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Best wishes,
Wierenga

Variation of soil and vegetation with distance along a transect in the Chihuahuan Desert*

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The number of systematic studies of the coincidence of soil and vegetation zones in arid areas is relatively limited. In this study the spatial variability of soil morphological characteristics, soil moisture and vegetation were determined along a 3-km transect in the Chihuahuan Desert in southern New Mexico. There is extensive spatial variability in soil physical properties, in water content and in vegetation along the transect. However, using a multivariate technique, it was found that this spatial variability could be partitioned into distinct zones. The boundaries between zones based on soil morphological characteristics coincide closely with boundaries based on soil water content and those based on vegetation. It is concluded that the multivariate moving split-window technique is a valuable tool for evaluating soil and vegetation boundaries along transects.

Introduction

Studies of soil and vegetation in arid and semi-arid areas have shown large spatial variations that result from differences in many factors affecting soil and vegetation. The number of systematic studies of the variation in soil properties and vegetation in arid areas, however, is limited. For the North American Southwest, El-Ghonemy, Wallace *et al.* (1980) studied soil–plant patterns in the Mojave Desert–Great Basin Desert interface. Phillips & MacMahon (1978) and Key, Delph *et al.* (1984) found strong vegetation–soil relationships along Sonoran Desert transects and Stein & Ludwig (1979) delimited four vegetation–soil groups along a Chihuahuan Desert transect.

During the past 10 years, several studies have been made of the variation in soil properties of agricultural soils. These studies have shown that many soil properties are log-normally distributed (Nielsen, Biggar *et al.*, 1973) while other properties are normally distributed. It has also been shown, through the use of geostatistical methods of analysis, that many properties are spatially dependent, i.e. that soil and vegetation are more alike when measurement points are close together rather than far apart (Peck, 1983). The distance over which properties are related, the range of influence or integral scale of many

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soil physical properties and vegetation, varies greatly, however (Warrick, Myers *et al.*, 1986). Few measurements have been made of the distribution and spatial dependence of soil properties and vegetation in arid areas.

This study is directed toward a better understanding of the spatial variability of soil morphological characteristics, soil moisture and vegetation along a 3-km transect in the Chihuahuan Desert in southern New Mexico. This study is part of the Long-Term Ecological Research Program (LTER) of the National Science Foundation, in response to the need for continuous long-term data to evaluate the effects of human perturbations on the stability and productivity of major ecosystems in the United States. A large number of biotic and abiotic variables are being measured at regular time intervals along the LTER transect. This paper presents a site description and gives the variation in soil morphological characteristics, soil water and vegetation along the transect observed during the first 2 years (spring 1982–spring 1984). Future papers will deal with the other variables measured along the transect.

Methods and materials

Site description

The study was conducted on the New Mexico State University College ranch, 40 km northeast of Las Cruces, NM. All measurements were taken along a 2,700 m transect extending northeast from the east slope of Summerford Mountain downward into an ephemeral dry lake (*playa*). Summerford Mountain is at the north end of the Dona Ana Mountains. The Dona Ana Mountains form a domal uplift complex of the younger rhyolitic and the older andesitic volcanics intruded by monzonite (Gile, Hawley *et al.*, 1970). Summerford Mountain is late mid-Tertiary igneous monzonite. The study area transect traverses three basic landforms with their associated surfaces. It starts on the steep, rocky slopes of Mount Summerford, traverses piedmont and basin slopes and ends in a basin *playa* (Fig. 1). The mountain slopes are undifferentiated rocklands. The geomorphic sediments bordering the mountain slopes have young soils (2,500–1,000 years B.C.) of the Hawkeye series (sandy Aridic Entic Haplustolls) and Aladdin series (coarse-loamy Aridic Entic Haplustolls). The sediments on the mid-piedmont slopes also have young soils (6,500–4,000 years B.C.) of the Dona Ana and Onite series (coarse-loamy Typic Haplargids) while sediments on the lower piedmont slopes are older soils (mid–late Pleistocene) dominated by the Berino and Bucklebar series (fine-loamy Typic Haplargids). The lake tank surface of the *playa* has soils of Holocene age. These soils are dominantly of the Dalby tax adjunct series (fine-mixed Typic Torrerts).

The geological features, geomorphic surfaces, soil series and vegetation types covered by the transects in this study are typical of many areas of southern New Mexico, and are similar to arid and semi-arid areas of the southwestern United States and northern Mexico.

Climate in the region is characterized by an abundance of sunshine, low relative humidity and an average Class A pan evaporation of 239 cm per year (Malm & Houghton, 1977). Rainfall is extremely variable. Average annual precipitation is 23 cm with 52% of the rainfall occurring between 1 July and 30 September. The average maximum air temperature is highest in June at 36°C, and lowest in January at 13°C.

Data collection

Measurement stations were established at 30-m intervals along the 2,700 m long transect. Rainfall and maximum and minimum air temperature were measured at each station at 1-week intervals, and soil moisture at 2-week intervals. Rainfall was measured with funnel-type rain gauges. Oil prevented evaporation from the gauges. Air temperature was

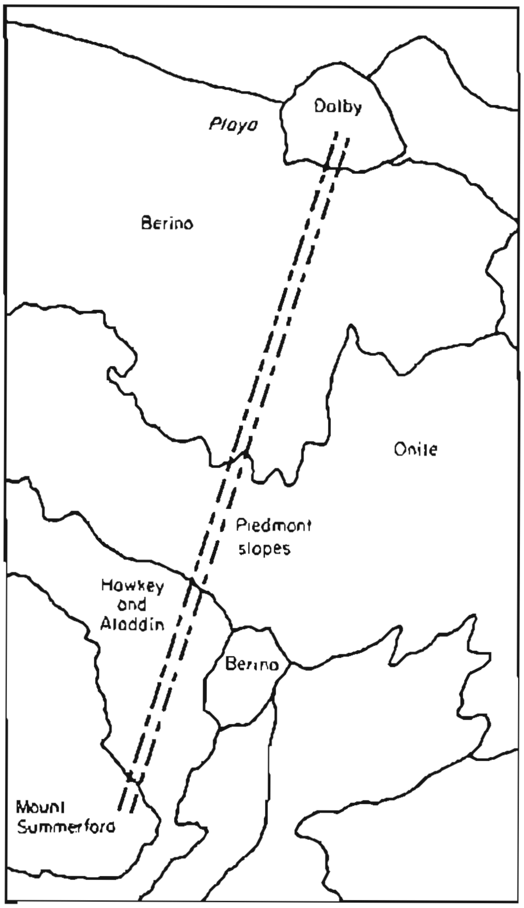

Figure 1. Landforms and geomorphic surfaces traversed by the long-term monitoring transects on the New Mexico State University college ranch.

measured with maximum and minimum thermometers. Soil moisture was measured with a neutron probe at depths of 30, 60, 90, 110 and 130 cm below the soil surface. Near the centre of the transect, solar radiation, precipitation, wind speed and direction, relative humidity, air temperature and soil temperature at 1, 5, 10, 20, 50, 100 and 200 cm are measured continuously. Average values are recorded at hourly intervals on cassette tape. The cassette tapes are subsequently read into a computer for further analysis.

Concrete blocks were placed along the entire transect to serve as a walkway, and to prevent development of a path and subsequent erosion. Traffic is confined to this walkway and, after 2 years, no signs of human-caused surface erosion are evident. Elevations along the transect were also measured. The difference in elevation between the southwest end of the transect, at the base of Mount Summerford, and the northeast end, in the playa, is 94 m. The elevation of the playa is 1,150 m. The slope along the transect is generally smooth, but is steepest near Mount Summerford.

Soil texture was determined on soil samples taken at 30, 60, 90 and 120 cm depth on a parallel transect 7 m to the northwest side of the main transect. Particle size distribution was determined with the pipette method, and sand fractions were separated by sieving (Day, 1965). Vegetation data were from 30-m lines perpendicular to the study transect at each of the 91 sampling stations, 30 m apart along the 2,700 m transect. Along each line, the intercept of living plant canopy was measured. From the intercept measurements, the absolute ground cover of each species occurring along the study transect was estimated. Intercept measurements are made twice a year, once in the spring to monitor growth following any winter rains and again in the fall after the summer rainy season. This study reports only the patterns of perennial vegetation measured in the fall of 1983. The perennial shrub, grass and forb cover is relatively constant from year to year. The greatest variation is in the cover of annual plants.

Data analysis

Neutron meter readings were converted to volumetric water contents using one calibration curve for the whole transect. The calibration curve was verified by determining the water content in 150 cm deep lysimeters, 91 cm in diameter, which were filled with soil from the transect and had known bulk density and volumetric water contents. Three of these lysimeters were constructed along the transect.

To differentiate zones along the transect having similar properties, we used the multivarite 'moving split-window' technique proposed by Webster (1973). The advantage of the technique is that the positioning of observations is taken into account, so a clear boundary between zones is obtained. With this technique, two adjacent sections (split window) of the transect, each consisting of n observations, are compared using the Hotelling–Lawley trace. The split window is moved along the transect and the position where the value of the Hotelling–Lawley trace, or its F-value, reaches a maximum is considered the optimal location of a boundary.

When small window widths are applied, more observations are recorded at each position than there are positions exposed. As a result, matrices calculated directly from the complete set of observations are overdefined and the Hotelling–Lawley trace cannot be calculated. To overcome this difficulty, the original data set is reduced to a smaller data set with principal component analysis in the same manner as described by Webster (1973). Another approach is to calculate a Euclidean distance between the two adjacent sections of the transect. With this approach, the number of observations at each position does not interfere with the calculations. The moving split-window technique with principal component analysis was applied to the texture data, as well as to the moisture content data. The Euclidean distance calculation was used for the vegetation data.

Results and discussion

Soil texture

The variation in clay content and percent sand along the transect is shown in Fig. 2 for the 0–30 cm depth. Texture information for the 30–60, 60–90 and 90–120 cm depths has been presented elsewhere (Nash, 1985). Note the sharp boundary at position 7 between the *playa* soil and the soil along the rest of the transect. Except for the high clay content in the *playa* (a Typic Torrerts, fine-mixed thermic: see Nash, 1985), the soil along the transect contains 75% or more sand. Based upon these texture data and additional information including pH, percent $CaCO_3$ and percent organic matter, a total of eight soil series were described along the transect (Table 1). The moving split-window technique was used to determine discontinuities in clay and sand contents at 30, 60 and 90 cm depths along the transect. Figure 3*a* plots the F-value for clay contents at 30, 60 and 90 cm versus position number for a window width of eight, while Fig. 3*b* shows the same for the sand contents at 30, 60 and 90 cm. Note the change at position 7 from the *playa* soil to the sandy soil outside the *playa*. Changes are most visible using a window width of eight (four transect positions compared with the adjacent four transect positions), although widths of 16, 24 and 32 were also examined.

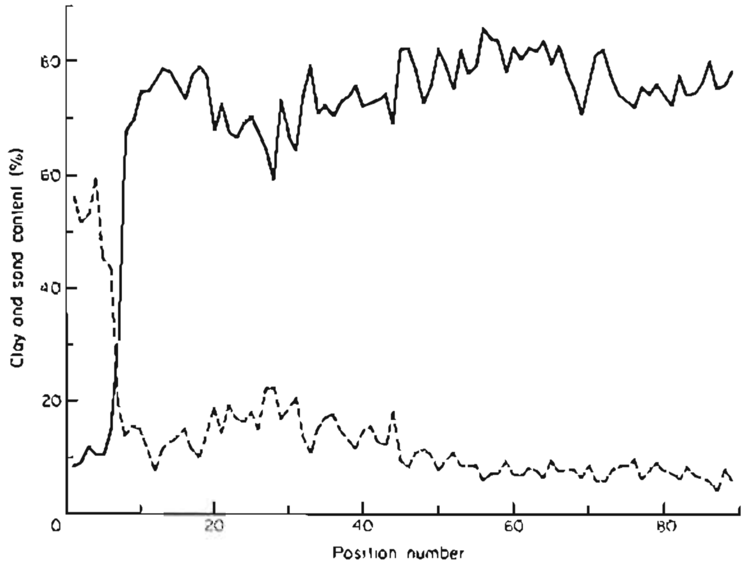

Figure 2. Variation in clay content (---) and percent sand (——) along transect at 0–30 cm depth.

Table 1. *Major soil series and station position and classification along the transect*

Zone		Stations		Classification*
No.	Series	Range	No.	
1	Dalby	1–6	6	Typic Torrerts, fine
2	Headquarter variant	7	1	Ustollic Haplargid, fine–loamy
3	Headquarter	8–10	3	Ustollic Haplargid, fine–loamy
4	Bucklebar	11–25	15	Typic Haplargid, fine–loamy
5	Berino	26–45	20	Typic Haplargid, fine–loamy
6	Onite	46–55	10	Typic Haplargid, coarse–loamy
7	Dona Ana	56–70	15	Typic Haplargid, coarse–loamy
8	Aladdin	71–89	19	Torriorthentic Haplustoll, coarse–loamy
9	Rockland	90–91	2	Rockland

* All soils have mixed mineralogy and thermic temperature regimes.

Other major changes in soil texture along the transect appear at positions 58 and 66 for the clay content and at positions 28, 61 and 70 for the sand content. Comparing these texture boundaries with those obtained from the soil survey (Table 1), changes in soil series are noted at positions 7, 25, 55 and 70 from the survey, as compared to positions 8, 28, 58, 61, 66 and 70 from the multivariate analysis. This shows good agreement between the two methods and justification for using multivariate analysis to evaluate transects used in soil survey.

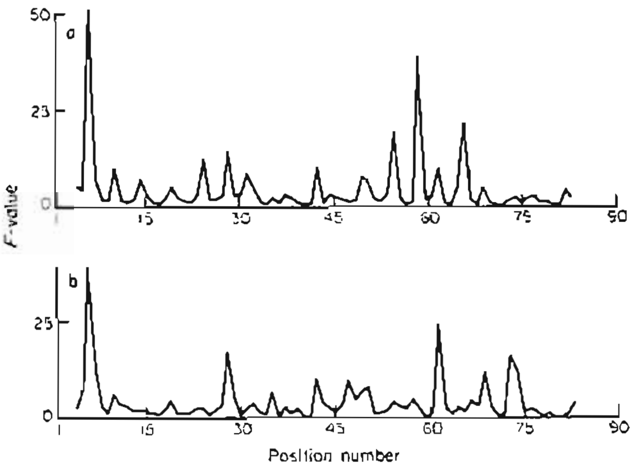

Figure 3. *F*-values for clay content (*a*) and sand content (*b*) for the 30, 60 and 90 cm depths versus distance along transect for a window width of eight.

Vegetation

Seven vegetation zones (Table 2) were delimited by locating ecotones along the transect using the moving split-window technique (Fig. 4). A window width of eight was used, giving results essentially identical to widths of four, six, 10 and 12. A Euclidean distance was calculated between two adjacent sets of four transect positions (the split window) based on the cover of 19 species (Table 3).

Vegetation zone 1 occurs in the bottom of the small ephemeral lake (*playa*) and is characterized by the C4 perennial vine–mesquite grass, *Panicum obtusum* (Table 3). Two perennial forbs, *Helianthus ciliaris* and *Sida leprosa*, occur only on the clay soils of the *playa* bottom. Vegetation zone 1 encompasses sampling stations 1–7.

Vegetation zone 2 is characterized by honey mesquite, *Prosopis glandulosa*, as a narrow fringe around the playa (sample stations 8–10). Vine–mesquite grass also occurs within this *playa* fringe, but is dwarfed in aspect by the shrub honey mesquite. Snakeweed, *Xanthocephalum sarothrae*, is abundant around the *playa*, which had a history of intensive livestock grazing before LTER protection in 1982.

Zone 3 is a broad stretch of relatively open grassland (stations 11–57), where original grasses, such as *Bouteloua eriopoda*, have been greatly reduced in cover (Table 3). This area of the transect also had a long history of intense livestock usage before LTER protection. However, soap-tree yucca, *Yucca elata*, is still a conspicuous component of this disturbed grassland (Smith & Ludwig, 1978). *Xanthocephalum sarothrae* maintains a relatively high cover in this zone, but perennial forbs, such as globe mallow, *Sphaeralcea subhastata*, and perennial grasses, such as red three-awn, *Aristida longiseta*, now characterize this zone.

Vegetation zone 4 is dominated by creosote bush, *Larrea tridentata*, with a mean canopy cover of about 20% (Table 3). *Zinnia grandiflora* is restricted to this zone along our study transects. This zone extends over about 15 stations (450 m) from 58 through 72, and occurs on an eroded, sandy alluvial fan (bajada).

Zone 5 above the *Larrea* zone is characterized by grassland of relatively short-lived perennial grasses, such as *Aristida hamulosa* and *Erioneuron pulchellum* (Table 3). Black grama, *Bouteloua eriopoda*, is also abundant, but this lower piedmont slope (stations 73–81) tends to be characterized by eroded–dissected soils, with broomweed, *Xanthocephalum microcephalum*, having a canopy cover of 5% in the fall of 1983.

Table 2. *Vegetation zones and station positions along the Jornada LTER control transect*

Zone		Stations	
No.	Name	Range	No.
1	*Playa*—grassland (*Panicum obtusum*)	1–7	7
2	*Playa* fringe—shrubland (*Prosopis glandulosa*)	8–10	3
3	Lower basin slope—grassland (*Aristida longiseta*)	11–57	47
4	Upper basin slope—shrubland (*Larrea tridentata*)	58–72	15
5	Lower piedmont slope—grassland (*Erioneuron pulchellum*)	73–81	9
6	Upper piedmont slope—grassland (*Bouteloua eriopoda*)	82–89	8
7	Rocky slope—shrubland (*Ericamera laricifolia*)	90–91	2

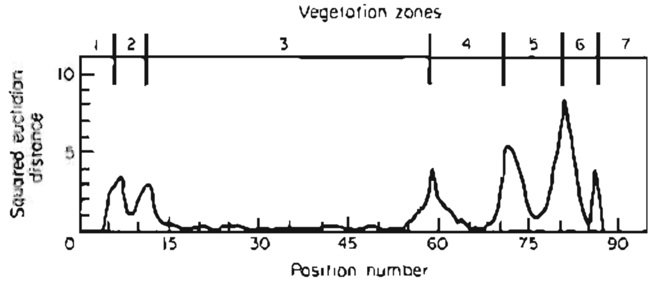

Figure 4. Squared Euclidean distance across the 91 transect stations of the LTER Jornada study transect for a window width of eight. Seven vegetation zones were distinguished along the transect.

Vegetation zone 6 is on a steeper, upper piedmont slope (stations 82–89) of coarser soils and is dominated by a relatively high canopy cover of *Bouteloua eriopoda* (Table 3). This grassland is also characterized by large but scattered clumps of prickly pear, *Opuntia phaeacantha*, and *Yucca elata*. Soils of this vegetation type have a higher organic carbon and total nitrogen content than those on lower piedmont and bajada slopes (Stein & Ludwig, 1979).

Zone 7 occurs on the steep, rocky slopes of Mount Summerford, with the end of the transect terminating in this zone (stations 90 and 91). This zone is characterized by a relatively high cover of the aromatic shrubs white sage, *Artemesia ludoviciana*, and turpentine bush, *Ericamera laricifolia* (Table 3). Scattered clumps of *Opuntia*, *Bouteloua* and *Xanthocephalum* also occur. Large plants of sotol, *Dasylirion wheeleri*, are conspicuous.

Soil moisture

The spatial variation in water content along the transect is presented in Fig. 5 for the week of 30 April–6 May 1982 (a dry period) and in Fig. 6 for the week of 22–28 January 1983 (a wet period). There is a large variation in water content along the transect at 30, 90 and 130 cm. There is a greater water content in the clay soil in the *playa* (positions 1–7), compared to sandy soils beyond position 7. Clay soils hold a much larger amount of water by adsorptive forces than do sandy soils.

The rains in the fall and winter of 1982 caused a significant increase in water content at 30 cm along the entire transect, except in the *playa*. The increase in water content at the 90 and 130 cm depths, however, was much smaller.

Figures 7 and 8 show the results of the moving split-window technique applied to the water contents at depths of 30, 60 and 90 cm along the transect during the week of 30 April–6 May 1982 (a dry period) and the week of 22–28 January 1983 (a wet period).

Table 3. *Mean cover (SE) for major perennial plants in seven vegetation zones along the Jornada LTER control transect*

	Zone						
Species	1	2	3	4	5	6	7
Helianthus ciliaris	1·3(0·7)	0	0	0	0	0	0
Sida leprosa	2·0(0·8)	0	0	0	0	0	0
Panicum obtusum	4·1(1·4)	4·6(4·6)	0	0	0	0	0
Xanthocephalum sarothrae	0	6·5(2·3)	4·2(0·5)	0·1(0·1)	0	0	0
Prosopis glandulosa	0	23·8(9·6)	0·2(0·2)	0·4(0·2)	1·9(1·2)	0	0
Sphaeralcea subhastata	0	0·2(0·2)	1·2(0·2)	0	0	0	0
Perezia nana	0	0·1	0·4(0·1)	0	0	0	0
Astragalus nuttallianus	0	0	0·4(0·1)	0	0	0	0
Baileya multiradiata	0	0	0·4(0·1)	0·1(0·1)	0	0	0
Larrea tridentata	0	0	0·1	18·7(2·6)	0	1·2(0·6)	0
Zinnia grandiflora	0	0	0	0·7(0·4)	0	0	0
Aristida longiseta	0	0	1·5(0·1)	0·2(0·1)	0·8(0·3)	0	0
Erioneuron pulchellum	0	0	1·2(0·3)	0·3(0·1)	1·7(0·5)	0·8(0·3)	0
Aristida hamulosa	0	0	0	0	2·4(0·7)	0·1	0
Xanthocephalum microcephalum	0	0	0·7(0·2)	2·7(0·8)	5·0(1·5)	0·5(0·3)	6·8(2·0)
Bouteloua eriopoda	0	0·1(0·1)	0·2(0·1)	0·6(0·6)	8·3(1·8)	33·8(2·3)	7·6(2·3)
Opuntia phaecantha	0	0	0·1	0	2·7(2·7)	3·1(2·0)	3·9(3·9)
Artemesia ludoviciana	0	0	0	0	0·2(0·1)	0·2(0·2)	5·6(2·4)
Ericamera laricifolia	0	0	0	0	0	0	7·2(7·2)

Major peaks in *F*-value can be found around positions 6, 11, 19, 42, 56, 73 and 81. These peaks are more pronounced for the dry soil conditions (Fig. 7) than for the moist soil conditions (Fig. 8).

The boundaries detected from soil water content are comparable to the boundaries found from texture analysis, soil survey (Table 1) and vegetation zones (Table 2). The boundaries at positions 6, 11, 56 and 73 closely coincide with the boundaries from the soil survey and for the vegetation zones. The boundary at position 42 coincides more or less with the boundary found at position 45 from the soil survey. It appears the soil water content boundary found at position 19, is related to the boundary at position 25 in the soil survey. During the soil survey, it was found that the boundary between soil series Bucklebar and Berino was a transition over several positions. The soil water content boundary at position 81 was not detected in the soil survey but coincides with the boundary between vegetation zones 5 and 6 (Table 2).

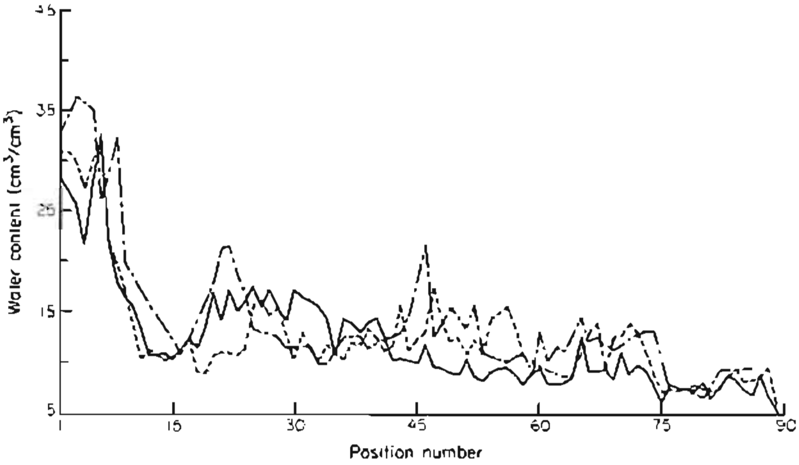

Figure 5. Variation in water content along the transect at depths of 30, 90 and 130 cm during the week of 30 April–6 May 1982. ——, 30 cm; – – –, 90 cm; — - —, 130 cm.

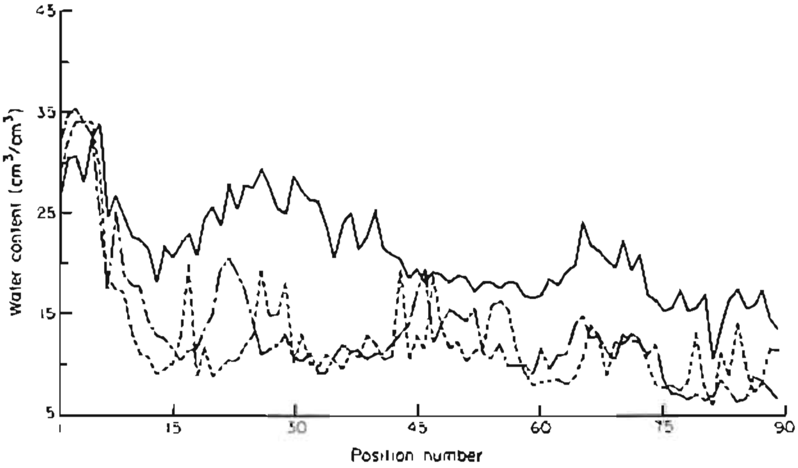

Figure 6. Variation in water content along the transect at depths of 30, 90 and 130 cm during the week of 22–28 January 1983. ——, 30 cm; – – –, 90 cm; —·—, 130 cm.

Soil–vegetation patterns

From the above it is clear that there exists a strong coincidence in spatial zonations based on soil texture and morphology, soil water content and vegetation along the LTER transect. Similar coincidences in soil–vegetation zones have been found along other desert transects (Key, Delph *et al.*, 1984; Phillips & MacMahon, 1978; Stein & Ludwig, 1979). Comparison of the coincidence of soil zones (Table 1) with vegetation zones (Table 2) along the LTER study transect, indicates the close relationship between specific soil series and certain vegetation zones. For example, the Dalby series comprises the clay soils of the *playa* dominated by grassland; the Headquarters sandy clay loam forms the narrow *playa* fringe (stations 8–10) occupied by vegetation zone 2; and the Aladdin sandy loams are dominated by piedmont grasslands (stations 73–89). Zone 3, where three different soil series occur, is a broad grassland zone (stations 11–57). This part of the study transect was in a pasture with a long history of livestock use, where former vegetation zones have most likely been obscured. However, soil zones have persisted and, with livestock exclusion

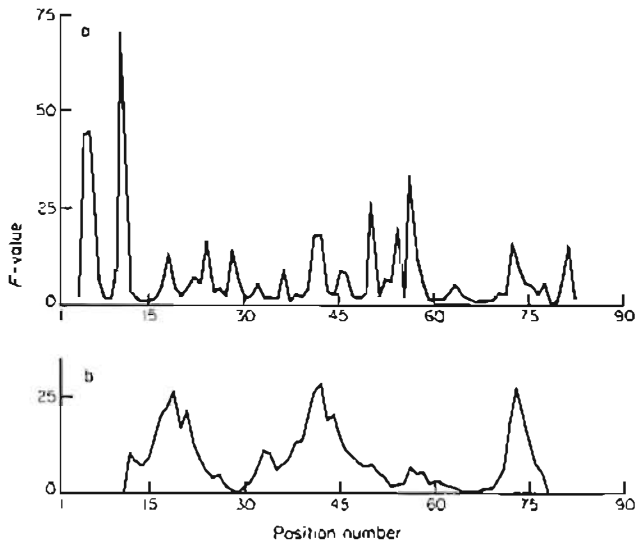

Figure 7. F-values for water contents at 30, 60 and 90 cm along the transect during the week of 30 April–6 May 1982. (*a*) Window width = 8; (*b*) window width = 24.

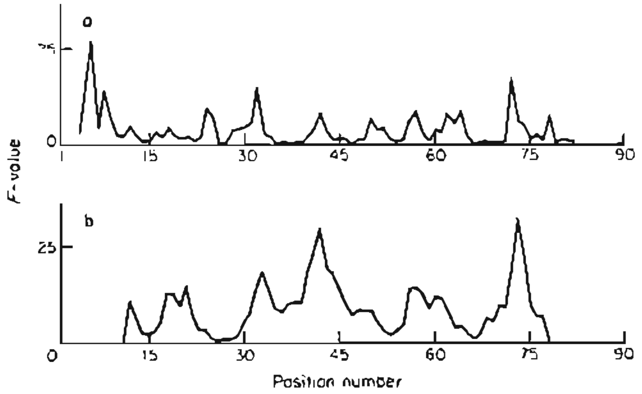

Figure 8. F-values for water contents at 30, 60 and 90 cm along the transect during the week of 22–28 January 1983. (*a*) Window width = 8; (*b*) window width = 24.

from the study transect, vegetation may undergo changes to form zones that coincide with the soil zones. The strong spatial relationship for zones based on soil texture and soil moisture content indicates that soil water content, especially during a drying cycle, may be a useful indicator in soil classification and mapping.

Conclusions

The above data present an initial evaluation of spatial variation and zonation in soil texture, moisture content and vegetation along a 2.7-km transect in a desert area. There is extensive spatial variability in soil physical properties, in water content and in vegetation along the transect. Using the multivariate moving split-window technique, boundaries between zones based on soil morphological characteristics closely coincide with boundaries based on soil water content, and with boundaries between vegetation zones. Future papers will deal with the quantitative relationships between soil morphological characteristics, soil moisture and vegetation using cross-correlation and co-kriging (Journel & Huijbregts, 1978).

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