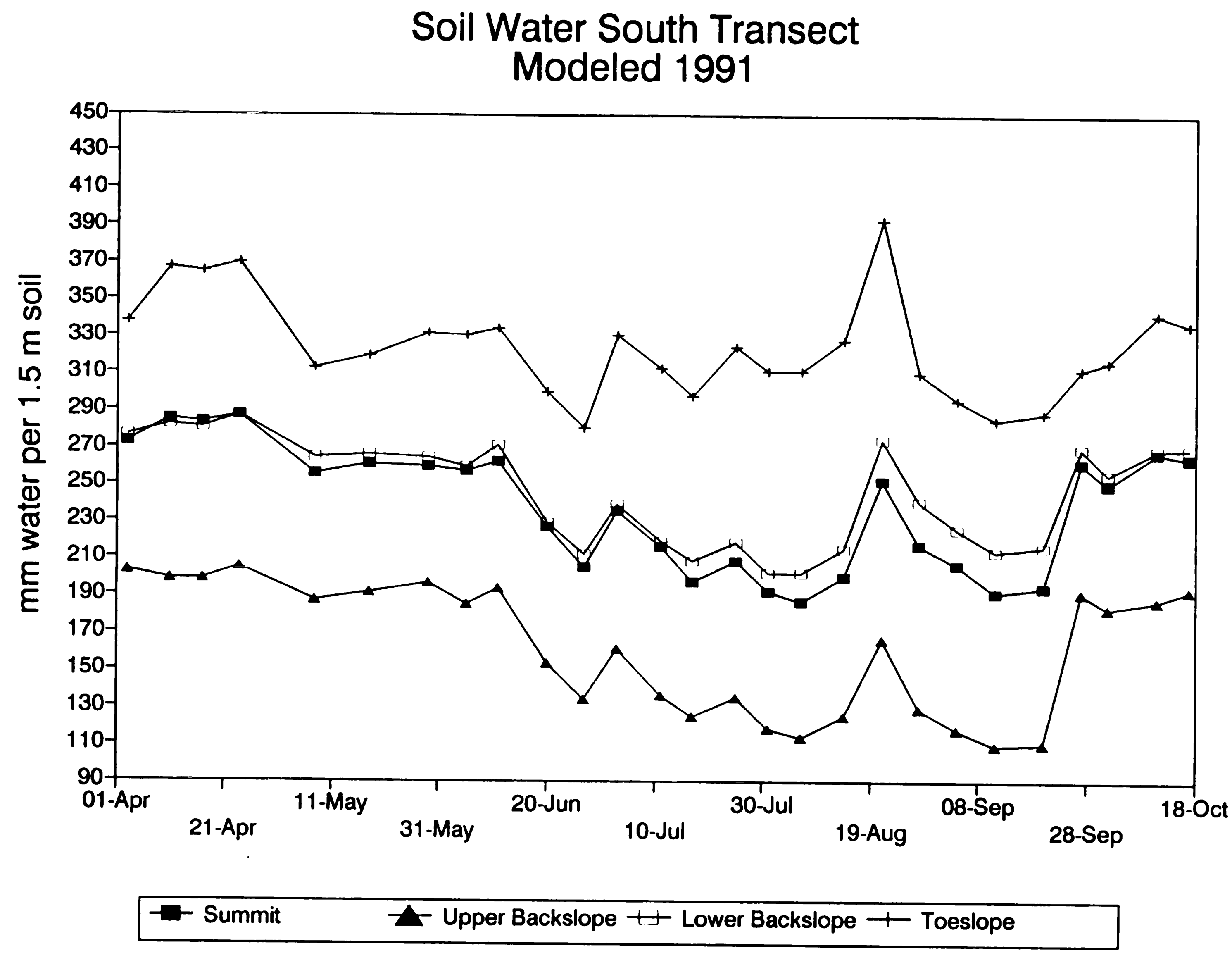

Figure 3.14. Simulated total soil water of the south transect for 1991.

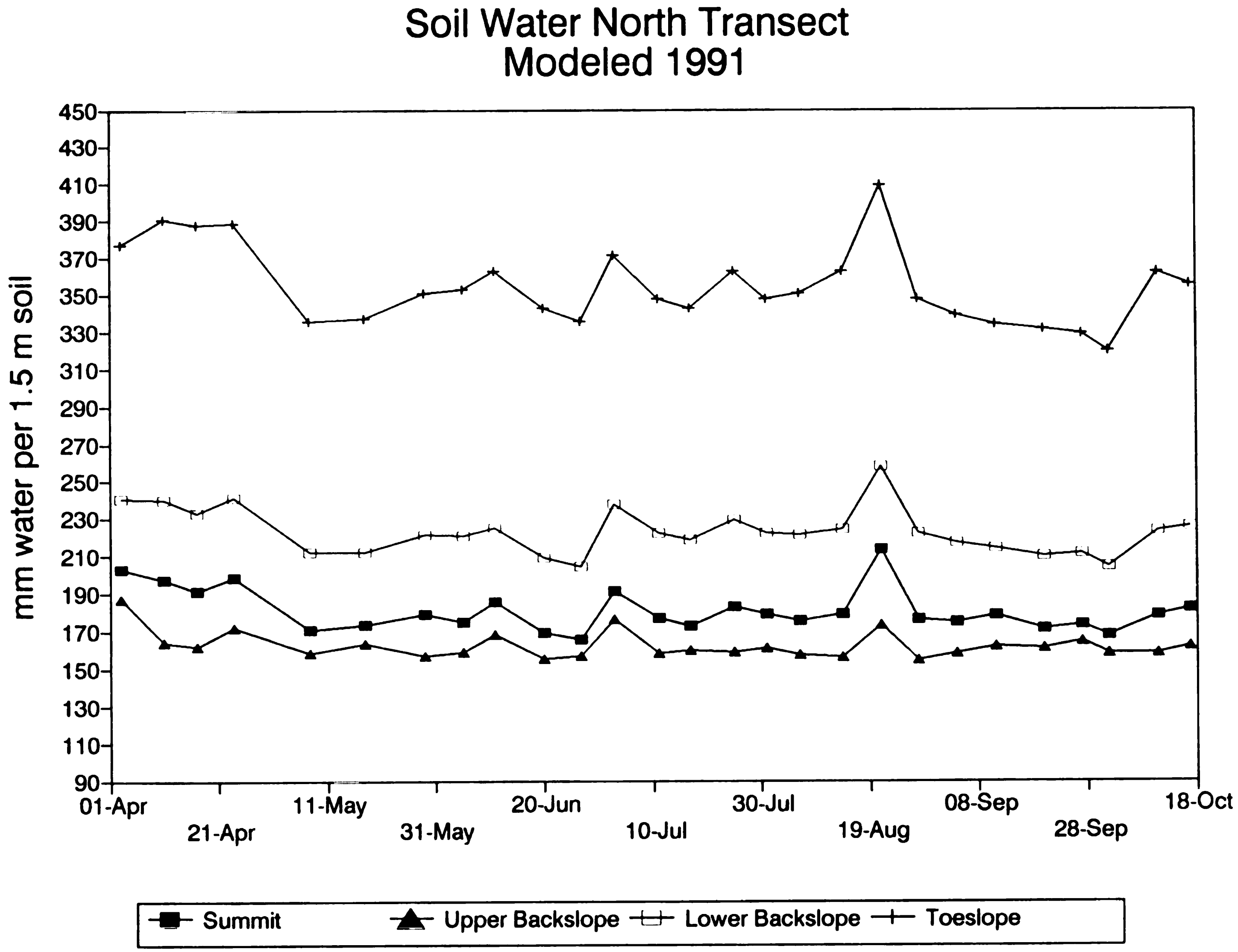

Figure 3.15. Simulated total soil water of the north transect for 1991.

Table 3.

Year	T
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1991	Sc
	No

Table 3.5. Statistical comparison of measured and simulated values of mm soil water per 150 cm soil.

Year	Transect	Slope Position	Md	RMSE	Corr. Coeff.	P(T≤t)
			mm	%	r	
1990	South	Summit	5.8	8.2	0.62	0.172
		Upper Back.	2.2	10.3	0.60	0.569
		Lower Back.	-1.9	3.8	0.60	0.611
		Foot-Toe	10.8	8.5	0.44	0.047
	North	Summit	0.7	8.4	0.55	0.830
		Upper Back.	-3.9	4.4	0.63	0.177
		Lower Back.	3.3	2.8	0.73	0.348
		Foot-Toe	10.5	7.0	0.60	0.027
1991	South	Summit	7.1	7.9	0.87	0.038
		Upper Back.	-3.6	12.8	0.82	0.390
		Lower Back.	4.4	7.5	0.83	0.207
		Foot-Toe	0.6	5.9	0.71	0.872
	North	Summit	-1.9	7.1	0.71	0.455
		Upper Back.	-1.5	11.9	0.47	0.700
		Lower Back.	-4.4	7.9	0.76	0.203
		Foot-Toe.	-0.7	3.5	0.81	0.781

0.05 probability level, except the 1990 toeslope values, which were not statistically different from zero at the 0.01 probability level.

There are two possible reasons why the Runoff Curve Numbers and field capacity moisture values needed to be changed. First, the Soil Conservation Service, Runoff Curve Number method assumes that daily precipitation occurs over the entire 24 hour span. Thus, rainfall intensity is underestimated. Second, CERES Maize does not take preferential water flow into account, which is significant in both well structured soils, (like the Bt1 horizon of the Kalamazoo soils), and sandy soils, (like the 2Bt2 and 3E/Bt horizons of the Kalamazoo and Oshtemo soils) (Steenhuis and Parlange, 1991).

Surface and subsurface runoff estimates for the summit positions (1.9% to 4.7% of ppt) were similar to subsurface and subsurface runoff estimates for the lower backslope positions (0.7% to 3.3% of ppt), while surface and subsurface runoff estimates for the upper backslope positions were greater (10.0% to 23.2% of ppt) (Table 3.6). Surface and subsurface flow to the footslope-toeslope of both transects was 1.8 times ppt in 1990 and 1.6 times ppt in 1991. Surface and subsurface runoff from the footslope-toeslope (there is an outlet of the toeslope on the north end of the site) ranged from 12.3% to 20.2% of ppt + surface and subsurface run-on (Table 3.6).

Evapotranspiration values (calculated by CERES when drainage > 0, or the water balance equation when drainage = 0) for the summit (66.7% to 82.7% of ppt), upper backslope (60.1% to 78.2% of ppt), and lower backslope (66.8% to 83.7% of ppt) positions were similar (Table 3.6). Evapotranspiration values for the footslope-toeslope ranged from 41.9% to 55.6% of ppt + run-on.

Drainage values (calculated by the water balance equation) for the summit soils (15.1% to 30.6% of ppt) were similar to the lower backslope soils (15.7% to 32.1% of ppt), while drainage values for the upper backslope soils (6.9% to 19.3% of ppt) were less (Table 3.6). Drainage values of the footslope and toeslope soils ranged from 31.2% to 39.6% of ppt + run-on.

Table 3.6 Water flux amounts for each slope position.

		mm				
Transect and Year	Position	Pricip. + Run-on and Throughflow	Runoff and Throughflow	Change in Soil Water	Et	Drainage
South 1990	Summit	767.8	36	-15.1	512.5	234.4 mm
			4.7	-2.0	66.7	30.6 % of PPT
	Upper Back.	767.8	178.2	-19.6	461.4	147.8 mm
			23.2	-2.6	60.1	19.3 % of PPT
	Lower Back.	767.8	25.5	-12.5	547.8	207.0 mm
			3.3	-1.6	71.3	27.0 % of PPT
	Foot-Toe.	1414.5	268.9	-6.9	592.3	560.2 mm
		1.8X ppt.	19.0	-0.5	41.9	39.6 % of PPT
North 1990	Summit	767.8	16.3	-8.5	542.0	218.0 mm
			2.1	-1.1	70.5	28.4 % of PPT
	Upper Back.	767.8	137.5	-12.8	511.1	132.0 mm
			17.9	-1.7	66.6	17.2 % of PPT
	Lower Back.	767.8	12.9	-4.6	513.2	246.3 mm
			1.7	-0.6	66.8	32.1 % of PPT
	Foot-Toe.	1376.5	277.8	-0.4	658.1	441.0 mm
		1.8X ppt.	20.18	-0.03	47.81	32.04 % of PPT
South 1991	Summit	751.3	14.1	4.6	598.9	133.7 mm
			1.9	0.6	79.7	17.8 % of PPT
	Upper Back.	751.3	75.4	2.6	587.4	85.9 mm
			10.0	0.3	78.2	11.5 % of PPT
	Lower Back.	751.3	5.4	-6.4	629.0	123.3 mm
			0.7	-0.8	83.7	16.4 % of PPT
	Foot-Toe.	1215.0	149.8	1.7	675.8	387.7 mm
		1.6X ppt.	12.3	0.2	55.6	31.9 % of PPT
North 1991	Summit	751.3	14.6	2.1	621.5	113.1 mm
			1.9	0.2	82.7	15.1 % of PPT
	Upper Back.	751.3	142.3	9.2	547.7	52.1 mm
			19.0	1.2	72.9	6.9 % of PPT
	Lower Back.	751.3	11.4	7.5	614.1	118.3 mm
			1.5	1.0	81.8	15.7 % of PPT
	Foot-Toe.	1213.4	166.6	-5.5	674.3	378.1 mm
		1.6X ppt	13.7	-0.5	55.6	31.2 % of PPT

Geostatistical Analysis

Semivariograms and cross-semivariograms for the soil water properties are presented in Figure 3.16. All semivariograms and cross-semivariograms were fitted to linear models. The spatial dependence for the soil water properties are summarized in Table 3.7. The "explained" variance (the portion of the total variance correlated with distance) ranged from 63.1 to 87.7 percent. The range of spatial dependence varied from 22.0 to 26.1 meters. Significant anisotropy in the east-west direction (up/down the slope) is exhibited for all soil water variables.

Geostatistical estimation of mm soil water per 150 cm soil were performed on the soil profiles from the grid between 4 and 52 meters north of the south access tube transect. All soil water estimates in this grid were estimated by CERES Maize as previously described. CERES estimates of mm soil water were removed from selected rows in the North-South and East-West directions from the data sets of August 6 and October 17, 1991. The number of X coordinate rows removed from the data sets was increased until the minimum number of data required to estimate mm soil water via kriging and cokriging was determined. A statistical comparison of the minimum number of CERES input data used to geostatistically estimate mm soil water per 150 cm soil are presented in Table 3.8. The maximum distance that X coordinate rows were separated to reliably estimate mm soil water at the 0.05 probability level using kriging was 16 meters for August 6 and October 17. The maximum distance that X coordinate rows could be separated to reliably estimate mm soil at the 0.05 probability level using cokriging, with mm soil water at field capacity as the auxiliary function, was 24 and 44 meters for August 6 and October 17, respectively. The maximum distance that X coordinate rows could be separated to reliably estimate mm soil water at the 0.01 probability level using cokriging was 44 meters. Other combinations of rows and columns deleated from the data set did not yield reliable estimates of mm soil water with fewer soil water data than those above. The pooled estimation variance

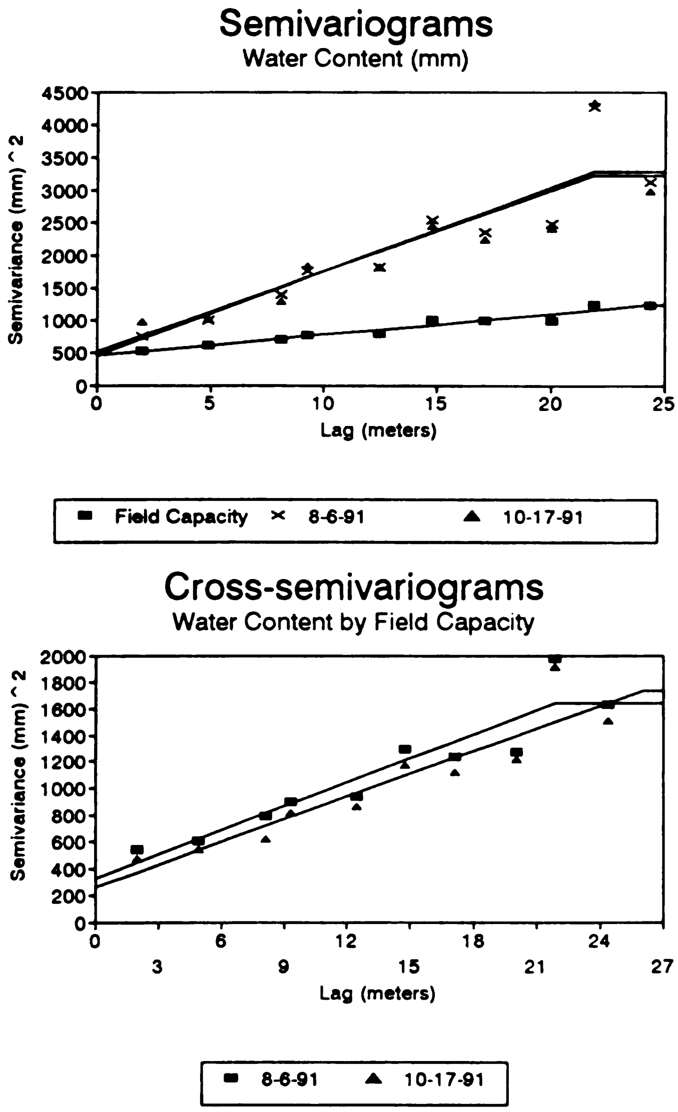

Figure 3.16. Semivariograms and cross-semivariograms for soil water properties.

Table 3.7. Semivariance and cross-semivariance statistics.

Property: Water Content	Nugget Variance	Sill	Variance Explained	Corr. Coeff.	Range	Anisotropy Ratio East-West
	(mm)^2	(mm)^2	(%)	r	(m)	
F.C.	455.0	1233.2	63.1	0.97	24.1	1.92
8-6-91	455.5	3276.8	86.1	0.92	22.0	7.77
10-17-91	513.1	3220.1	84.1	0.89	22.0	3.13
8-6-91 by F.C.	325.3	1638.6	80.1	0.94	22.0	4.27
10-17-91 by F.C.	260.9	1681.9	87.7	0.93	26.1	2.87

Table 3.8. Statistical comparison of CERES mm soil water values of mm soil water per 150 cm soil with kriged and cokriged estimates.

Date	X coordinate rows used in geostatistical estimation	n*	Md	RSME	Corr. Coeff.	P(T≤t)
	meters north of south border		mm	%	r	
Kriged						
8-6-91	4, 20, 36, 52	36	6.5	17.0	0.84	0.052
10-17-91	4, 20, 36, 52	36	3.9	13.2	0.87	0.272
Cokriged						
8-6-91	4, 28, 52	27	1.4	11.7	0.92	0.520
8-6-91	4, 48	18	-7.7	18.1	0.82	0.026
10-17-91	4, 48	18	-3.5	16.5	0.71	0.391

* n = number of mm soil water per 150 cm soil data points used in estimation.

values of mm soil water estimates are reported in Table 3.9.

Table 3.9. Pooled kriging estimation variance.

Property: Water content in 150 cm soil	Transects used in geostatistical estimation	Pooled estimation variance
	meters north of south border	$(mm)^2$
Kriged		
8-6-91	4, 20, 36, 52	787.9
10-17-91	4, 20, 36, 52	1698.7
Cokriged		
8-6-91	4, 28, 52	934.4
8-6-91	4, 48	633.2
10-17-91	4, 48	1505.1

SUMMARY AND CONCLUSIONS

The lowest mm soil water per 150 cm soil depth occurred in the soils of the upper backslope positions, and the highest in the soils of the footslope and toeslope positions, which were at or near field capacity during most of the study period. The mm soil water of the lower backslope and summit positions were between the mm soil water of the upper backslope and footslope-toeslope positions. The amount of water entering the lower backslope via infiltration from precipitation and run-on, and subsurface lateral downslope throughflow may be similar to that infiltrating into the summit soils from precipitation, as they both have similar total soil water contents. The necessity to make the Runoff Curve Number of the lower backslope soils the same as that of the summit soils, in order to simulate field moisture conditions with CERES Maize is further evidence the summit and lower backslope soils are receiving similar quantities of water. The mm soil water per 150 cm soil depth of the footslope and toeslope positions can be simulated with CERES Maize by adding simulated estimates of surface and subsurface runoff from the upper backslope positions to precipitation.

The results of this research show geostatistics can be used to estimate stored soil water within a sloping landscape. Data sets of stored soil water can be reduced by using semivariograms and cross-semivariograms from a large data set. The variogram models used in this study could possibly be used in other stored soil water prediction studies that have similar soils and landscapes. By using mm soil water at field capacity as the auxiliary variable, the distance between measurements of soil water could be as far apart as twice the range of spatial dependence, parallel to the contour of the slope. Therefore, stored soil water of the study site can be characterized geostatistically by monitoring changes in soil water content at intervals of approximately 4.25 meters up/down the slope and 44 meters apart on the same landscape position.

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GENERAL CONCLUSIONS

The results of this research show landscape position, in part, control soil formation, (i.e. Organic matter accumulation, formation of soil horizons and soil structure, and clay translocation) morphology, and amount of water in the soil profile. In general, within a sloping landscape where all soils are well drained, percent organic carbon, percent clay and silt, soil thickness, and water holding capacity decrease from the summit position to the upper backslope position, and then increase downslope. Deposition of material at the lower backslope, footslope, and toeslope from upslope contribute to thicker Ap horizons with more organic carbon, clay, and silt from the lower backslope position downslope, relative to the summit and upper backslope positions. Overland flow and subsurface lateral downslope throughflow of water contribute to greater soil thickness and percent clay of the argillic horizon below the middle of the backslope by increasing leaching and clay translocation. Sorting of material at deposition probably can contribute to differences in the amounts of sand, silt, and clay seen at various parts of the landscape.

The amount of soil water within a sloping landscape with Kalamazoo and Oshtemo soils is least within the upper backslope position, moderate within the summit and lower backslope positions, and greatest within the footslope and toeslope positions. The amount of water in the soils of a sloping landscape can be simulated by accounting for precipitation, field capacity moisture content, potential evapotranspiration, and surface and subsurface flow. The amount of soil water in the footslope and toeslope positions can be simulated by combining overland flow from the upper backslope (or shoulder) position with precipitation. Because the lower backslope and summit position soils seem to behave similarly with respect to soil water in the profile, the amount of soil water in the lower backslope and summit positions can be simulated similarly with respect to degree of slope, which influences the amount of surface and subsurface flow from these positions.

The results of this research show geostatistics can be used to estimate the amount of soil water within a sloping landscape. By using mm soil water at field capacity as the auxiliary variable, the distance between measurements of soil water could be as far apart as twice the range of spatial dependence, parallel to the contour of the slope. Variogram models of the amount of soil water from large data sets could be used to predict the amount of soil water in other studies with similar landscape and soil conditions.

APPENDIX A.

Soil Profile Horizon Depth, Particle Size Distribution, Control Section Clay Content, and Soil Series Data

APPENDIX A.

Soil profile horizon depth, particle size distribution, control section clay content, and soil series. The southwest corner of the field is the origin of the sample points at 0 meters in the east and north directions.

Sample point location East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
0.00	0.00	Ap	0-33	33	24	43	30	Kal.
		E	33-50	33	24	43		
		Bt1	50-71	55	30	15		
		Bt2	71-107	74	20	6		
		2Bt3	107-173	89	9	2		
2.00	0.00	Ap	0-23	34	23	43	33	Kal.
		E	23-40	34	23	43		
		Bt1	40-64	50	33	17		
		Bt2	64-97	74	18	8		
		2Bt3	97-173	88	11	1		
4.00	0.00	Ap	0-23	41	22	37	28	Kal.
		E	23-40	41	22	37		
		Bt1	40-64	55	28	17		
		Bt2	64-97	74	22	4		
		2Bt3	97-173	90	10	0		
6.00	0.00	Ap	0-23	39	21	40	26	Kal.
		Bt1	23-58	53	31	16		
		2Bt2	58-122	83	15	2		
		3E/Bt	122-150	94	6	0		
8.00	0.00	Ap	0-20	39	21	40	27	Kal.
		E	20-28	31	29	40		
		Bt1	28-58	43	35	22		
		2Bt2	58-86	83	16	1		
		3E/Bt	86-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
10.00	0.00	Ap	0-20	41	21	38	28	Kal.
		Bt1	20-40	44	36	20		
		Bt2	40-53	78	21	1		
		2Bt3	53-91	89	11	0		
		3E/Bt	91-150	94	6	0		
12.00	0.00	Ap	0-20	41	22	37	34	Kal.
		Bt1	20-46	31	37	32		
		Bt2	46-64	76	22	2		
		2Bt3	64-122	81	16	3		
		3E/Bt	122-150	94	6	0		
14.00	0.00	Ap	0-23	47	23	30	23	Kal.
		Bt1	23-43	57	28	15		
		Bt2	43-56	77	21	2		
		2Bt3	56-104	85	13	2		
		3E/Bt	104-150	94	6	0		
16.00	0.00	Ap	0-23	45	24	31	27	Kal.
		Bt1	23-43	47	33	20		
		Bt2	43-58	78	20	2		
		2Bt3	58-102	85	13	2		
		3E/Bt	102-150	94	6	0		
18.00	0.00	Ap	0-20	46	26	28	25	Kal.
		Bt1	20-43	63	28	9		
		Bt2	43-61	76	21	3		
		2Bt3	61-122	90	10	0		
		3E/Bt	122-150	94	6	0		
20.00	0.00	Ap	0-23	47	23	30	18	Kal.
		Bt1	23-38	52	31	17		
		2Bt2	38-74	87	12	1		
		3E/Bt	74-150	94	6	0		
22.00	0.00	Ap	0-23	51	23	26	15	Osh.
		Bt1	23-38	67	27	6		
		2Bt2	38-79	89	10	1		
		3E/Bt	79-150	94	6	0		
24.00	0.00	Ap	0-25	47	21	32	18	Kal.
		Bt1	25-43	66	29	5		
		2Bt2	43-74	87	12	1		
		3E/Bt	74-150	94	6	0		
26.00	0.00	Ap	0-28	45	21	34	17	Osh.
		Bt1	28-50	57	25	18		
		2Bt2	50-75	87	10	3		
		3E/Bt	75-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
28.00	0.00	Ap	0-23	41	22	37	19	Kal.
		Bt1	23-38	69	25	6		
		2Bt2	38-86	81	16	3		
		3E/Bt	86-150	94	6	0		
30.00	0.00	Ap	0-23	41	21	38	20	Kal.
		Bt1	23-36	49	29	22		
		Bt2	36-48	76	20	4		
		2Bt3	48-137	82	11	7		
		3E/Bt	137-150	94	6	0		
32.00	0.00	Ap	0-20	25	20	55	30	Kal.
		E	20-28	25	20	55		
		Bt1	28-48	51	34	15		
		Bt2	48-69	72	20	8		
		2Bt3	69-157	87	11	2		
34.00	0.00	Ap	0-20	41	21	38	39	Kal.
		E	20-28	22	21	57		
		Bt1	28-58	27	39	34		
		Bt2	58-91	74	20	6		
		2Bt3	91-157	89	11	0		
0.00	4.00	Ap	0-28	34	23	43	27	Kal.
		E	28-43	36	24	40		
		Bt1	43-84	53	31	16		
		2Bt2	84-150	87	11	2		
4.25	4.00	Ap	0-25	40	21	39	24	Kal.
		E	25-43	33	27	40		
		Bt1	43-69	45	32	23		
		2Bt2	69-142	84	15	1		
		3E/Bt	142-150	94	6	0		
8.50	4.00	Ap	0-20	40	21	39	30	Kal.
		Bt1	20-56	44	36	20		
		2Bt2	56-91	85	14	1		
		3E/Bt	91-150	94	6	0		
12.75	4.00	Ap	0-23	44	22	34	27	Kal.
		Bt1	23-58	43	32	25		
		2Bt2	58-112	84	14	2		
		3E/Bt	112-150	94	6	0		
17.00	4.00	Ap	0-23	45	24	31	28	Kal.
		Bt1	23-66	54	31	15		
		2Bt2	66-112	87	12	1		
		3E/Bt	112-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
21.25	4.00	Ap	0-23	49	23	28	23	Kal.
		Bt1	23-53	59	29	12		
		2Bt2	53-86	87	13	0		
		3E/Bt	86-150	94	6	0		
25.50	4.00	Ap	0-25	47	21	32	26	Kal.
		Bt1	25-71	63	27	10		
		2Bt2	71-102	87	11	2		
		3E/Bt	102-150	94	6	0		
29.75	4.00	Ap	0-23	42	21	37	19	Kal.
		Bt1	23-43	60	27	13		
		2Bt2	43-117	81	14	5		
		3E/Bt	117-150	94	6	0		
34.00	4.00	Ap	0-20	35	20	45	36	Kal.
		Bt1	20-76	39	36	25		
		2Bt2	76-150	88	11	1		
0.00	8.00	Ap	0-28	35	23	42	25	Kal.
		E	28-46	37	25	38		
		Bt1	46-81	55	31	14		
		2Bt2	81-150	85	12	3		
4.25	8.00	Ap	0-25	40	21	39	21	Kal.
		E	25-46	35	25	40		
		Bt1	46-69	51	31	18		
		2Bt2	69-132	86	13	1		
		3E/Bt	132-150	94	6	0		
8.50	8.00	Ap	0-23	40	21	39	29	Kal.
		Bt1	23-56	44	36	20		
		2Bt2	56-94	84	15	1		
		3E/Bt	94-150	94	6	0		
12.75	8.00	Ap	0-23	44	21	35	27	Kal.
		Bt1	23-61	48	32	20		
		2Bt2	61-114	85	13	2		
		3E/Bt	114-150	94	6	0		
17.00	8.00	Ap	0-23	45	23	32	29	Kal.
		Bt1	23-66	52	32	16		
		2Bt2	66-114	86	12	2		
		3E/Bt	114-150	94	6	0		
21.25	8.00	Ap	0-23	48	22	30	25	Kal.
		Bt1	23-56	58	30	12		
		2Bt2	56-83	84	14	2		
		3E/Bt	83-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
25.5	8.00	Ap	0-23	48	21	31	25	Kal.
		Bt1	23-66	65	27	8		
		2Bt2	66-109	87	11	2		
		3E/Bt	109-150	94	6	0		
29.75	8.00	Ap	0-23	45	19	36	19	Kal.
		Bt1	23-41	63	27	10		
		2Bt2	41-114	81	15	4		
		3E/Bt	114-150	94	6	0		
34.00	8.00	Ap	0-23	39	20	41	34	Kal.
		Bt1	23-71	39	35	26		
		2Bt2	71-142	87	11	2		
		3E/Bt	142-150	94	6	0		
0.00	12.00	Ap	0-30	38	22	40	24	Kal.
		E	30-43	37	28	35		
		Bt1	43-76	61	27	12		
		2Bt2	76-102	23	77	17		
		3E/Bt	102-150	94	6	0		
4.25	12.00	Ap	0-30	40	212	39	21	Kal.
		E	30-46	35	27	38		
		Bt1	46-66	47	33	20		
		2Bt2	66-102	85	13	2		
		3E/Bt	102-150	94	6	0		
8.50	12.00	Ap	0-25	41	21	38	30	Kal.
		Bt1	25-58	45	36	19		
		2Bt2	58-102	80	17	3		
		3E/Bt	102-150	94	6	0		
12.75	12.00	Ap	0-25	45	19	36	22	Kal.
		E	25-38	34	28	38		
		Bt1	38-63	56	32	12		
		2Bt2	63-112	89	11	0		
		3E/Bt	112-150	94	6	0		
17.00	12.00	Ap	0-25	45	20	35	28	Kal.
		Bt1	25-61	47	34	19		
		2Bt2	61-117	84	13	3		
		3E/Bt	117-150	454	19	36		
21.25	12.00	Ap	0-20	47	22	31	29	Kal.
		Bt1	20-61	55	31	14		
		2Bt2	61-74	75	21	4		
		3E/Bt	74-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
25.50	12.00	Ap	0-20	51	22	27	20	Kal.
		Bt1	20-56	71	23	6		
		2Bt2	56-132	88	12	0		
		3E/Bt	132-150	94	6	0		
29.75	12.00	Ap	0-20	53	23	24	23	Kal.
		Bt1	20-61	71	24	5		
		2Bt2	61-102	79	18	3		
		3E/Bt	102-150	51	22	27		
34.00	12.00	Ap	0-28	52	20	28	18	Kal.
		Bt1	28-61	75	20	5		
		2Bt2	61-117	86	13	1		
		3E/Bt	117-150	94	6	0		
0.00	16.00	Ap	0-33	41	23	36	24	Kal.
		E	33-46	37	28	35		
		Bt1	46-79	61	27	12		
		2Bt2	79-109	77	17	6		
		3E/Bt	109-150	94	6	0		
4.25	16.00	Ap	0-28	41	21	38	28	Kal.
		E	28-36	29	28	43		
		Bt1	36-66	43	35	22		
		2Bt2	66-104	76	17	7		
		3E/Bt	104-150	94	6	0		
8.50	16.00	Ap	0-28	49	19	32	29	Kal.
		Bt1	28-63	45	35	20		
		2Bt2	63-102	82	15	3		
		3E/Bt	102-150	94	6	0		
12.75	16.00	Ap	0-25	47	19	34	30	Kal.
		Bt1	25-66	38	33	29		
		2Bt2	66-104	82	14	4		
		3E/Bt	104-150	94	6	0		
17.00	16.00	Ap	0-20	55	20	25	25	Kal.
		Bt1	20-56	49	31	20		
		2Bt2	56-127	86	11	3		
		3E/Bt	127-150	94	6	0		
21.25	16.00	Ap	0-25	55	21	24	27	Kal.
		Bt1	25-61	52	31	17		
		2Bt2	61-137	81	15	4		
		3E/Bt	137-150	94	6	0		
25.50	16.00	Ap	0-20	57	23	20	16	Osh.
		Bt1	20-43	74	22	4		
		2Bt2	43-79	89	11	0		
		3E/Bt	79-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
29.75	16.00	Ap	0-20	53	24	23	20	Kal.
		Bt1	20-43	67	25	8		
		2Bt2	43-122	83	15	2		
		3E/Bt	122-150	94	6	0		
34.00	16.00	Ap	0-20	47	21	32	21	Kal.
		Bt1	20-61	62	23	15		
		2Bt2	61-114	85	12	3		
		3E/Bt	114-150	94	6	0		
0.00	20.00	Ap	0-28	33	24	43	30	Kal.
		Bt1	28-69	44	33	23		
		2Bt2	69-124	79	17	4		
		3E/Bt	124-150	94	6	0		
4.25	20.00	Ap	0-28	41	21	38	28	Kal.
		E	28-41	27	28	45		
		Bt1	41-69	41	33	26		
		2Bt2	69-117	57	22	21		
		3E/Bt	117-150	94	6	0		
8.50	20.00	Ap	0-23	47	19	34	27	Kal.
		E	23-38	29	30	41		
		Bt1	38-69	44	35	21		
		2Bt2	69-119	86	14	0		
		3E/Bt	119-150	94	6	0		
12.75	20.00	Ap	0-23	51	19	30	25	Kal.
		E	23-38	51	19	30		
		Bt1	38-75	55	29	16		
		2Bt2	75-109	85	13	2		
		3E/Bt	109-150	94	6	0		
17.00	20.00	Ap	0-20	48	22	30	27	Kal.
		Bt1	20-58	53	31	16		
		2Bt2	58-102	84	15	1		
		3E/Bt	102-150	94	6	0		
21.25	20.00	Ap	0-20	57	22	21	16	Osh.
		Bt1	20-50	79	20	1		
		2Bt2	50-86	91	9	0		
		3E/Bt	86-150	94	6	0		
25.50	20.00	Ap	0-20	53	25	22	16	Osh.
		Bt1	20-50	73	21	6		
		2Bt2	50-94	91	9	0		
		3E/Bt	94-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
29.75	20.00	Ap	0-23	48	24	28	20	Kal.
		Bt1	23-48	68	27	5		
		2Bt2	48-91	86	13	1		
		3E/Bt	91-150	94	6	0		
34.00	20.00	Ap	0-23	51	23	26	19	Kal.
		Bt1	23-46	66	28	6		
		2Bt2	46-74	89	11	0		
		3E/Bt	74-150	94	6	0		
0.00	24.00	Ap	0-33	31	24	45	20	Kal.
		E	33-48	28	31	41		
		Bt1	48-71	54	29	17		
		2Bt2	71-119	85	13	2		
		3E/Bt	119-150	94	6	0		
4.25	24.00	Ap	0-30	45	23	32	26	Kal.
		E	30-48	26	30	44		
		Bt1	48-71	34	34	32		
		2Bt2	71-112	75	19	6		
		3E/Bt	112-150	94	6	0		
8.50	24.00	Ap	0-30	46	20	34	21	Kal.
		Bt1	30-51	45	31	24		
		2Bt2	51-114	87	13	0		
		3E/Bt	114-150	94	6	0		
12.75	24.00	Ap	0-23	48	20	32	32	Kal.
		Bt1	23-71	46	33	21		
		2Bt2	71-102	85	14	1		
		3E/Bt	102-150	94	6	0		
17.00	24.00	Ap	0-20	47	22	31	30	Kal.
		Bt1	20-53	40	36	24		
		2Bt2	53-150	82	17	1		
21.25	24.00	Ap	0-18	49	23	28	19	Kal.
		Bt1	18-32	62	30	8		
		2Bt2	32-150	82	15	3		
25.50	24.00	Ap	0-23	46	25	29	21	Kal.
		Bt1	23-66	69	23	8		
		2Bt2	66-104	89	8	3		
		3E/Bt	104-150	94	6	0		
29.75	24.00	Ap	0-23	41	27	32	20	Kal.
		Bt1	23-46	63	29	8		
		2Bt2	46-104	83	13	4		
		3E/Bt	104-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
34.00	24.00	Ap	0-20	53	23	24	18	Kal.
		Bt1	20-41	66	26	8		
		2Bt2	41-114	85	13	2		
		3E/Bt	114-150	94	6	0		
0.00	28.00	Ap	0-25	33	26	41	23	Kal.
		E	25-46	29	31	40		
		Bt1	46-71	51	33	16		
		2Bt2	71-150	83	13	4		
4.25	28.00	Ap	0-28	45	22	33	20	Kal.
		E	28-43	41	27	32		
		Bt1	43-66	62	27	11		
		2Bt2	66-102	85	14	1		
		3E/Bt	102-150	94	6	0		
8.50	28.00	Ap	0-20	49	19	32	25	Kal.
		E	20-36	27	31	42		
		Bt1	36-63	47	34	19		
		2Bt2	63-150	85	14	1		
12.75	28.00	Ap	0-20	48	19	33	27	Kal.
		E	20-33	31	29	40		
		Bt1	33-66	43	35	22		
		2Bt2	66-107	85	12	3		
		3E/Bt	107-150	94	6	0		
17.00	28.00	Ap	0-30	49	21	30	26	Kal.
		E	30-56	41	23	36		
		Bt1	56-107	61	26	13		
		2Bt2	107-173	90	10	0		
21.25	28.00	Ap	0-15	53	23	24	26	Kal.
		Bt1	15-69	72	26	2		
		2Bt2	69-102	89	10	1		
		3E/Bt	102-150	94	6	0		
25.50	28.00	Ap	0-15	50	24	26	23	Kal.
		Bt1	15-50	69	29	2		
		2Bt2	50-102	89	9	2		
		3E/Bt	102-150	94	6	0		
29.75	28.00	Ap	0-23	49	25	26	23	Kal.
		Bt1	23-46	65	29	6		
		2Bt2	46-89	81	18	1		
		3E/Bt	89-150	94	6	0		
34.00	28.00	Ap	0-23	48	24	28	22	Kal.
		Bt1	23-53	61	29	10		
		2Bt2	53-104	87	12	1		
		3E/Bt	104-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
0.00	32.00	Ap	0-33	36	22	42	32	Kal.
		E	33-38	27	28	45		
		Bt1	38-91	40	32	28		
		2Bt2	91-150	80	17	3		
4.25	32.00	Ap	0-33	44	21	35	22	Kal.
		E	33-53	38	26	36		
		Bt1	53-69	51	32	17		
		2Bt2	69-97	80	17	3		
		3E/Bt	97-150	47	21	32		
8.50	32.00	Ap	0-20	48	35	17	32	Kal.
		E	20-33	81	17	2		
		Bt1	33-74	44	21	35		
		2Bt2	74-150	38	26	36		
12.75	32.00	Ap	0-18	65	22	13	31	Kal.
		Bt1	18-69	49	31	20		
		2Bt2	69-138	83	14	3		
		3E/Bt	138-150	94	6	0		
17.00	32.00	Ap	0-18	57	23	20	24	Kal.
		Bt1	18-48	52	31	17		
		2Bt2	48-94	82	13	5		
		3E/Bt	94-150	94	6	0		
21.25	32.00	Ap	0-20	49	25	26	20	Kal.
		Bt1	20-48	65	29	6		
		2Bt2	48-150	92	8	0		
25.50	32.00	Ap	0-20	48	25	27	15	Osh.
		Bt1	20-40	71	23	6		
		2Bt2	40-150	89	9	2		
29.75	32.00	Ap	0-20	49	24	27	23	Kal.
		Bt1	20-53	63	29	8		
		2Bt2	53-107	88	12	0		
		3E/Bt	107-150	94	6	0		
34.00	32.00	Ap	0-20	45	25	30	23	Kal.
		Bt1	20-48	53	33	14		
		2Bt2	48-150	89	11	0		
0.00	36.00	Ap	0-28	34	25	41	32	Kal.
		E	28-41	27	29	44		
		Bt1	41-79	42	36	22		
		2Bt2	79-97	77	19	4		
		3E/Bt	97-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
4.25	36.00	Ap	0-25	39	19	42	20	Kal.
		E	25-38	31	31	38		
		Bt1	38-61	55	31	14		
		2Bt2	61-114	87	11	2		
		3E/Bt	114-150	94	6	0		
8.50	36.00	Ap	0-23	47	21	32	24	Kal.
		E	23-33	47	21	32		
		Bt1	33-58	45	34	21		
		2Bt2	58-104	85	14	1		
		3E/Bt	104-150	94	6	0		
12.75	36.00	Ap	0-20	47	21	32	20	Kal.
		Bt1	20-43	60	30	10		
		2Bt2	43-91	86	12	2		
		3E/Bt	91-150	94	6	0		
17.00	36.00	Ap	0-23	50	24	26	24	Kal.
		Bt1	23-38	42	30	28		
		2Bt2	38-89	76	21	3		
		3E/Bt	89-150	94	6	0		
21.25	36.00	Ap	0-23	51	24	25	18	Kal.
		Bt1	23-114	79	18	3		
		3E/Bt	114-150	94	6	0		
25.50	36.00	Ap	0-15	49	23	28	18	Kal.
		Bt1	15-30	61	29	10		
		2Bt2	30-150	87	13	0		
29.75	36.00	Ap	0-20	46	23	31	24	Kal.
		Bt1	20-56	60	28	12		
		2Bt2	56-117	86	13	1		
		3E/Bt	117-150	94	6	0		
34.00	36.00	Ap	0-18	43	23	34	20	Kal.
		Bt1	18-38	55	29	16		
		2Bt2	38-119	86	14	0		
		3E/Bt	119-150	46	23	31		
0.00	40.00	Ap	0-25	37	23	40	26	Kal.
		E	25-36	30	30	40		
		Bt1	36-56	46	36	18		
		2Bt2	56-122	76	19	5		
		3E/Bt	122-150	94	6	0		
4.25	40.00	Ap	0-20	45	21	34	27	Kal.
		E	20-28	31	32	37		
		Bt1	28-56	41	36	23		
		2Bt2	56-102	85	15	0		
		3E/Bt	102-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
8.50	40.00	Ap	0-18	49	22	29	26	Kal.
		Bt1	18-46	51	33	16		
		2Bt2	46-109	81	16	3		
		3E/Bt	109-150	94	6	0		
12.75	40.00	Ap	0-15	47	22	31	19	Kal.
		Bt1	15-36	57	30	13		
		2Bt2	36-94	89	11	0		
		3E/Bt	94-150	94	6	0		
17.00	40.00	Ap	0-13	49	23	28	25	Kal.
		Bt1	13-36	59	29	12		
		2Bt2	36-79	73	22	5		
		3E/Bt	79-150	94	6	0		
21.25	40.00	Ap	0-18	54	23	23	20	Kal.
		Bt1	18-33	71	23	6		
		2Bt2	33-84	80	18	2		
		3E/Bt	84-150	94	6	0		
25.50	40.00	Ap	0-23	52	23	25	21	Kal.
		Bt1	23-46	58	31	11		
		2Bt2	46-114	86	13	1		
		3E/Bt	114-150	94	6	0		
29.75	40.00	Ap	0-18	49	21	30	27	Kal.
		Bt1	18-46	58	31	11		
		2Bt2	46-79	86	13	1		
		3E/Bt	79-150	94	6	0		
34.00	40.00	Ap	0-18	49	21	30	24	Kal.
		Bt1	18-56	59	30	11		
		2Bt2	56-119	76	17	7		
		3E/Bt	119-150	94	6	0		
0.00	44.00	Ap	0-28	37	21	42	23	Kal.
		Bt1	28-58	49	32	19		
		2Bt2	58-122	91	9	0		
		3E/Bt	122-150	94	6	0		
4.25	44.00	Ap	0-25	46	18	36	24	Kal.
		Bt1	25-56	52	30	18		
		2Bt2	56-112	81	15	4		
		3E/Bt	112-150	94	6	0		
8.50	44.00	Ap	0-25	47	19	34	25	Kal.
		Bt1	25-53	55	31	14		
		2Bt2	53-99	80	17	3		
		3E/Bt	99-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
12.75	44.00	Ap	0-20	51	21	28	27	Kal.
		Bt1	20-58	53	32	15		
		2Bt2	58-117	90	10	0		
		3E/Bt	117-150	94	6	0		
17.00	44.00	Ap	0-18	49	22	29	28	Kal.
		Bt1	18-48	53	32	15		
		2Bt2	48-102	75	21	4		
		3E/Bt	102-150	94	6	0		
21.25	44.00	Ap	0-20	54	21	25	17	Osh.
		Bt1	20-38	52	21	27		
		2Bt2	38-84	84	15	1		
		3E/Bt	84-150	94	6	0		
25.50	44.00	Ap	0-18	53	21	26	23	Kal.
		Bt1	18-50	63	29	8		
		2Bt2	50-124	89	11	0		
		3E/Bt	124-150	94	6	0		
29.75	44.00	Ap	0-20	55	20	25	16	Osh.
		Bt1	20-50	71	17	12		
		2Bt2	50-107	86	14	0		
		3E/Bt	107-150	94	6	0		
34.00	44.00	Ap	0-20	53	21	26	29	Kal.
		Bt1	20-69	63	29	8		
		2E/Bt	69-150	94	6	0		
0.00	48.00	Ap	0-28	38	22	40	31	Kal.
		E	28-38	28	31	41		
		Bt1	38-74	43	35	22		
		2Bt2	74-117	78	19	3		
		3E/Bt	117-150	94	6	0		
4.25	48.00	Ap	0-23	49	19	32	25	Kal.
		E	23-36	29	31	40		
		Bt1	36-61	53	33	14		
		2Bt2	61-119	81	17	2		
		3E/Bt	119-150	94	6	0		
8.50	48.00	Ap	0-23	47	19	34	26	Kal.
		Bt1	23-56	47	31	22		
		2Bt2	56-112	81	17	2		
		3E/Bt	112-150	94	6	0		
12.75	48.00	Ap	0-20	49	20	31	24	Kal.
		Bt1	20-48	55	33	12		
		2Bt2	48-97	87	13	0		
		3E/Bt	97-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
17.00	48.00	Ap	0-20	49	20	31	23	Kal.
		Bt1	20-48	55	33	12		
		2Bt2	48-112	87	13	0		
		3E/Bt	112-150	94	6	0		
21.25	48.00	Ap	0-23	47	21	32	15	Osh.
		Bt1	23-41	49	33	18		
		2Bt2	41-150	89	10	1		
25.5	48.00	Ap	0-20	51	21	28	27	Kal.
		Bt1	20-46	63	28	9		
		2Bt2	46-122	93	7	0		
		3E/Bt	122-150	94	6	0		
29.75	48.00	Ap	0-23	52	22	26	20	Kal.
		Bt1	23-38	61	30	9		
		2Bt2	38-122	82	16	2		
		3E/Bt	122-150	51	21	28		
34.00	48.00	Ap	0-18	49	21	30	21	Kal.
		Bt1	18-48	62	28	10		
		2Bt2	48-86	89	11	0		
		3E/Bt	86-150	94	6	0		
0.00	52.00	Ap	0-25	37	22	41	23	Kal.
		E	25-36	41	25	34		
		Bt1	36-63	61	27	12		
		2Bt2	63-112	78	19	3		
		3E/Bt	112-150	94	6	0		
4.25	52.00	Ap	0-25	47	19	34	22	Kal.
		E	25-38	35	28	37		
		Bt1	38-66	58	30	12		
		2Bt2	66-114	88	12	0		
		3E/Bt	114-150	94	6	0		
8.50	52.00	Ap	0-25	48	19	33	23	Kal.
		E	25-38	36	28	36		
		Bt1	38-58	55	30	15		
		2Bt2	58-107	81	18	1		
		3E/Bt	107-150	94	6	0		
12.75	52.00	Ap	0-23	48	20	32	23	Kal.
		E	23-33	35	29	36		
		Bt1	33-61	45	30	25		
		2Bt2	61-102	83	15	2		
		3E/Bt	102-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
17.00	52.00	Ap	0-23	48	22	30	31	Kal.
		E	23-30	37	30	33		
		Bt1	30-61	50	38	12		
		2Bt2	61-97	82	17	1		
		3E/Bt	97-150	94	6	0		
21.25	52.00	Ap	0-18	53	21	26	17	Osh.
		Bt1	18-41	67	28	5		
		2Bt2	41-112	92	8	0		
		3E/Bt	112-150	94	6	0		
25.50	52.00	Ap	0-18	51	23	26	23	Kal.
		Bt1	18-61	67	25	8		
		2Bt2	61-150	91	9	0		
29.75	52.00	Ap	0-18	55	21	24	22	Kal.
		Bt1	18-36	62	30	8		
		2Bt2	36-79	81	17	2		
		3E/Bt	79-150	94	6	0		
34.00	52.00	Ap	0-20	41	22	37	22	Kal.
		Bt1	20-48	59	29	12		
		2Bt2	48-127	85	13	2		
		3E/Bt	127-150	94	6	0		
0.00	56.00	Ap	0-30	41	20	39	29	Kal.
		Bt1	30-61	48	35	17		
		2Bt2	61-119	76	20	4		
		3E/Bt	119-150	94	6	0		
4.25	56.00	Ap	0-30	47	18	35	22	Kal.
		E	30-46	41	21	38		
		Bt1	46-61	59	28	13		
		2Bt2	61-119	73	20	7		
		3E/Bt	119-150	94	6	0		
8.50	56.00	Ap	0-28	52	18	30	26	Kal.
		E	28-41	40	26	34		
		Bt1	41-69	52	33	15		
		2Bt2	69-117	79	18	3		
		3E/Bt	117-150	94	6	0		
12.75	56.00	Ap	0-18	51	19	30	25	Kal.
		E	18-33	37	27	36		
		Bt1	33-61	47	31	22		
		2Bt2	61-91	79	17	4		
		3E/Bt	91-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
17.00	56.00	Ap	0-23	55	20	25	28	Kal.
		E	23-38	45	25	30		
		Bt1	38-66	61	31	8		
		2Bt2	66-79	79	20	1		
		3E/Bt	79-150	94	6	0		
21.25	56.00	Ap	0-18	51	20	29	23	Kal.
		Bt1	18-61	67	25	8		
		2Bt2	61-119	89	11	0		
		3E/Bt	119-150	94	6	0		
25.50	56.00	Ap	0-20	47	20	33	27	Kal.
		Bt1	20-61	58	30	12		
		2Bt2	61-122	85	13	2		
		3E/Bt	122-150	94	6	0		
29.75	56.00	Ap	0-20	48	19	33	26	Kal.
		Bt1	20-61	65	28	7		
		2Bt2	61-81	84	15	1		
		3E/Bt	81-150	94	6	0		
34.00	56.00	Ap	0-23	41	19	40	20	Kal.
		E	23-38	41	25	34		
		Bt1	38-56	61	27	12		
		2Bt2	56-81	81	15	4		
		3E/Bt	81-150	94	6	0		
0.00	60.00	Ap	0-30	45	21	34	24	Kal.
		Bt1	30-61	55	30	15		
		2Bt2	61-124	85	14	1		
		3E/Bt	124-150	94	6	0		
4.25	60.00	Ap	0-30	52	16	32	21	Kal.
		E	30-41	64	18	18		
		Bt1	41-66	54	24	22		
		2Bt2	66-102	81	17	2		
		3E/Bt	102-150	94	6	0		
8.50	60.00	Ap	0-25	60	17	23	23	Kal.
		E	25-56	57	21	22		
		Bt1	56-81	71	23	6		
		2E/Bt	81-150	94	6	0		
12.75	60.00	Ap	0-20	59	18	23	15	Osh.
		E	20-30	51	24	25		
		Bt1	30-46	44	27	29		
		2Bt2	46-109	90	10	0		
		3E/Bt	109-150	96	4	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
17.00	60.00	Ap	0-20	61	18	21	18	Kal.
		Bt1	20-61	81	18	1		
		2E/Bt	61-150	94	6	0		
21.25	60.00	Ap	0-20	59	20	21	19	Kal.
		Bt1	20-48	79	19	2		
		2E/Bt	48-150	94	6	0		
25.50	60.00	Ap	0-20	49	22	29	24	Kal.
		Bt1	20-41	63	30	7		
		2Bt2	41-79	79	19	2		
		3E/Bt	79-150	94	6	0		
29.75	60.00	Ap	0-23	45	18	37	22	Kal.
		E	23-36	39	27	34		
		Bt1	36-58	62	27	11		
		2Bt2	58-90	81	15	4		
		3E/Bt	90-150	94	6	0		
34.00	60.00	Ap	0-18	42	19	39	28	Kal.
		E	18-30	30	27	43		
		Bt1	30-69	51	32	17		
		2Bt2	69-102	87	11	2		
		3E/Bt	102-150	94	6	0		
0.00	64.00	Ap	0-48	41	22	37	20	Kal.
		E	48-58	51	21	28		
		Bt1	58-71	57	29	14		
		2Bt2	71-117	82	17	1		
		3E/Bt	117-150	94	6	0		
4.25	64.00	Ap	0-31	61	15	24	10	Spinks
		E	31-48	59	21	20		
		2E/Bt	48-150	94	6	0		
8.50	64.00	Ap	0-23	62	15	23	16	Osh.
		E	23-41	63	16	21		
		Bt1	41-135	83	16	1		
		2E/Bt	135-150	94	6	0		
12.75	64.00	Ap	0-20	65	19	16	15	Osh.
		Bt1	20-33	71	25	4		
		2Bt2	33-102	88	12	0		
		3E/Bt	102-150	94	6	0		
17.00	64.00	Ap	0-20	71	17	12	14	Osh.
		Bt1	20-79	86	14	0		
		2E/Bt	79-150	94	6	0		
21.25	64.00	Ap	0-23	61	19	20	14	Osh.
		Bt1	23-46	85	14	1		
		2E/Bt	46-150	94	60			

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
25.50	64.00	Ap	0-20	41	22	37	25	Kal.
		Bt1	20-38	39	37	24		
		2Bt2	38-74	76	19	5		
		3E/Bt	74-150	94	6	0		
29.75	64.00	Ap	0-18	41	20	39	30	Kal.
		Bt1	18-56	48	34	18		
		2Bt2	56-89	79	17	4		
		3E/Bt	89-150	41	22	37		
34.00	64.00	Ap	0-18	48	19	33	26	Kal.
		E	18-30	43	25	32		
		Bt1	30-69	62	29	9		
		2Bt2	69-102	86	14	0		
		3E/Bt	102-150	94	6	0		
0.00	68.00	Ap	0-28	41	23	36	28	Kal.
		E	28-53	57	28	15		
		Bt1	53-75	73	18	9		
		Bt2	75-102	83	15	2		
		2Bt3	102-150	94	6	0		
2.00	68.00	Ap	0-25	47	23	30	22	Kal.
		E	25-53	41	24	35		
		Bt1	53-71	57	24	19		
		Bt2	71-94	75	22	3		
		3E/Bt	94-150	94	6	0		
4.00	68.00	Ap	0-28	51	18	31	38	Kal.
		E	28-56	31	29	40		
		Bt1	56-84	24	38	38		
		Bt2	84-112	74	29	6		
		2Bt3	112-142	91	9	0		
		3E/Bt	142-150	94	6	0		
6.00	68.00	Ap	0-20	66	15	19	8	Osh.
		E	20-30	73	13	14		
		2Bt1	30-97	90	8	0		
		2E/Bt	97-150	94	6	0		
8.00	68.00	Ap	0-20	66	13	21	10	Osh.
		E	20-30	66	13	21		
		Bt1	30-86	89	10	1		
		2E/Bt	86-150	94	6	0		
10.00	68.00	Ap	0-15	67	15	18	12	Osh.
		E	15-51	61	19	20		
		2Bt1	51-99	88	12	0		
		3E/Bt	99-150	94	6	0		

East meters	North meters	Horizon	Depth cm	Percent Sand	Percent Clay	Percent Silt	Control Section Clay %	Soil Series
12.00	68.00	Ap	0-15	71	14	15	29	Kal.
		Bt1	15-66	54	29	17		
		2Bt2	66-117	91	9	0		
		3E/Bt	117-150	94	6	0		
14.00	68.00	Ap	0-15	69	14	17	11	Osh.
		Bt1	15-102	89	11	0		
		2E/Bt	102-150	94	6	0		
16.00	68.00	Ap	0-15	69	14	17	10	Osh.
		2Bt1	15-117	90	10	0		
		2E/Bt	117-150	94	6	0		
18.00	68.00	Ap	0-15	71	13	16	12	Osh.
		Bt1	15-137	88	12	0		
		2E/Bt	137-150	94	6	0		
20.00	68.00	Ap	0-15	47	19	34	20	Kal.
		2Bt1	15-117	80	20	0		
		3E/Bt	117-150	94	6	0		
22.00	68.00	Ap	0-18	59	20	21	15	Osh.
		2Bt1	18-56	83	15	2		
		3E/Bt	56-150	94	6	0		
24.00	68.00	Ap	0-20	55	19	26	12	Osh.
		2Bt1	20-75	88	12	0		
		3E/Bt	75-150	94	6	0		
26.00	68.00	Ap	0-23	49	19	32	18	Kal.
		Bt1	23-46	63	28	9		
		2Bt2	46-124	86	10	4		
		3E/Bt	124-150	94	6	0		
28.00	68.00	Ap	0-20	51	19	30	18	Kal.
		Bt1	20-56	77	21	2		
		2Bt2	56-84	86	10	4		
		3E/Bt	84-150	94	6	0		
30.00	68.00	Ap	0-15	29	24	47	17	Osh.
		Bt1	15-43	65	21	14		
		2Bt2	43-71	87	13	0		
		3E/Bt	71-150	94	6	0		
32.00	68.00	Ap	0-15	51	19	30	18	Kal.
		Bt1	15-58	79	19	2		
		2Bt2	58-86	87	13	0		
		3E/Bt	86-150	94	6	0		
34.00	68.00	Ap	0-15	50	19	0	33	Kal.
		Bt1	15-63	35	34	31		
		2Bt2	63-94	86	14	0		
		3E/Bt	94-173	94	6	0		

APPENDIX B

Soil Moisture Retention Input for CERES Maize Simulation of Soil-Water Cotent.

APPENDIX B

Volumetric soil moisture retention input for CERES Maize simulation of soil-water content for the south 52 meters of the grid. The southwest corner of the field is the origin of the sample points at 0 meters in the east and north directions.

Sample point location

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
0.00	0.00	Ap	0-33	0.096	0.291
		E	33-50	0.12	0.299
		Bt1	50-71	0.036	0.221
		Bt2	71-107	0.080	0.208
		2Bt3	107-150	0.036	0.196
2.00	0.00	Ap	0-23	0.092	0.292
		E	23-40	0.092	0.302
		Bt1	40-64	0.132	0.274
		Bt2	64-97	0.072	0.193
		2Bt3	97-150	0.044	0.148
4.00	0.00	Ap	0-23	0.088	0.267
		E	23-40	0.088	0.278
		Bt1	40-64	0.112	0.269
		Bt2	64-97	0.088	0.206
		2Bt3	97-150	0.040	0.174
6.00	0.00	Ap	0-23	0.084	0.269
		Bt1	23-58	0.124	0.280
		2Bt2	58-122	0.060	0.190
		3E/Bt	122-150	0.024	0.116
8.00	0.00	Ap	0-20	0.084	0.262
		E	20-28	0.116	0.290
		Bt1	28-58	0.140	0.214
		2Bt2	58-86	0.064	0.123
		3E/Bt	86-150	0.024	0.120

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
10.00	0.00	Ap	0-20	0.084	0.263
		Bt1	20-40	0.144	0.274
		Bt2	40-53	0.084	0.162
		2Bt3	53-91	0.044	0.137
		3E/Bt	91-150	0.024	0.109
12.00	0.00	Ap	0-20	0.088	0.266
		Bt1	20-46	0.148	0.295
		Bt2	46-64	0.088	0.211
		2Bt3	64-122	0.064	0.169
		3E/Bt	122-150	0.024	0.118
14.00	0.00	Ap	0-23	0.092	0.274
		Bt1	23-43	0.112	0.292
		Bt2	43-56	0.084	0.182
		2Bt3	56-104	0.052	0.106
		3E/Bt	104-150	0.024	0.101
16.00	0.00	Ap	0-23	0.096	0.274
		Bt1	23-43	0.132	0.283
		Bt2	43-58	0.080	0.205
		2Bt3	58-102	0.052	0.120
		3E/Bt	102-150	0.024	0.096
18.00	0.00	Ap	0-20	0.104	0.267
		Bt1	20-43	0.112	0.265
		Bt2	43-61	0.084	0.154
		2Bt3	61-122	0.040	0.107
		3E/Bt	122-150	0.024	0.096
20.00	0.00	Ap	0-23	0.092	0.265
		Bt1	23-38	0.124	0.276
		2Bt2	38-74	0.048	0.142
		3E/Bt	74-150	0.024	0.081
22.00	0.00	Ap	0-23	0.092	0.260
		Bt1	23-38	0.108	0.241
		2Bt2	38-79	0.040	0.096
		3E/Bt	79-150	0.024	0.085
24.00	0.00	Ap	0-25	0.084	0.259
		Bt1	25-43	0.116	0.233
		2Bt2	43-74	0.048	0.120
		3E/Bt	74-150	0.024	0.076
26.00	0.00	Ap	0-28	0.084	0.256
		Bt1	28-50	0.100	0.240
		2Bt2	50-75	0.040	0.160
		3E/Bt	75-150	0.024	0.093

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
28.00	0.00	Ap	0-23	0.088	0.264
		Bt1	23-38	0.100	0.235
		2Bt2	38-86	0.064	0.179
		3E/Bt	86-150	0.024	0.121
30.00	0.00	Ap	0-23	0.084	0.263
		Bt1	23-36	0.116	0.262
		Bt2	36-48	0.080	0.159
		2Bt3	48-137	0.044	0.121
		3E/Bt	137-150	0.024	0.077
32.00	0.00	Ap	0-20	0.080	0.255
		E	20-28	0.080	0.255
		Bt1	28-48	0.136	0.288
		Bt2	48-69	0.080	0.221
		2Bt3	69-150	0.044	0.109
34.00	0.00	Ap	0-20	0.084	0.261
		E	20-28	0.084	0.287
		Bt1	28-58	0.156	0.281
		Bt2	58-91	0.080	0.190
		2Bt3	91-150	0.044	0.132
0.00	4.00	Ap	0-28	0.092	0.268
		E	28-43	0.096	0.271
		Bt1	43-84	0.124	0.290
		2Bt2	84-150	0.044	0.133
4.25	4.00	Ap	0-25	0.084	0.257
		E	25-43	0.108	0.284
		Bt1	43-69	0.128	0.298
		2Bt2	69-142	0.060	0.150
		3E/Bt	142-150	0.024	0.095
8.50	4.00	Ap	0-20	0.084	0.257
		Bt1	20-56	0.144	0.314
		2Bt2	56-91	0.056	0.144
		3E/Bt	91-150	0.024	0.095
12.75	4.00	Ap	0-23	0.088	0.259
		Bt1	23-58	0.128	0.299
		2Bt2	58-112	0.056	0.150
		3E/Bt	112-150	0.024	0.095
17.00	4.00	Ap	0-23	0.096	0.266
		Bt1	23-66	0.124	0.289
		2Bt2	66-112	0.048	0.133
		3E/Bt	112-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
21.25	4.00	Ap	0-23	0.092	0.260
		Bt1	23-53	0.116	0.279
		2Bt2	53-86	0.052	0.133
		3E/Bt	86-150	0.024	0.095
25.50	4.00	Ap	0-25	0.084	0.253
		Bt1	25-71	0.108	0.269
		2Bt2	71-102	0.044	0.133
		3E/Bt	102-150	0.024	0.095
29.75	4.00	Ap	0-23	0.084	0.256
		Bt1	23-43	0.108	0.270
		2Bt2	43-117	0.056	0.166
		3E/Bt	117-150	0.024	0.095
34.00	4.00	Ap	0-20	0.080	0.255
		Bt1	20-76	0.144	0.316
		2Bt2	76-150	0.044	0.128
0.00	8.00	Ap	0-28	0.092	0.267
		E	28-46	0.0.100	0.274
		Bt1	46-81	0.124	0.289
		2Bt2	81-150	0.048	0.144
4.25	8.00	Ap	0-25	0.084	0.257
		E	25-46	0.100	0.275
		Bt1	46-69	0.124	0.291
		2Bt2	69-132	0.052	0.139
		3E/Bt	132-150	0.024	0.095
8.50	8.00	Ap	0-23	0.084	0.257
		Bt1	23-56	0.144	0.314
		2Bt2	56-94	0.060	0.150
		3E/Bt	94-150	0.024	0.095
12.75	8.00	Ap	0-23	0.084	0.255
		Bt1	23-61	0.128	0296
		2Bt2	61-114	0.052	0.144
		3E/Bt	114-150	0.024	0.095
17.00	8.00	Ap	0-23	0.092	0.262
		Bt1	23-66	0.128	0.294
		2Bt2	66-114	0.048	0.139
		3E/Bt	114-150	0.024	0.095
21.25	8.00	Ap	0-23	0.088	0.257
		Bt1	23-56	0.120	0.283
		2Bt2	56-83	0.056	0.150
		3E/Bt	83-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
25.5	8.00	Ap	0-23	0.084	0.253
		Bt1	23-66	0.108	0.268
		2Bt2	66-109	0.044	0.133
		3E/Bt	109-150	0.024	0.095
29.75	8.00	Ap	0-23	0.076	0.246
		Bt1	23-41	0.108	0.269
		2Bt2	41-114	0.060	0.166
		3E/Bt	114-150	0.024	0.095
34.00	8.00	Ap	0-23	0.080	0.253
		Bt1	23-71	0.140	0.313
		2Bt2	71-142	0.044	0.133
		3E/Bt	142-150	0.024	0.095
0.00	12.00	Ap	0-30	0.088	0.262
		E	30-43	0.122	0.286
		Bt1	43-76	0.108	0.270
		2Bt2	76-102	0.024	0.095
		3E/Bt	102-150	0.084	0.257
4.25	12.00	Ap	0-30	0.108	0.283
		E	30-46	0.132	0.301
		Bt1	46-66	0.052	0.144
		2Bt2	66-102	0.024	0.095
		3E/Bt	102-150	0.084	0.256
8.50	12.00	Ap	0-25	0.084	0.256
		Bt1	25-58	0.144	0.313
		2Bt2	58-102	0.068	0.172
		3E/Bt	102-150	0.024	0.095
12.75	12.00	Ap	0-25	0.076	0.246
		E	25-38	0.112	0.287
		Bt1	38-63	0.128	0.292
		2Bt2	63-112	0.044	0.122
		3E/Bt	112-150	0.024	0.095
17.00	12.00	Ap	0-25	0.080	0.250
		Bt1	25-61	0.136	0.305
		2Bt2	61-117	0.052	0.150
		3E/Bt	117-150	0.024	0.095
21.25	12.00	Ap	0-20	0.088	0.257
		Bt1	20-61	0.124	0.289
		2Bt2	61-74	0.084	0.199
		3E/Bt	74-150	0.024	0.095
25.50	12.00	Ap	0-20	0.088	0.255
		Bt1	20-56	0.092	0.249
		2Bt2	56-132	0.048	0.128
		3E/Bt	132-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
29.75	12.00	Ap	0-20	0.092	0.258
		Bt1	20-61	0.096	0.253
		2Bt2	61-102	0.072	0.177
		3E/Bt	102-150	0.024	0.095
34.00	12.00	Ap	0-28	0.080	0.247
		Bt1	28-61	0.080	0.199
		2Bt2	61-117	0.052	0.139
		3E/Bt	117-150	0.024	0.095
0.00	16.00	Ap	0-33	0.092	0.264
		E	33-46	0.112	0.286
		Bt1	46-79	0.108	0.270
		2Bt2	79-109	0.068	0.188
		3E/Bt	109-150	0.024	0.095
4.25	16.00	Ap	0-28	0.084	0.256
		E	28-36	0.112	0.290
		Bt1	36-66	0.140	0.311
		2Bt2	66-104	0.068	0.194
		3E/Bt	104-150	0.024	0.095
8.50	16.00	Ap	0-28	0.076	0.244
		Bt1	28-63	0.140	0.310
		2Bt2	63-102	0.060	0.161
		3E/Bt	102-150	0.024	0.095
12.75	16.00	Ap	0-25	0.076	0.245
		Bt1	25-66	0.132	0.305
		2Bt2	66-104	0.056	0.161
		3E/Bt	104-150	0.024	0.095
17.00	16.00	Ap	0-20	0.080	0.245
		Bt1	20-56	0.124	0.292
		2Bt2	56-127	0.044	0.139
		3E/Bt	127-150	0.024	0.095
21.25	16.00	Ap	0-25	0.084	0.249
		Bt1	25-61	0.124	0.290
		2Bt2	61-137	0.060	0.166
		3E/Bt	137-150	0.024	0.095
25.50	16.00	Ap	0-20	0.092	0.256
		Bt1	20-43	0.088	0.244
		2Bt2	43-79	0.044	0.122
		3E/Bt	79-150	0.024	0.095
29.75	16.00	Ap	0-20	0.096	0.262
		Bt1	20-43	0.100	0.259
		2Bt2	43-122	0.060	0.155
		3E/Bt	122-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
34.00	16.00	Ap	0-20	0.084	0.253
		Bt1	20-61	0.092	0.254
		2Bt2	61-114	0.048	0.144
		3E/Bt	114-150	0.024	0.095
0.00	20.00	Ap	0-28	0.096	0.225
		Bt1	28-69	0.132	0.251
		2Bt2	69-124	0.068	0.190
		3E/Bt	124-150	0.024	0.095
4.25	20.00	Ap	0-28	0.084	0.211
		E	28-41	0.112	0.242
		Bt1	41-69	0.132	0.253
		2Bt2	69-117	0.088	0.206
		3E/Bt	117-150	0.024	0.095
8.50	20.00	Ap	0-23	0.076	0.201
		E	23-38	0.120	0.248
		Bt1	38-69	0.140	0.258
		2Bt2	69-119	0.056	0.151
		3E/Bt	119-150	0.024	0.095
12.75	20.00	Ap	0-23	0.076	0.199
		E	23-38	0.076	0.199
		Bt1	38-75	0.116	0.232
		2Bt2	75-109	0.052	0.151
		3E/Bt	109-150	0.024	0.095
17.00	20.00	Ap	0-20	0.088	0.211
		Bt1	20-58	0.124	0.240
		2Bt2	58-102	0.060	0.163
		3E/Bt	102-150	0.024	0.095
21.25	20.00	Ap	0-20	0.088	0.206
		Bt1	20-50	0.080	0.202
		2Bt2	50-86	0.036	0.112
		3E/Bt	86-150	0.024	0.095
25.50	20.00	Ap	0-20	0.100	0.219
		Bt1	20-50	0.084	0.195
		2Bt2	50-94	0.036	0.112
		3E/Bt	94-150	0.024	0.095
29.75	20.00	Ap	0-23	0.096	0.218
		Bt1	23-48	0.108	0.218
		2Bt2	48-91	0.052	0.147
		3E/Bt	91-150	0.024	0.095
34.00	20.00	Ap	0-23	0.092	0.213
		Bt1	23-46	0.112	0.223
		2Bt2	46-74	0.044	0.128
		3E/Bt	74-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
0.00	24.00	Ap	0-33	0.096	0.226
		E	33-48	0.124	0.252
		Bt1	48-71	0.116	0.232
		2Bt2	71-119	0.052	0.151
		3E/Bt	119-150	0.024	0.095
4.25	24.00	Ap	0-30	0.092	0.216
		E	30-48	0.120	0.250
		Bt1	48-71	0.136	0.260
		2Bt2	71-112	0.076	0.213
		3E/Bt	112-150	0.024	0.095
8.50	24.00	Ap	0-30	0.080	0.205
		Bt1	30-51	0.124	0.244
		2Bt2	51-114	0.052	0.144
		3E/Bt	114-150	0.024	0.095
12.75	24.00	Ap	0-23	0.080	0.204
		Bt1	23-71	0.132	0.250
		2Bt2	71-102	0.056	0.155
		3E/Bt	102-150	0.024	0.095
17.00	24.00	Ap	0-20	0.088	0.211
		Bt1	20-53	0.144	0.264
		2Bt2	53-150	0.068	0.179
21.25	24.00	Ap	0-18	0.092	0.214
		Bt1	18-32	0.120	0.232
		2Bt2	32-150	0.060	0.171
25.50	24.00	Ap	0-23	0.100	0.222
		Bt1	23-66	0.092	0.204
		2Bt2	66-104	0.032	0.116
		3E/Bt	104-150	0.024	0.095
29.75	24.00	Ap	0-23	0.108	0.232
		Bt1	23-46	0.116	0.228
		2Bt2	46-104	0.052	0.159
		3E/Bt	104-150	0.024	0.095
34.00	24.00	Ap	0-20	0.092	0.212
		Bt1	20-41	0.104	0.216
		2Bt2	41-114	0.052	0.151
		3E/Bt	114-150	0.024	0.095
0.00	28.00	Ap	0-25	0.104	0.232
		E	25-46	0.124	0.252
		Bt1	46-71	0.132	0.248
		2Bt2	71-150	0.052	0.159

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
4.25	28.00	Ap	0-28	0.088	0.212
		E	28-43	0.108	0.232
		Bt1	43-66	0.108	0.221
		2Bt2	66-102	0.056	0.155
		3E/Bt	102-150	0.024	0.095
8.50	28.00	Ap	0-20	0.076	0.200
		E	20-36	0.124	0.253
		Bt1	36-63	0.136	0.253
		2Bt2	63-150	0.056	0.155
12.75	28.00	Ap	0-20	0.076	0.200
		E	20-33	0.116	0.244
		Bt1	33-66	0.140	0.259
		2Bt2	66-107	0.048	0.147
		3E/Bt	107-150	0.024	0.095
17.00	28.00	Ap	0-30	0.084	0.207
		E	30-56	0.092	0.218
		Bt1	56-107	0.104	0.218
		2Bt2	107-150	0.040	0.120
21.25	28.00	Ap	0-15	0.092	0.212
		Bt1	15-69	0.104	0.213
		2Bt2	69-102	0.040	0.124
		3E/Bt	102-150	0.024	0.095
25.50	28.00	Ap	0-15	0.096	0.217
		Bt1	15-50	0.116	0.225
		2Bt2	50-102	0.036	0.120
		3E/Bt	102-150	0.024	0.095
29.75	28.00	Ap	0-23	0.100	0.221
		Bt1	23-46	0.116	0.227
		2Bt2	46-89	0.072	0.186
		3E/Bt	89-150	0.024	0.095
34.00	28.00	Ap	0-23	0.096	0.218
		Bt1	23-53	0.116	0.229
		2Bt2	53-104	0.048	0.140
		3E/Bt	104-150	0.024	0.095
0.00	32.00	Ap	0-33	0.088	0.217
		E	33-38	0.112	0.242
		Bt1	38-91	0.128	0.250
		2Bt2	91-150	0.092	0.217

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
4.25	32.00	Ap	0-33	0.084	0.209
		E	33-53	0.104	0.230
		Bt1	53-69	0.128	0.244
		2Bt2	69-97	0.068	0.186
		3E/Bt	97-150	0.024	0.095
8.50	32.00	Ap	0-20	0.084	0.208
		E	20-33	0.084	0.208
		Bt1	33-74	0.140	0.256
		2Bt2	74-150	0.068	0.182
12.75	32.00	Ap	0-18	0.088	0.202
		Bt1	18-69	0.124	0.242
		2Bt2	69-138	0.056	0.163
		3E/Bt	138-150	0.024	0.095
17.00	32.00	Ap	0-18	0.092	0.210
		Bt1	18-48	0.124	0.240
		2Bt2	48-94	0.052	0.163
		3E/Bt	94-150	0.024	0.095
21.25	32.00	Ap	0-20	0.100	0.221
		Bt1	20-48	0.116	0.227
		2Bt2	48-150	0.032	0.104
25.50	32.00	Ap	0-20	0.100	0.221
		Bt1	20-40	0.092	0.203
		2Bt2	40-150	0.036	0.120
29.75	32.00	Ap	0-20	0.096	0.217
		Bt1	20-53	0.116	0.228
		2Bt2	53-107	0.048	0.136
		3E/Bt	107-150	0.024	0.095
34.00	32.00	Ap	0-20	0.100	0.223
		Bt1	20-48	0.132	0.247
		2Bt2	48-150	0.044	0.128
0.00	36.00	Ap	0-28	0.100	0.228
		E	28-41	0.116	0.246
		Bt1	41-79	0.144	0.263
		2Bt2	79-97	0.076	0.206
		3E/Bt	97-150	0.024	0.095
4.25	36.00	Ap	0-25	0.076	0.205
		E	25-38	0.124	0.251
		Bt1	38-61	0.124	0.239
		2Bt2	61-114	0.044	0.136
		3E/Bt	114-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
8.50	36.00	Ap	0-23	0.084	0.208
		E	23-33	0.084	0.208
		Bt1	33-58	0.136	0.254
		2Bt2	58-104	0.056	0.155
		3E/Bt	104-150	0.024	0.095
12.75	36.00	Ap	0-20	0.084	0.208
		Bt1	20-43	0.120	0.233
		2Bt2	43-91	0.048	0.143
		3E/Bt	91-150	0.024	0.095
17.00	36.00	Ap	0-23	0.096	0.217
		Bt1	23-38	0.120	0.242
		2Bt2	38-89	0.084	0.217
		3E/Bt	89-150	0.024	0.095
21.25	36.00	Ap	0-23	0.096	0.216
		Bt1	23-114	0.072	0.194
		3E/Bt	114-150	0.024	0.095
25.50	36.00	Ap	0-15	0.092	0.214
		Bt1	15-30	0.116	0.229
		2Bt2	30-150	0.052	0.144
29.75	36.00	Ap	0-20	0.092	0.215
		Bt1	20-56	0.112	0.226
		2Bt2	56-117	0.052	0.147
		3E/Bt	117-150	0.024	0.095
34.00	36.00	Ap	0-18	0.092	0.217
		Bt1	18-38	0.116	0.232
		2Bt2	38-119	0.056	0.151
		3E/Bt	119-150	0.024	0.095
0.00	40.00	Ap	0-25	0.092	0.220
		E	25-36	0.120	0.248
		Bt1	36-56	0.144	0.261
		2Bt2	56-122	0.076	0.209
		3E/Bt	122-150	0.024	0.095
4.25	40.00	Ap	0-20	0.084	0.209
		E	20-28	0.128	0.254
		Bt1	28-56	0.144	0.263
		2Bt2	56-102	0.060	0.159
		3E/Bt	102-150	0.024	0.095
8.50	40.00	Ap	0-18	0.088	0.210
		Bt1	18-46	0.132	0.248
		2Bt2	46-109	0.064	0.178
		3E/Bt	109-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
12.75	40.00	Ap	0-15	0.088	0.211
		Bt1	15-36	0.120	0.234
		2Bt2	36-94	0.044	0.128
		3E/Bt	94-150	0.024	0.095
17.00	40.00	Ap	0-13	0.092	0.214
		Bt1	13-36	0.116	0.230
		2Bt2	36-79	0.088	0.198
		3E/Bt	79-150	0.024	0.095
21.25	40.00	Ap	0-18	0.092	0.211
		Bt1	18-33	0.092	0.203
		2Bt2	33-84	0.072	0.190
		3E/Bt	84-150	0.024	0.095
25.50	40.00	Ap	0-23	0.092	0.212
		Bt1	23-46	0.124	0.237
		2Bt2	46-114	0.052	0.147
		3E/Bt	114-150	0.024	0.095
29.75	40.00	Ap	0-18	0.084	0.207
		Bt1	18-46	0.124	0.237
		2Bt2	46-79	0.052	0.147
		3E/Bt	79-150	0.024	0.095
34.00	40.00	Ap	0-18	0.084	0.207
		Bt1	18-56	0.120	0.233
		2Bt2	56-119	0.068	0.201
		3E/Bt	119-150	0.024	0.095
0.00	44.00	Ap	0-28	0.084	0.213
		Bt1	28-58	0.128	0.245
		2Bt2	58-122	0.036	0.112
		3E/Bt	122-150	0.024	0.095
4.25	44.00	Ap	0-25	0.072	0.198
		Bt1	25-56	0.120	0.237
		2Bt2	56-112	0.060	0.174
		3E/Bt	112-150	0.024	0.095
8.50	44.00	Ap	0-25	0.076	0.201
		Bt1	25-53	0.124	0.239
		2Bt2	53-99	0.068	0.186
		3E/Bt	99-150	0.024	0.095
12.75	44.00	Ap	0-20	0.084	0.206
		Bt1	20-58	0.128	0.243
		2Bt2	58-117	0.040	0.120
		3E/Bt	117-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
17.00	44.00	Ap	0-18	0.088	0.210
		Bt1	18-48	0.128	0.243
		2Bt2	48-102	0.084	0.221
		3E/Bt	102-150	0.024	0.095
21.25	44.00	Ap	0-20	0.084	0.204
		Bt1	20-38	0.084	0.205
		2Bt2	38-84	0.060	0.163
		3E/Bt	84-150	0.024	0.095
25.50	44.00	Ap	0-18	0.084	0.205
		Bt1	18-50	0.116	0.228
		2Bt2	50-124	0.044	0.128
		3E/Bt	124-150	0.024	0.095
29.75	44.00	Ap	0-20	0.080	0.200
		Bt1	20-50	0.068	0.182
		2Bt2	50-107	0.056	0.151
		3E/Bt	107-150	0.024	0.095
34.00	44.00	Ap	0-20	0.084	0.205
		Bt1	20-69	0.116	0.228
		2E/Bt	69-150	0.024	0.095
0.00	48.00	Ap	0-28	0.088	0.216
		E	28-38	0.124	0.252
		Bt1	38-74	0.140	0.259
		2Bt2	74-117	0.076	0.202
		3E/Bt	117-150	0.024	0.095
4.25	48.00	Ap	0-23	0.076	0.200
		E	23-36	0.124	0.252
		Bt1	36-61	0.132	0.247
		2Bt2	61-119	0.068	0.182
		3E/Bt	119-150	0.024	0.095
8.50	48.00	Ap	0-23	0.076	0.201
		Bt1	23-56	0.124	0.243
		2Bt2	56-112	0.068	0.182
		3E/Bt	112-150	0.024	0.095
12.75	48.00	Ap	0-20	0.080	0.203
		Bt1	20-48	0.132	0.246
		2Bt2	48-97	0.052	0.144
		3E/Bt	97-150	0.024	0.095
17.00	48.00	Ap	0-20	0.084	0.208
		Bt1	20-48	0.132	0.249
		2Bt2	48-112	0.040	0.124
		3E/Bt	112-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
21.25	48.00	Ap	0-23	0.084	0.206
		Bt1	23-41	0.112	0.224
		2Bt2	41-150	0.028	0.097
25.5	48.00	Ap	0-20	0.084	0.206
		Bt1	20-46	0.108	0.219
		2Bt2	46-122	0.104	0.264
		3E/Bt	122-150	0.024	0.095
29.75	48.00	Ap	0-23	0.088	0.209
		Bt1	23-38	0.120	0.232
		2Bt2	38-122	0.064	0.175
		3E/Bt	122-150	0.024	0.095
34.00	48.00	Ap	0-18	0.084	0.207
		Bt1	18-48	0.112	0.225
		2Bt2	48-86	0.044	0.128
		3E/Bt	86-150	0.024	0.095
0.00	52.00	Ap	0-25	0.088	0.262
		E	25-36	0.100	0.272
		Bt1	36-63	0.108	0.270
		2Bt2	63-112	0.057	0.183
		3E/Bt	112-150	0.024	0.095
4.25	52.00	Ap	0-25	0.076	0.245
		E	25-38	0.112	0.287
		Bt1	38-66	0.120	0.283
		2Bt2	66-114	0.040	0.128
		3E/Bt	114-150	0.024	0.095
8.50	52.00	Ap	0-25	0.076	0.245
		E	25-38	0.112	0.286
		Bt1	38-58	0.120	0.285
		2Bt2	58-107	0.052	0.166
		3E/Bt	107-150	0.024	0.095
12.75	52.00	Ap	0-23	0.080	0.249
		E	23-33	0.116	0.291
		Bt1	33-61	0.120	0.290
		2Bt2	61-102	0.049	0.155
		3E/Bt	102-150	0.024	0.095
17.00	52.00	Ap	0-23	0.088	0.257
		E	23-30	0.120	0.294
		Bt1	30-61	0.152	0.319
		2Bt2	61-97	0.050	0.161
		3E/Bt	97-150	0.024	0.095

East meters	North meters	Horizon	Depth cm	Water Content -15 bar (mm)	Water Content -1/3 bar (mm)
21.25	52.00	Ap	0-18	0.084	0.250
		Bt1	18-41	0.112	0.271
		2Bt2	41-112	0.032	0.106
		3E/Bt	112-150	0.024	0.095
25.50	52.00	Ap	0-18	0.092	0.259
		Bt1	18-61	0.100	0.259
		2Bt2	61-150	0.035	0.111
29.74	52.00	Ap	0-18	0.084	0.249
		Bt1	18-36	0.120	0.281
		2Bt2	36-79	0.052	0.166
		3E/Bt	79-150	0.024	0.095
34.00	52.00	Ap	0-20	0.088	0.260
		Bt1	20-48	0.116	0.279
		2Bt2	48-127	0.045	0.144
		3E/Bt	127-150	0.084	0.249