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The Variation of Soil Properties with Slope Position in Asir Highlands, Saudi Arabia

Marei Hussain Al-Qahtani
King Khaled University, Abha,
Saudi Arabia

Abstract:

This study demonstrates quantitatively that the soil of southwest Asir highlands is generally loamy sand, shallow and somewhat rich in moisture, organic matter, organic carbon, nitrogen and phosphorus, but lacking in $CaCO_3$, potassium, electrical conductivity and pH, compared with the north-east of Asir highlands. In the northeast of the research area, the soil is mostly sandy loam to sand, deep and very lacking in moisture, organic matter, organic carbon, nitrogen and phosphorus. Also, this region is affected by salinity. On the vertical level, deeper soils were found in the lower slopes whereas shallow soil is found in the middle and upper slopes. Soil moisture, potassium and electrical conductivity increase down-slope and decrease in the middle and upper slopes. Soil organic matter, $CaCO_3$ and pH decrease along the slope units from top to bottom.

Introduction:

Despite the vast area of the Kingdom of Saudi Arabia (2,200,518 sq. Km), unfortunately there has so far been few studies on its soils, which has not attracted the interest of specialists, particularly in the south-west part where the research area is situated. This may be due to the lack of agricultural planning and the difficulty of carrying out research in a tough region such as Asir, which is characterized by its mountains. However, in 1965, the Ministry of Agriculture and Water in Saudi Arabia initiated a wide plan for water, soil and agriculture

This paper was received in June 2001 and approved for publication in March 2002.

potentiality studies. According to this plan, the Kingdom of Saudi Arabia was divided into eight areas. Each area was assigned to international engineering consultants to investigate and report on the natural potentialities of those areas (Al-Jerash, 1968). Unfortunately, the deficit of soil information is still found because the results of these investigations were either very weak or so far have not seen the light of day.

For the above reasons, the purpose of this study is to investigate and analyse in detail the soil properties of the research area, in terms of its formation, morphological types and distribution. These investigations, and the analyses of soil properties depend on data collected from 300 soil samples taken from the research area. To facilitate full understanding of these investigations and analyses, a brief account of the present knowledge of the soil of Saudi Arabia, with special emphasis on the south-western territory, is presented in the following paragraphs.

According to the United States system (Department of agriculture), studies of soil genesis indicate that the soils of Saudi Arabia belong to the broad Entisol and Aridisol hierarchies, except for those with a humid local climate and older soils that had been developed under different climatic conditions.

In respect to the latter point, Powers et al. (1966), Chapman (1978), Sharief (1984) and Youssef (1987) indicated that the Arabian Peninsula was under a humid climate during the Upper Pleistocene (0.3 million years B.P), Early Pleistocene (1.8 million years B.P) and Late Pliocene (3.3 million years B.P) periods (Moshrif, 1990). In particular, the Arabian Shield soils were formed then. After these periods, the soils of Saudi Arabia then underwent a change in climate to reach their current condition (arid in most parts and semi-arid in the south-western mountains).

In terms of soil classification, only two works have been carried out in this field so far, namely a soil map (Ministry of Agriculture and Water, 1981) and the general soil map (Ministry of Agriculture and Water, 1985) of Saudi Arabia. These works, production of which depended strongly on both general information and field observations, both confirmed that the soils of Saudi Arabia are Entisols and Aridisols and mainly undeveloped.

Concerning the soil of the south-western part of Saudi Arabia, which includes the research area, the studies of soil in this region have been either general studies, depending on general information and field observations, or very specialized studies, conducted in a very small part of this region. Unfortunately, the results of these studies have, without any reservation, usually been generalized to the whole region and used to describe the overall soil properties. However, the results of these studies have varied, and were at times conflicting. Some of them have described the soil of this region as being shallow and undeveloped. The following paragraphs are presented as examples of these discrepancies.

Al Souli et al. (1980: 117) said of the soil of the Arabian shield:

"*The soils are often shallow, rocky and occur on relatively steep slopes. They are grayish brown to yellowish red in color. Local areas of soil are found in creek positions. Foot slopes, terrace and some nearly level areas have deeper soils which have medium texture (loams and sandy loams), are fertile and are suitable for cultivation. The sedimentary limestone, sandstone and shale areas of shield also have shallow soils and may, in places, be deeply dissected*".

Aba-Husayn et al. (1980: 643), presented a mineralogical description of the soil of the mountains of Asir region as follows:

"*Soils developed on stable landscapes at higher elevation, (> 2,000 m) have well-developed profiles, a clay loam texture, about 6% organic material, and near neutral pH. Soils developed on alluvial terraces near* *wadi banks at lower elevations (> 1,500 m) have a deep but less developed profile, a loamy sand texture, about 1% organic material, and higher than neutral pH with carbonate minerals. Quartz, feldspars, and micaceous minerals are the major components of the silt and sand fractions of the soil. Clay fractions of the soils are composed mainly of kaolinite, smectite, vermiculite, mica and chlorite minerals. Kaolinite is the most abundant clay mineral of the soils developed on well drained highland areas. On the other hand, smectite is the most abundant clay mineral in the alluvial soils developed on lower terrace area*".

In respect to the research area, there have not been many soil studies and all writings about it have been at the level of general information. The only work which can be considered a good contribution in showing some important aspects of classification and distribution of the main types of soil is the general soil map of the Kingdom of Saudi Arabia prepared by the Ministry of Agriculture and Water in 1985.

The Study Area

Asir highlands occupy a unique position in the southwest of Saudi Arabia. In terms of geographical location, they lie in the zone between 17° 20′ and 20° 45′ N latitudes and between 41° 40′ and 44° 17′ E longitudes (Fig. 1). Geologically, they belong to the greater Afro-Arabian shield which is a part of the Precambrian crystalline plate (Schmidt et al, 1973). The elevation of the area ranges between 1000 m and 3130 m above sea level. It contains mountains, escarpments, deep valleys, rolling land and rocky hills (Abulfatih, 1981). The area is distinguished by moderate temperature throughout most months of the year (Mean annual 17.7°C, Summer 22°C, Winter 12.7°C). Although there is a decrease in temperature in winter (12.7°C), it does not reach freezing point because Asir highlands are influenced by the warm marine wind. Asir highlands receive high rainfall (332 mm). These rains are distributed throughout the year peaking in spring and summer (Al-Shareef, 1976 & 1994 & Al-Qahtani, 1998).

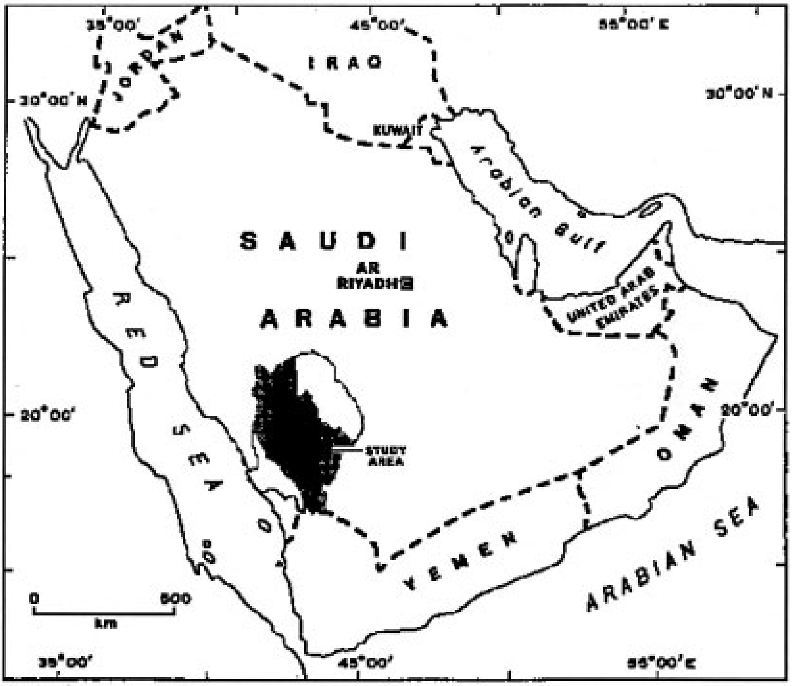

Figure 1 Geographical and Regional Location of Asir Highlands.

Methods and Procedures

Sixty transects were selected systematically as profile lines along eastern slopes of Asir highlands (Fig.1). Each transect started from a specific measured point on the lower slope and crossed the facing slope to the edge of Asir highlands. The distance between transects was 5 km. Each transect was subdivided into five slope units from the ridge to the toe: summit, shoulder, mid-slope, foot-slope, and toe-slope. These units cover all the physiographic and physiognomic variations of the region. Selection of these units, which can be seen everywhere, depended on variation of slope gradient and form, with soil uniformity. Sample collection sites were established in the centre of each slope unit on each transect. In other words, this technique was used to measure, investigate and analyse 300 samples of soil in 300 sites. In each sample, soil depth was measured, and soil moisture, texture, organic matter, organic carbon, total calcium carbonate, nitrogen, phosphorus, potassium, pH of soil and electrical conductivity were analysed. This technique has proven to be sufficient and effective in previous investigations of soil, such as Al-Arifi (1992), Martz (1992), Derose et al. (1993), Makhnach (1994), Simanton et al. (1994) And Al-Qahtani (2001). Procedures suggested by Tarzi (1984) were applied in collecting and preparing soil samples, which were analysed according to the procedures that were suggested by soil survey staff (1992), and are applied at the soil laboratories of King Saud University and the National Agriculture and Water Research Centre, Saudi Arabia.

Results and Discussion

Soil is an environmental milieu involving the interaction of physical, chemical and biological processes. This complex interaction causes all soil properties to be associated with each other, whether directly or indirectly, to comprise a fully integral system of soil conditions. From this point of view, it is very natural to find out that some soil properties are in fact distinctive features and can be used as important differentiating criteria, while others seem to be of little pedological significance but are important in relation to crop production. Selection of these properties is based on their important role in the formation and production of soil, as well as their direct relationship with environmental factors, such as slope factors. The following sections will therefore focus only on those morphological, physical and chemical properties that are most commonly encountered in the context of soil-environmental study. The morphological and physical properties comprise soil depth (thickness), moisture, texture (sand, silt and clay) and organic matter. The chemical properties comprise organic carbon, total calcium carbonate, nitrogen, phosphorus, potassium, pH of soil and electrical conductivity. Analysis of each soil property will start first by examining the summary soil data in the whole research area, as these are fundamental to an understanding of soil properties. Secondly, because the research area includes two regions, a mountainous region and a plateau, which differ greatly in terms of elevation, morphology, climate and vegetation cover, the diversity of soil properties between these regions and also between slope units (toe-slope, foot-slope, mid-slope, shoulder-slope and top-slope) is examined in the following paragraphs.

Soil Depth

Perhaps it is questionable whether soil depth or thickness of soil should be considered as an important differentiating property. However, in most circumstances, the depth of soil is considered as one of the major indications of soil development. It should be noted though, that the development of soil can occur in a few centimetres when the environmental conditions are appropriate (FitzPatrick, 1980). Soil depth or thickness (T) consists of the vertical arrangement of all the soil horizons down to the parent material (Birkeland, 1984; Al-Shalash, 1985) and reflects the relative amounts of deepening (D), upbuilding (U) and removals (R) that occurred during the evolution of the soil, where $T = D + U - R$ (Johnson, 1985). "Deepening" refers to the down-migration of the lower soil boundary through leaching and weathering. Upbuilding refers mainly to surface additions of minerals and organic material derived from eolian and slope processes. "Removal" refers mainly to surface-material loss through erosion and mass wasting. In reference to the relationship $T = D + U - R$, soil thinning (or shallowing) occurs when $D + U < R$, and soil thickening occurs when $D + U > R$, $D > U - R$, or $U > D - R$ (Johnson, 1985).The surface part of soil that extends from the top of the ground to c. 50 centimetres depth is generally the important part that plays a major role in plant life. Most interactions occur in this zone and reflect their influence, either negative or positive, on life forms. For the above reasons, as well as other environmental and research factors, the soil depth in this study was measured only up to 50 centimetres thickness. Two methods were utilised to measure the depth of soil, namely digging the ground and using the auger. As can be seen from Table 1, the mean depth of soil in the 300 stands surveyed in the research area was 31.31 centimetres. Values of standard deviation (13.50) and variance (182.267) as well as range value (40) indicated a somewhat high variation in soil depths in the research area. Frequency of soil depth in the 300 sites confirmed this result, with 52% of soil depth values less than 30 centimetres, 23% between 30 and 50 centimetres and 25% more than 50 centimetres. From the above results, it is possible to say that the current soil of research area is rather shallow. This is due to removal factors (erosion and mass wasting) that exceed deepening and upbuilding factors (interior and surface additions of minerals and organic matter).

Comparison of the mean soil depth (30.07) and the standard deviation (12.58) in the south-west (a mountainous region) with equivalent values (32.55 and 14.29 respectively) in the the north-east (a plateau region) of the research area (Table 2) indicates that the soils of the south-western region are more shallow than the soils of the north-eastern region (Fig.2). As can be seen from Table 3, the significance of a difference between the means of soil depth in the south-western and the north-eastern regions was examined, using the t-test (Independent samples; t-test model). T-value (- 1.59) and t-probability ($p > 0.05$) indicate that the difference between the means of soil depth in these regions is not insignificant, at least from the statistical standpoint, at the 95 percent confidence level.

Table 1 Data Summary of Morphological and Physical Properties of Soil in Asir Highlands.

Soil properties	Items					
	Mean	**std Deviation**	**Variance**	**Range**	**Minimum**	**Maximum**
Soil depth	31.31	13.50	182.267	40.00	10	> 50
Sand	80.14	9.80	95.967	60	36	96
Silt	13.78	7.61	57.838	42	0	42
Clay	6.08	4.01	16.101	32	0	32
Moisture	2.46	2.11	4.437	10.53	0.30	10.83
OM	1.11	1.35	1.814	9.68	0.0130	9.6900

Table 2 Data Summary of Morphological and Physical Properties of Soil in the South-west and North-east Regions of the Research Area.

Soil properties	Soil South-western region			North-eastern region		
	Mean	**std. deviation**	**Variance**	**Mean**	**std. deviation**	**Variance**
Soil depth	30.07	12.58	158.37	32.55	14.29	204.29
Sand	78.64	9.94	98.81	81.64	9.45	89.24
Silt	14.87	7.46	55.59	12.69	7.62	58.09
Clay	6.49	4.32	18.63	5.67	3.65	13.34
Moisture	3.47	2.42	5.84	1.45	1.00	0.99
OM	1.51	1.44	2.06	0.71	1.12	1.25

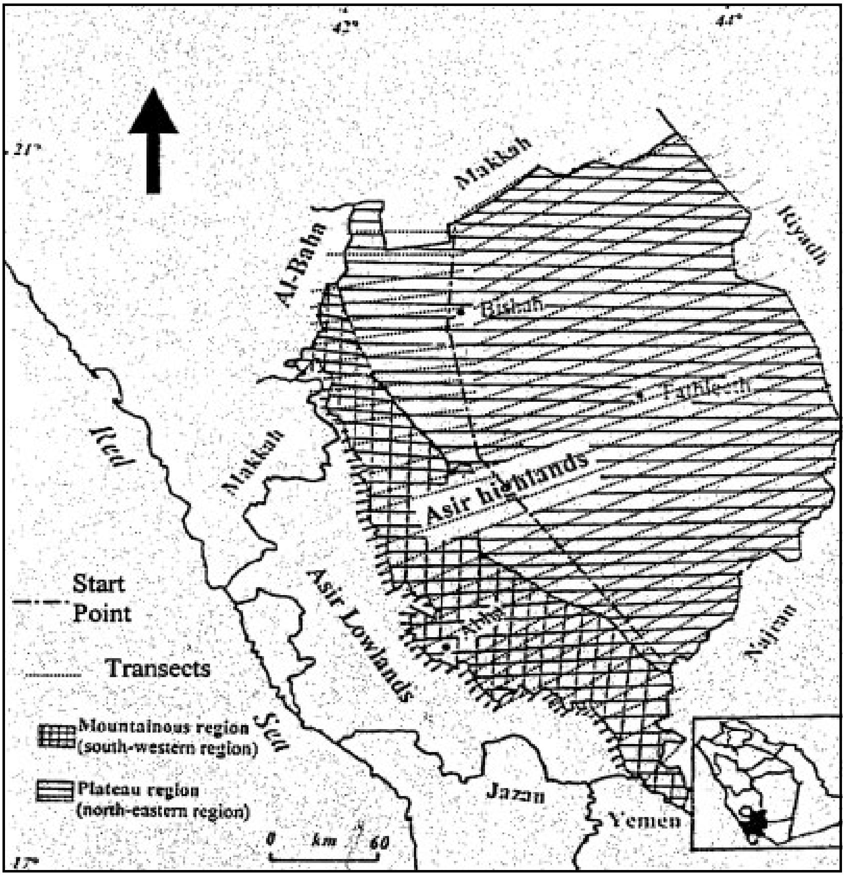

Figure 2 Distribution of Mountainous, Plateau Regions and Transects In Asir Highlands

Table 3 T-test of Morphological and Physical Soil Properties Variance Between the South-west and the North-east Regions of the Research Area.

Soil properties	Mean		T value	T probability
	South-west	North-east		
Soil depth	30.0667	32.5467	- 1.59	0.112
Texture	5.6533	6.0533	- 2.25	0.025
Moisture	3.4744	1.4461	9.50	0.000
Organic matter	1.5120	0.7074	5.41	0.000

In terms of vertical extent, the mean, standard deviation and variance of soil depth (thickness) were also computed in each slope unit (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope or top-slope), and these results are exhibited in Table 4. Comparison of the mean depth of soil between slope units (44.03, 38.98, 28.35, 24.42 and 20.88 respectively) indicates that the depth of soil increases downward of slope and decreases upward of slope, while the standard deviation values (10.04, 11.60, 11.97, 10.01 and 7.87 respectively) and variance values (100.81, 134.59, 136.30, 10.29 and 61.87 respectively) show little differences in soil depth within each slope unit. The differences in soil depth between slope units, shown above, were examined further by using one way ANOVA. As can be seen from Table 5 and Fig. 3, the F-value (45.0002) and an F-significance value ($p < 0.01$) indicate that the differences in soil depth between slope units are significant. This result is confirmed by Fig. 3. Multiple comparison tests for the differences in the mean depth of soil in the slope units (Table 6) indicate that there are significant differences at the level of 0.05 between means of soil depth in most slope units.

Table 4 Data Summary of Morphological and Physical Properties of Soil within Slope Units of the Research Area.

Slope units	Soil properties	Items		
		Mean	**std. deviation**	**Variance**
Toe-slope	Soil depth	44.03	10.04	100.81
	Sand	79.63	11.36	129.15
	Silt	13.63	8.17	66.78
	Clay	6.53	4.61	21.27
	Moisture	2.60	2.58	6.66
	OM	1.03	1.17	1.38
Foot-slope	Soil depth	38.98	11.60	134.59
	Sand	79.87	10.30	106.15
	Silt	14.23	8.33	69.44
	Clay	5.90	3.67	13.48
	Moisture	2.48	2.33	5.45
	OM	1.06	1.21	1.47
Mid-slope	Soil depth	28.35	11.67	136.30
	Sand	79.47	9.64	93.00
	Silt	13.80	6.46	41.72
	Clay	6.73	4.72	22.23
	Moisture	2.38	1.97	3.89
	OM	1.15	1.40	1.95
Shoulder-slope	Soil depth	24.52	10.01	100.29
	Sand	81.27	7.91	62.50
	Silt	13.00	6.28	39.39
	Clay	5.73	3.42	11.72
	Moisture	2.33	1.48	2.20
	OM	1.16	1.36	1.86
Summit-slope	Soil depth	20.88	7.87	61.87
	Sand	80.43	9.66	93.30
	Silt	14.07	8.55	73.08
	Clay	5.50	3.43	11.75
	Moisture	2.53	2.06	4.25
	OM	1.15	1.59	2.52

Table 5 Analysis of Variance of Soil Morphological and Physical Properties Between Slope Units (toe-slope, foot-slope, mid-slope, shoulder-slope and top-slope).

Soil properties	Analysis of variance					
	source of variance	**D.F**	**Sum of squares**	**mean squares**	**F value**	**F sig.**
Soil depth	between groups	4	23062.8133	5765.7033	45.0002	0.0000
	within groups	295	31497.7333	106.7720		
	Total	**299**	**54560.5467**			
Texture	between groups	4	5.8133	1.4533	0.6007	0.6624
	within groups	295	713.7333	2.4194		
	Total	**299**	**719.5467**			
Moisture	between groups	4	2.7692	0.6923	0.1542	0.9610
	within groups	295	1324.4779	4.4898		
	Total	**299**	**1327.2471**			
Organic matter	between groups	4	0.8985	0.2246	0.1224	0.9744
	within groups	295	541.4570	1.8354		
	Total	**299**	**542.3555**			

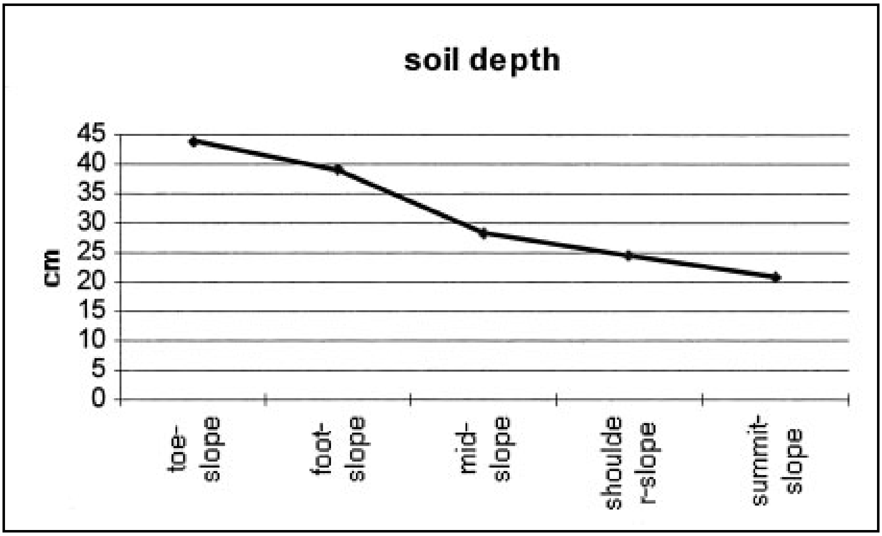

Figure 3 Amount of Soil Depth Between Slope Units.

Table 6 Multiple Comparisons Test (Least Significant Difference Model) for the Differences Between the Mean Depth of Soil in the Slope Units.

Slope units	Toe-slope	Foot-slope	Mid-slope	Shoulder slope	Summit slope
Toe-slope		*	*	*	*
Foot-slope			*	*	*
Mid-slope				*	*
Shoulder-slope					
Summit-slope					

* Significant at 0.05 level.

Soil Texture

Soil texture is one of the important internal characteristics of soil. The principal property of soil mineral particles in an environmental context is their size. The mineral fraction of soils consists of particles that vary dramatically in size from large boulders (several m in diameter) through cobbles and pebbles (several cm in diameter) to sand, slit and clay (less than 2 mm in diameter) (Ellis & Mellor, 1995). Most studies of soil texture depend upon the proportion of sand, silt and clay sizes, as based on the inorganic soil fraction that is less than 2 mm in diameter (Birkeland, 1984). The dominant size fraction is used to describe the texture. If no fraction is dominant, the soil is described as a loam (Wild, 1994). The commonly-used textural classification systems are the International System, United States System and British Standards System (White, 1987). The United States System is used in this study to classify the texture of soil into sand, silt and clay. In this, particles of sand range from 0.05 to 2.0 mm in diameter. The individual particles of silt are microscopic in size (0.002 to 0.05 mm). The individual clay particles are even more minute (less than 0.002 mm). The hydrometer method was used as the best method of analysing soil texture. The texture triangle was used to determine the soil texture classes. The results of soil texture analysis are reported in the following paragraphs.

The means of sand, silt and clay in the research area are about 80%, 14% and 6% respectively. Although the range values of sand (60), silt (42) and clay (32) are very wide, the values of standard deviation (9.80, 7.61 and 4.01 respectively) and variance (95.967, 57.838 and 16.101 respectively) indicate that the sand, silt and clay proportions in most samples appear to be homogeneous (Table 1). Nevertheless, comparison of the mean proportions of sand (78.64), silt (14.87) and clay (6.49) in the south-western region with the equivalent values (81.64, 12.69 and 5.67 respectively) in the north-eastern region of the research area (Table 2) indicates that the sand proportion increases in the north-eastern region, whereas the silt and clay proportions decrease. Conversely, the sand proportion decreases in the south-western region whereas the silt and clay proportions increase. As can be seen from Table 2, the standard deviation and variance values denote that the sand, silt and clay proportions are somewhat homogeneous within each region. The importance of differences in soil texture between the south-western region and north-eastern region was examined by using t-test (Table 3). The t-value (- 2.25) and t-probability ($p < 0.05$) indicate that the diversity of soil texture between the south-western and the north-eastern regions is significant. Through the slope units (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope) or soil catena, small differences were noted between the mean proportions of sand (79.63, 79.87, 79.47, 81.27 and 80.43 respectively), silt (13.63, 14.23, 13.80, 13.00 and 14.07 respectively) and clay (6.53, 5.90, 6.73, 5.73 and 5.50 respectively) (Table 4). The variance of soil texture between slope units, mentioned above, was also examined via ANOVA (Table 5). As can be seen from this table, the f-value (0.6007) and f-significance ($p > 0.05$) denote that the differences in soil texture between slope units are not significant at the level of 0.05, at least from the statistical point of view. This finding can be attributed mainly to the short distances between slope segments and to increased vegetation density in the upper parts of slopes that reduces migration of fine materials toward the lower parts of slopes.

According to the modern division system of the United States, the soils of the research area were classified into two types: loamy soils and sandy soils (Table 7). Loamy soils comprise 31.7% and consist of sandy clay loam (1%), sandy loam/sandy clay (0.7%), loam (1%), sandy loam (24.3%) and loam sandy/sandy loam (4.7%). Sandy soils comprise 68.3% and consist of loamy sand (42%), sandy loam sand (3.3%)and sand (23%). As can be seen from Fig. 4, the loamy sand (LS), sandy loam (SL) and sand (S) predominate, accounting for about 89% of the soil texture classes in the research area, whereas the other classes constitute less than 11%.

In terms of the soil type and texture class within each slope unit, sandy soils compose most of the stands within each slope unit, covering about 75%, 70%, 68.3%, 66.6% and 61.7% of top-slope, shoulder-slope, mid-slope, foot-slope and toe-slope respectively (Table 8). As can be seen from this Table and Fig. 5, loamy sand occupies the first rank in summit-slopes (48.3%), shoulder-slopes (40%), mid-slopes (53.3%) and foot-slopes (38.3%), and the second rank in toe-slopes (30%) after sand (31.7%). Some texture classes are not found in some slope units. Sandy loam/sandy clay and sandy loamy sand are not found in toe-slopes. Sandy loam/sandy clay and loam sandy/sandy loam do not appear in foot-slopes. Sandy clay loam is absent from mid-slopes. Sandy loam/sandy clay, sandy clay loam and loam are not found in shoulder-slopes. Due to the down migration of fine materials, via leaching and erosion, particularly in the north-eastern part of the research area, the last two soil texture classes also are not found in summit-slopes.

Table 7 Classification of Soil and Soil Texture in the Research Area; According to the Modern Division of the United States.

Soil type	Percent	Texture class	Percent
Loamy soils	31.7	Sandy clay loam (SCL)	1.0
		Sandy loam / Sandy clay (SL/SC)	0.7
		Loam (L)	1.0
		Sandy loam (SL)	24.3
		Loam sandy / Sandy loam (LS/SL)	4.7
Sandy soils	68.3	Loamy sand (LS)	42.0
		Sandy loamy sand (S/LS)	3.3
		Sand (S)	23.0
Total	**100.0**		**100.0**

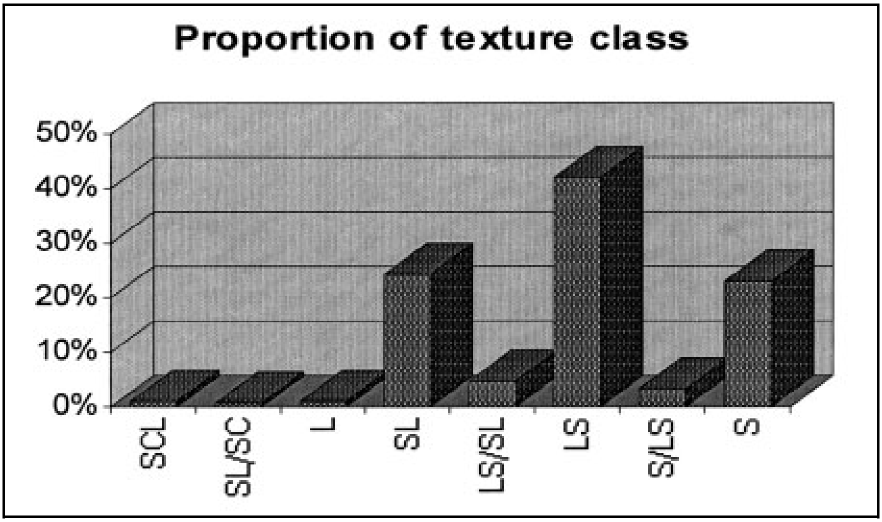

Figure 4 Proportions of the Texture Class of Soil in the Research Area.
(Source: Table 7)
Key to Texture Classes (see Table 7)

SCL = Sandy clay loam
SL/SC = Sandy loam / Sandy clay
L = Loam
SL = Sandy loam
LS/SL = Loam sandy / Sandy loam
LS = Loamy sand
S/LS = Sandy loamy sand
S = Sand

Soil Moisture

Soil moisture is defined as the solvent medium by which minerals are transported upward to the leaves of plant and sugar is transported downward to the roots. Soil moisture potential is the total effect of all types of energy acting on water in the soil, including gravity, capillary, surface absorption and osmois (Pitty, 1978; Omer & Metwally, 1978; Ellis & Mellor, 1995). The amount of moisture content in soil depends basically on its mechanical texture; the smaller the particle size, the higher the amount of soil moisture and its availability (Migahid et al. 1987). Rainfall is the most important source and in some conditions is the single source of soil moisture in the research area (Al-Qhatani, 1991&1998).

Table 8 Classification of Soil and Soil Texture within the Slope Units; According to the Modern Division of the United States.

Soil type	Texture class	Toe-slope %	Foot-slope %	Mid-slope %	Shoulder-slope %	Summit-slope %
Loamy soils	Sandy clay loam	3.3	1.7	0.0	0.0	0.0
	Sandy loam / Sandy clay	0.0	0.0	1.7	0.0	1.7
	Loam	1.7	1.7	1.7	0.0	0.0
	Sandy loam	26.7	30.0	23.3	21.7	20.0
	Loam sandy / Sandy loam	6.7	0.0	5.0	8.3	3.3
Sandy soils	Loamy sand	30.0	38.3	53.3	40.0	48.3
	Sandy loamy sand	0.0	5.0	1.7	5.0	5.0
	Sand	31.7	23.3	13.3	25.0	21.7
Total		**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

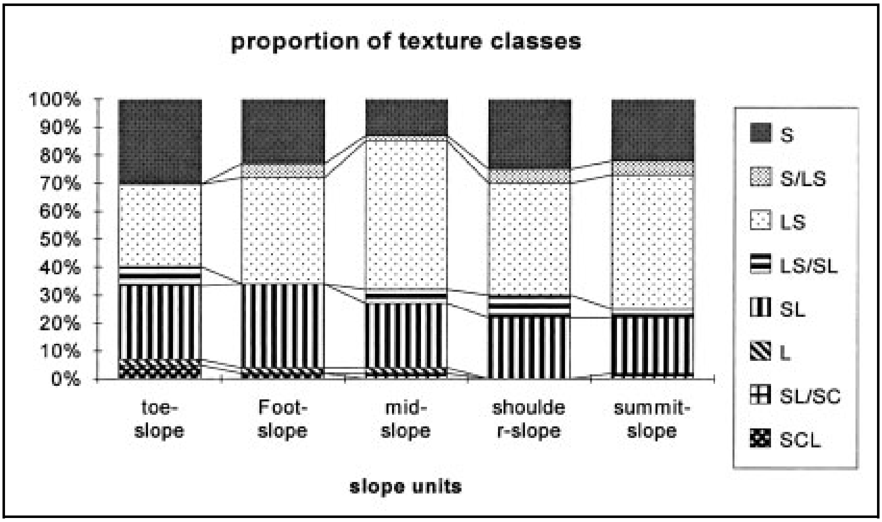

Figure 5 Proportions of the Texture Classes of Soil Within Slope Units.

(Source: Table 8)

Key to Texture Classes (see Table 8)

SCL = Sandy clay loam	SL/SC = Sandy loam / Sandy clay
L = Loam	SL = Sandy loam
LS/SL = Loam sandy / Sandy loam	LS = Loamy sand
S/LS = Sandy loamy sand	S = Sand

The soil moisture content of the research area samples was measured in the laboratory, using the weight method. The summarized results in Table 1 show that the mean moisture of soil is 2.46%. Comparing this mean with the equivalent value in the humid regions gives an initial impression that soil moisture in the research area is very low, but in fact, it may be considered a high value when compared with other regions in Saudi Arabia, e.g. the moisture content of soil in the central region of Saudi Arabia is about 1% or less (Youssef & El-Sheikh, 1981). Standard deviation (2.11) and variance value (4.437) as well as the range value (10.53) denote that soil moisture varies strongly from site to site. This variation may be related to differences in soil texture, elevation factor and its relationship with the amount of rainfall, vegetation cover size, etc. Frequency of soil moisture in the 300 examined samples confirmed the inequality of soil moisture throughout the research area: 55% of moisture amount values were less than 2%, 34% were between 2% to 5% and 11% were more than 5%.

As can be seen from Table 2, the standard deviation and variance values in the south-western region (2.42 and 5.84 respectively) and the north-eastern region (1.00 and 0.99 respectively) of the research area indicate that the soil moisture proportion within each region appears to be homogenous. However, variance is observed between the mean moisture of soil in the south-western region (3.47%) and the north-eastern region (1.45%). This variance relates in most conditions to the differences in elevation, rainfall amount, evaporation amount, vegetation cover size and soil texture class. The first region lies between 2000 m and 3130 m above sea level. The mean annual rainfall in this region is more than 300 millimetres, with an annual total of evaporation of about 2446.2 mm (Abha meteorological station) and an absolute vegetation density of 3.01/100 m. The second region is located at less than 2000 metres above sea level. The main annual rainfall of this region is less than 150 millimetres, with an annual total of evaporation of about 3893.3 mm (Al-Heifa meteorological station) and an absolute vegetation density of 2.46/100 m. Furthermore, the soil texture class in the south-western region is finer than in the north-eastern region. Reliability of the differences between mean moisture in both regions was examined, using the t-test (Table 3). The t-value (9.50) and t-probability ($p < 0.01$) show that the diversity of soil moisture between south-west and north-east of the research area is significant.

As can be seen from Table 4 and Fig. 6, the mean moisture of soil in slope units (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope or top-slope) is 2.60%, 2.48%, 2.38%, 2.33% and 2.53% respectively. Standard deviation and variance value in toe-slopes (2.58 and 6.66 respectively) and foot-slopes (2.33 and 5.45 respectively) indicate that the soil moisture within these two units is somewhat different, whereas it is homogenous in the other units. The ANOVA of mean moisture in slope units (Table 5) indicates that the differences between these means are not significant, since f-value equals 0.1542 and the significance of F is 0.9610.

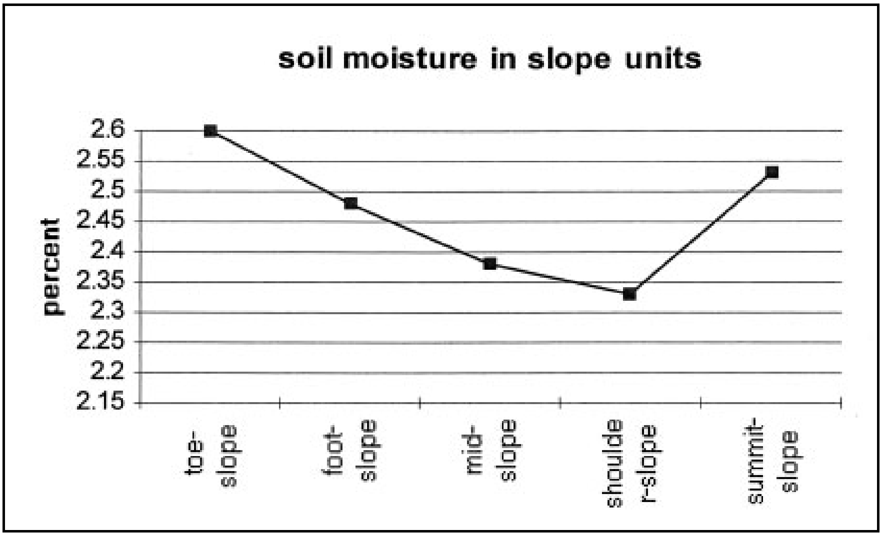

Figure 6 Diversity of Soil Moisture Within the Slope Units of the Research Area.

Organic Matter (OM)

Organic matter plays an important initial role in the physical, chemical and biotic properties of soils. It ranges in most soils between 1% and 7% (Bin Sadig, 1994). Forest soils have organic matter contents between 5.2% and 10.5% (Pitty, 1978). The percentage of organic matter in semi-arid region soils is very low, usually around 1% (Al-Mashhady et al. 1984). The main source of organic matter in the research area is dead roots, stems, seeds and leaves of vegetation cover. The second source is animal wastes, particularly in the north-east of the research area. Wind also plays a major role in carrying organic matter from source to other areas. Mean organic matter in the research area is very low (1.11%) (Table1). Organic matter percentages range between 0.013% and 9.690%. Distribution of these percentages confirms the lack of organic matter in the research area: 69% of organic matter values are less than 1%, 21% are between 1% and 3%, and 10% are more than 3%. As can be seen from Table 2, mean organic matter in the south-west of the research area was found to be higher than that found in the north-east (1.51% and 0.71% respectively). The significance of this variance between means of organic matter in the south-western and the north-eastern regions was examined, using the t-test. T-value (5.41) and t-probability ($p < 0.01$)) (Table3) confirmed the significance of this variance. The increased proportion of organic matter in the south-west of the research area related mainly to the greater vegetation cover there. As illustrated in Table 4, organic matter in the upper slopes was found to be a little higher than that found in the lower slopes, with the means of organic matter in top-slopes (1.5%), shoulder-slopes (1.16%) and mid-slopes (1.15%) being higher than those in foot-slopes (1.06%) and toe-slopes (1.03%). Despite these differences in organic matter between slope units, the f-value (0.2246) and f-significance (0.9744) (Table 5) resulting from ANOVA between means of organic matter in these units indicated that these differences are not important, at least from the statistical standpoint.

Organic Carbon (OC)

The organic carbon content of soil may be reported directly as percentage of C; or calculated as organic matter by multiplication by a factor. The conventional carbon to organic matter factor of long standing is 1.724, based on the assumption that soil organic matter is 58 percent C. The importance of carbon lies in its major contribution to the formation of humus, as well as the fact that fungi reform about 20% to 60% of carbon and divert it to protoplasm (Migahid et al. 1987). As expected in a semi-arid land, the soil of the research area has a low OC content, ranging from 0.0075% to 5.62%. About 79% of OC values are below 1.0% and 21% are between 1.0% and 5.62%. As can be seen from Table 9, the mean OC content in the surface soil of the research area is 0.64%. Although the values of standard deviation

(0.78) and variance (0.606) (Table 9) gave an initial impression that the values of OC content are somewhat homogeneous, however, in fact, there is a great variance between the means of OC in both the south-west and the north-east of the research area. Mean OC increases to 0.88% in the south-western region and drops to less than half that percentage in the north-eastern region (Table 10). Examination of this variance, using the t-test (Table 11) indicates that the difference between the means in both regions is quite significant at a level of 0.05, with t-value equal to 5.48 and t-probability, $p < 0.01$. This variance in OC content between the two regions can be attributed mainly to differences between them in vegetation cover size, organic matter content, texture class and climatic conditions. Along the slope catena, slight variations can be observed between means of OC content in slope units (Table12), where mean OC content increases with elevation toward the top-slopes. This variation relates mainly to the augmentation of organic matter in upper slope units (refer to Table 4).

Table 9 Data summary of chemical properties of soil in the research area.

Soil Properties	Items					
	Mean	std Deviation	Variance	Range	Minimum	Maximum
OC	0.64	0.78	0.606	5.61	0.0075	5.6200
$CaCO_3$	2.85	2.58	6.633	18.29	0.72	19.01
N	361.72	484.60	234834.965	3883.16	7.56	3890.72
P	48.52	28.25	797.989	215	1	216
K	115.93	105.36	11101.367	917.08	2.92	920
pH	8.26	0.50	0.252	5.52	3.88	9.40
EC	0.39	1.60	2.582	24.85	0.05	24.90

Table 10 Data summary of chemical properties of soil in south-west and north-east regions of the research area.

Soil properties	South-western region			North-eastern region		
	Mean	std. deviation	Variance	Mean	std. deviation	Variance
OC	0.88	0.83	0.69	0.41	0.65	0.41
CaCO3	2.09	1.39	1.94	3.60	3.20	10.22
N	496.03	533.68	284809.14	227.42	387.45	150117.85
P	54.03	27.87	776.47	43.02	27.64	763.89
K	91.41	67.87	4606.31	140.45	128.30	16460.26
pH	8.12	0.40	0.16	8.40	0.55	0.30
EC	0.27	0.61	0.37	0.51	2.19	4.78

Table 11 T test of chemical soil properties variance between south-west and north-east regions of the research area with degree of freedom 298.

Soil properties	Mean		T value	T probability
	South-west	North-east		
OC	0.8767	0.4060	5.48	0.000
CaCO3	2.0907	3.6003	- 5.30	0.000
N	496.0316	227.4171	4.99	0.000
P	54.0267	43.0200	3.43	0.001
K	91.4087	140.4515	- 4.14	0.000
pH	8.1160	8.4005	- 5.11	0.000
EC	0.2710	0.5097	- 1.29	0.200

Table 12 Data summary of chemical properties of soil in slope units of the research area.

Slope units	Soil properties	Items		
		Mean	std. deviation	Variance
Toe-slope	OC	0.59	0.67	0.45
	CaCO3	2.97	2.98	8.87
	N	318.93	385.74	148796.93
	P	51.62	30.65	939.26
	K	146.73	139.05	19334.62
	pH	8.21	0.46	0.21
	EC	0.96	3.47	12.05
Foot-slope	OC	0.61	0.70	0.49
	CaCO3	2.46	1.41	2.00
	N	352.07	550.52	303072.87
	P	50.12	26.88	722.31
	K	146.58	147.29	21695.53
	pH	8.24	0.69	0.47
	EC	0.35	0.58	0.34
Mid-slope	OC	0.67	0..81	0.64
	CaCO3	2.44	1.54	2.37
	N	357.84	438.49	192273.75
	P	46.87	27.11	735.17
	K	108.30	78.78	6205.57
	pH	8.23	0.47	0.22
	EC	0.31	0.53	0.28
Shoulder-slope	OC	0.67	0.79	0.62
	CaCO3	3.12	3.21	10.28
	N	351.89	414.34	171673.86
	P	49.42	33.17	1100.42
	K	96.31	56.80	3226.01
	pH	8.32	0.43	0.18
	EC	0.16	0.16	0.02
Summit-slope	OC	0.67	0.92	0.85
	CaCO3	3.24	3.09	9.53
	N	428.64	608.10	369787.80
	P	44.60	22.70	515.33
	K	82.05	46.88	2197.97
	pH	8.31	0.44	0.19
	EC	0.17	0.07	0.01

Total Calcium Carbonate ($CaCO_3$)

The content of soil from calcium carbonate (CaCO3) varies with the soil type, parent material and climatic conditions. In most soils, $CaCO_3$ is distinct from other nutrients in being originally derived from the weathering of primary minerals, and occurring in significant quantities in exchangeable form. It occurs in highly variable amounts, ranging from traces of less than 0.05% to quantities amounting to over a quarter of the bulk of some soils in arid areas (Pitty, 1978). The natural sources of soil calcium carbonate are boulders, rocks and the primary and minor minerals (Al-Niemi, 1987).

Table 13 Analysis of Variance (One-Way) of Soil Chemical Properties Between Slope Units (Toe-slope, Foot-slope, Mid-slope, Shoulder-slope and Top-slope)

Soil properties	Analysis of variance					
	source of variance	**D.F**	**Sum of squares**	**mean squares**	**F value**	**F sig.**
OC	between groups	4	0.3346	0.0836	0.1364	0.9688
	within groups	295	180.9066	0.6132		
	Total	**299**	**181.2412**			
$CaCO_3$	between groups	4	33.4688	8.3672	1.2659	0.2835
	within groups	295	1949.8234	6.6096		
	Total	**299**	**1983.2922**			
N	between groups	4	390819.8078	97704.952	0.4120	0.7999
	within groups	295	69950707.63	237121.04		
	Total	**299**	**70341527.44**			
P	between groups	4	1862.5533	465.6383	0.5802	0.6772
	within groups	295	236736.2833	802.4959		
	Total	**299**	**238598.8367**			

Table 13 (cont'd) Analysis of Variance (One-Way) of Soil Chemical Properties Between Slope Units (Toe-slope, Foot-slope, Mid-slope, Shoulder-slope and Top-slope)

Soil properties	Analysis of variance					
	source of variance	**D.F**	**Sum of squares**	**mean squares**	**F value**	**F sig.**
K	between groups	4	208755.2013	52188.800	4.9553	0.0007
	within groups	295	3106922.300	10531.940		
	Total	**299**	**3315677.501**			
pH	between groups	4	0.5845	0.1461	0.5728	0.6826
	within groups	295	75.2503	0.2551		
	Total	**299**	**75.8348**			
EC	between groups	4	26.0650	6.5163	2.5654	0.0384
	within groups	295	749.3142	2.5400		
	Total	**299**	**775.3792**			

The soils of the research area appear to be marginally calcic with CaCO3 contents ranging from 0.72% to 19.01%. However, most of the values were between 0.72% and 4.27%. About 91% of the values were less than 5%, whereas 9% of the values were between 5% and 19.01%. Although the mean calcium carbonate (CaCO3) in the research area was 2.58% (Table 9), this percentage decreases to 2.09% in the south-west of the research area, and increases to 3.60% in the north-east (Table 10). Augmentation of calcium carbonate in the north-east of the research area relates mainly to the parent material type, airborne calcium, a low level of organic matter (0.71%) and the arid climate, where the temperature is very high and the rainfall is limited, so that the removal of carbonate by rainfall is negligible. The variation between mean values of calcium carbonate (CaCO3) in the south-west and in north-east of the research area (2.0907% and 3.6003% respectively) was examined, via the t-test (Table 11). T-value (- 5.30) and t-probability ($p < 0.01$) indicate that this variation is significant. As can be seen from Table 12, values of total calcium carbonate ($CaCO_3$) in the upper slopes were found to be higher than those found in lower slopes, where mean $CaCO_3$ in summit-slopes (3.24%) and shoulder-slopes (3.12%) was greater than those in the mid-slopes (2.44%), foot-slopes (2.46%) and toe-slopes (2.97%). However, results of ANOVA (Table 13) between mean values of $CaCO_3$ within slope units denote that the differences in means of $CaCO_3$ are not significant, at least from the statistical viewpoint, with an f-value of 1.2659 and f-significance of 0.2835.

Nitrogen Content (N)

According to Campbell (1989) and Al-Niemi (1987), nitrogen is the most important element in soil organic matter, when considered from the economic standpoint. The other nutrients are also important but nitrogen is required in much larger amounts and accordingly is more likely to be deficient. About 97.82% of nitrogen is present in rocks (in the lithosphere), 1.96% is in the atmosphere and only 0.02% in the biosphere. About 86.7% of the biosphere nitrogen is relatively inert and only slowly made available to plants by microbial degradation. The lithosphere nitrogen is of very low concentration and not available to plants (Campbell, 1989). The amount of nitrogen exceeds 1% in some soils that are rich in organic matter, but it decreases to less than 0.03% in arid and semi-arid soils (Al-Niemi, 1987).

The surface soil of the area under study appears to be variable in respect of nitrogen with nitrogen contents ranging from 7.56 ppm (sample 196 in the eastern part of the research area) to 3890.72 ppm (sample 55 in the western part of the research area). About 42% of nitrogen values are less than 100 ppm, 50% are between 100 ppm and 1000 ppm and 8% are more than 1000 ppm. As can be seen from Table 9, although the mean nitrogen amount in soil of the research area is 361.72 ppm, the values of standard deviation (484.60) and variance (234834.965) as well as the range value (3883.16) indicate that the nitrogen amounts are not homogeneous in the research area. Heterogeneity of nitrogen amounts also appears to be obvious between the south-west and the north-east of the research area, where mean nitrogen amount is 496.03 ppm in the first region and 227.42 ppm in the second region. The difference between mean nitrogen amounts in both regions was examined via the t-test (Table 11). T-value (4.99) and t-probability ($p < 0.01$) indicate that the difference is very significant. These differences between mean nitrogen amounts in the two regions relate mainly to differences in their organic matter content (1.51% and 0.71% respectively), climate conditions and, to some extent, to the broad differences in soil type. As can be seen from Table 12, due to the augmentation of organic matter and decreasing of temperature, the amount of N in the upper slopes was found to be higher than that found in lower slopes, where mean N in summit-slopes (428.64 ppm) is more than the equivalent in toe-slopes (318.93%). The mean N in foot-slopes, mid-slopes and shoulder-slopes is 352.07 ppm, 357.84 ppm and 351.89 ppm respectively. However, the result of ANOVA (Table 13) between the mean N amounts in slope units mentioned above denotes that the differences between these means are not significant, where the f-value equals 0.4120 and f-significance is 0.7999.

Phosphorus Content (P)

Phosphorus is an essential nutrient element for plant life; indeed it is called the key to life. It plays a major role in storing and transferring the energy in soil and plants (Omer & Metwally, 1978). The amount of phosphorus in most soils ranges between 0.02% (or 200 ppm) and 0.15% (or 1,500 ppm), and it is concentrated mainly in the surface layer of soils. However, this amount may decrease to less than 0.02% in soil that contains only small amounts of organic matter (Al-Niemi, 1987).

The soils of the research area are variable in phosphorus content, with a mean phosphorus amount of only 48.52 ppm (or 0.005%) (Table 9). Although the phosphorus values in the samples analysed ranged between 1 ppm and 216 ppm , P values in most samples (95%) ranged between 1 ppm and 100 ppm., which is less than the desirable level for plant growth (Al-Niemi, 1987). Phosphorus deficiency is common in arid and semi-arid regions as a result of soil formation factors, the interaction of soil chemical properties, a coarse soil texture and the deficiency of organic matter. The values of standard deviation (28.25) and variance (797.989) of P in the research area indicate that the P amount in soil is somewhat homogeneous. However, moderate differences can be noted between mean P amounts in the south-west (54.03 ppm) and north-east (43.02 ppm) of the research area (Table 10). These differences could be related to variations in the amount of organic matter and texture class as well as the temperature rate in both regions. The significance of the difference between mean P amount in the south-west and north-east of the area under study was tested, using the t-test (Table 11). T-value (3.43) and t-probability ($p < 0.01$) confirm that the difference is very important. As shown in Table 12, due to the decrease in silt and clay on the upper slopes, the phosphorus amount also decreases toward the upper slopes, with mean P values in toe-slopes, foot-slopes, mid-slopes, shoulder-slopes and summit-slope of 51.62 ppm, 50.12 ppm, 46.87 ppm, 49.42 ppm and 44.60 ppm, respectively. The importance of the diversity in P amounts between slope units was examined via ANOVA (Table 13). As can be seen from this Table, f-value (0.5802) and f-significance (0.6772) indicate that the variation is not important.

Potassium Content (K)

Potassium is an important element in soil fertility and plant nutrition. The main sources of potassium are rocks that contain the primary potassium minerals, such as feldspar, muscovite and biotite. According to Al-Niemi (1987), potassium is widespread in the earth's crust, particularly in the fine soil texture, and its average in most soils is about 1.5% (or 15,000 ppm). The larger proportion of this potassium is fixed by most soil clay minerals in a form not available to plants, because the potassium ion fits precisely and is held in the hexagonal holes in the oxygen sheet of the silicate layers (Pitty, 1978).

The soil of the research area has low potassium levels, ranging from 2.92 ppm to 920 ppm. About 55% of potassium values are less than 100 ppm and 34% are between 100 ppm to 200 ppm, whereas only 11% are more than 200 ppm. As can be seen from Table 9, the mean potassium content in surface soil of the research area is 115.93 ppm, but the values of standard deviation (105.36) and variance (11101.367) as well as the range (917.08) between minimum and maximum values indicate that the potassium amounts are not identical in most analysed samples. This variation in the soil content of potassium is clearly evident in the mean K values in the south-west and north-east of the research area (Table 10), and also between the mean K values among slope units (Table 12). The importance of differences in the mean potassium amount in the south-west (91.41 ppm) and north-east (140.45 ppm) of the research area was examined, using the t-test (Table 11). T-value (4.14) and t-probability ($p < 0.01$) confirm that the difference between potassium amount in both regions is quite significant. This difference in the potassium amount can be attributed to the augmentation of washing and leaching processes in the south-western region as a result of the higher rainfall there. Due to the washing of potassium from the upper slopes toward the lower slopes, the mean potassium amount decreases in the upper slope units and increases in the down slope units, giving mean potassium values in toe-slopes, foot-slopes, mid-slopes, shoulder-slopes and top-slopes of 146.73 ppm, 146.58 ppm, 108.30 ppm, 96.31 ppm and 82.05 ppm respectively (Table 12 and Fig. 7). As can be seen from Table 13, the f-value (4.9553) and f-significance (0.0007), resulting from ANOVA analyses between mean potassium amounts within the slope units confirms that the differences are quite significant. Multiple comparison tests (Table 14) indicate that there are significant differences in mean potassium between most slope units at a level of 0.05. These differences can be attributed mainly to the washing and erosion of potassium from the upper slope segments, as well as the increase in vegetation density in these segments, which led to increase of absorption of potassium from the soil. Moreover, the augmentation of organic matter, and a decrease of temperature, in the upper slope segments, further contributed to the decrease in the amount of potassium there (Al-Niemi, 1987).

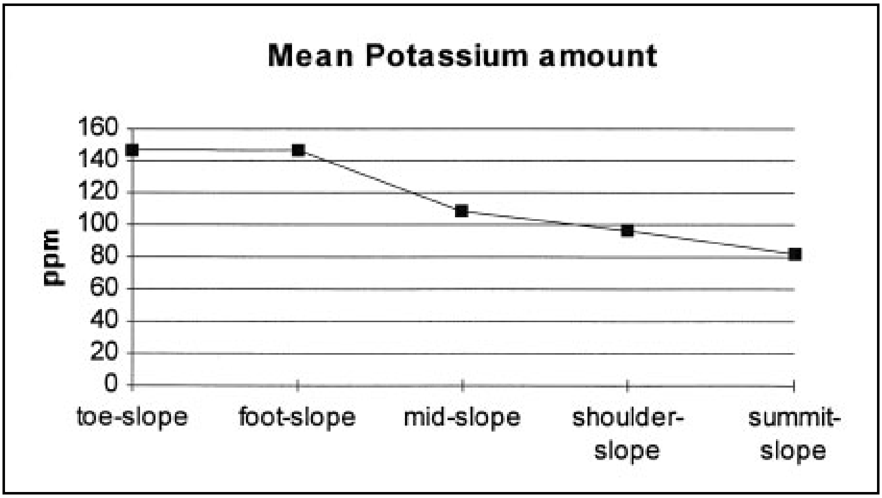

Figure 7 Diversity of Potassium Amount Within the Slope Units of the Research Area.

Table 14 Multiple Comparisons Test (Least Significant Difference Model) for the Differences Between Means of Potassium within Slope Units.

Slope units	Toe-slope	Foot-slope	Mid-slope	Shoulder slope	Summit slope
Toe-slope			*	*	*
Foot-slope			*	*	*
Mid-slope					
Shoulder-slope					
Summit-slope					

* Significant at 0.05 level.

Soil pH

Soil pH is dependent on the ionic content and concentration in both the soil solution and the exchangeable action complex the surface of colloids (Birkeland, 1984). The pH scale ranges from 1.0 at the most acidic extreme to 14.0 at the alkaline extreme, with a value of 7.0 at neutrality (Ellis & Mellor, 1995). Good soils for plant growth have a value around 6.0 to 7.0 (Al-Niemi, 1987). The pH values in the soil of the research area range from 3.88 to 9.40. However, more than 99% of pH values are slightly to strongly alkaline in reaction, ranging from 7.10 to 9.40. Only 2 of 300 soil samples were found to be not alkaline. One of them is neutral (6.80) and the other sample is acidic (3.88), found in a foot-slope in Al Qawba. As can be seen from Table 9, the values of standard deviation (0.50) and variance (0.252) denote that the values of pH are somewhat homogeneous around the mean pH (8.26). However, a slight difference can be noted between mean pH values in the south-west (8.12) and the north-east (8.40) of the research area (Table 10). The significance of this difference was examined via the t-test (Table 11). T-value (-5.11) and t-probability ($p < 0.01$) indicate that this difference is significant at the 0.05 level. Augmentation of pH values in the north-eastern region may relate to the reduction of organic matter and washing processes there, resulting from a scattered vegetation cover and a low rainfall amount, as well as an increase in evaporation processes. As can be seen from Tables 12 and 13, no considerable changes in pH values were observed through slope catenas; mean pH values in toe-slopes, foot-slopes, mid-slopes, shoulder-slopes and top-slopes are 8.21, 8.24, 8.23, 8.32 and 8.31 respectively.

Electrical Conductivity (EC)

EC is a good indicator for measuring the degree of soil salinity. Electrical conductivity analysis of soil samples collected from the research area indicates that the soil has a very low quantity of soluble salts, ranging between 0.05 mmhos/cm and 24.90 mmhos/cm. About 95% of the electrical conductivity values lies between 0.05 mmhos/cm and 0.96 mmhos/cm. Only 1 of the 300 samples exceeds 7.38 mmhos/cm, at 24.90 mmhos/cm. As can be seen from Tables 10, 11, and 13, the only noticeable differences in electrical conductivity values are those between slope units, particularly between toe-slope units and the other units (foot-slope, mid-slope, shoulder-slope and summit-slope) (Table 15 and Fig. 8). According to the US Salinity Laboratory Staff scale, and as Ellis & Mellor (1995) have defined it, the soils of the research area are Nonsaline-Alkali soil; 99% of the electrical conductivity of the saturated extract is less than 4 mmhos/cm at 25°C and the pH values range between 3.88 and 9.40. The low quantities of salt in the majority of soil samples can be related, in addition to the primary minerals found in the soil, to the high rates of leaching with the reasonable permeability of the soil, particularly after rainfall, in the upper slope units.

Table 15 Multiple Comparisons Test (Least Significant Difference Model) for the Differences Between Means of Electrical Conductivity within Slope Units.

Slope units	Toe-slope	Foot-slope	Mid-slope	Shoulder slope	Summit slope
Toe-slope			*	*	*
Foot-slope			*	*	*
Mid-slope					
Shoulder-slope					
Summit-slope					

* Significant at 0.05 level.

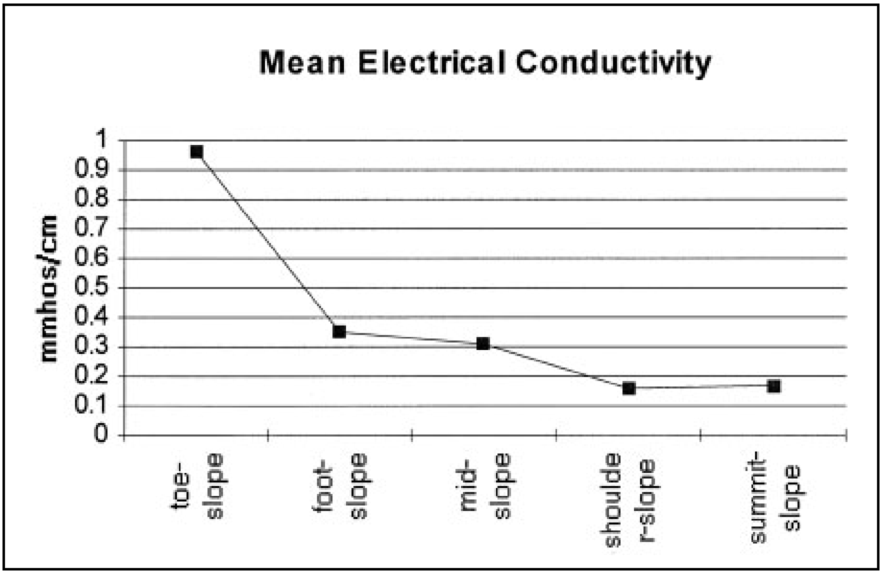

Figure 8 Diversity of Mean Electrical Conductivity Values Within the Slope Units of the Research Area

Conclusions

The most important properties of soil of Asir highlands were examined under morphological, physical and chemical headings, using original data, and using different scales(e.g. the south-western region and the north-eastern region on the horizontal level, and slope segments on the vertical level). Morphological properties have included soil depth. Physical properties have included those relating to the basic constituents of soil, such as soil texture, moisture and organic matter. The chemical characteristics of soil cover a wide range of the common elements and compounds in soil-environmental studies, such as organic carbon (OC), total calcium carbonate (CaCO3), nitrogen (N), phosphorus (P), potassium (K), soil pH and electrical conductivity (EC).

In terms of soil properties, it is obvious that various environmental factors have played a major role in the formation and composition of soil attributes in the research area. The impact of these factors in the formation of soil properties appears conspicuous on two levels, namely the horizontal level and the vertical level. On the horizontal level and according to the examined soil characteristics, the research area can be divided into two distinct regions, the mountainous region and the plateau region.

The mountainous region covers the south and west of the area under study. This region has high variation in morphology rising to elevations between about 2000 m and 3130 m above sea level, elevations which ensure low temperature as well as abundant rainfall. The soil texture of this region is generally loamy sand. However, gravels and stones are encountered in abundance, particularly in the bare lands. The upper parts of the wadis mostly have coarse mountain materials; in the soils of the alluvial plains, and where the valleys widen, fine grain-size soils are encountered including silt and clay, and these become gradually coarser as wadi beds are reached. In view of the steep-slopes and the abundance of gravels and stones, the depth of soil is generally slight and shallow. The soil is somewhat rich in moisture, organic matter, organic carbon, N and P, whereas the values of CaCO3, K, EC and pH in these soils are considered low compared with the plateau region.

The plateau region covers the north and east of the research area. Elevations in this region range from about 1000 m to 2000 m above sea level. The temperature rises to higher levels than in the mountainous region, while rainfall is less both in intensity and frequency. This region is arid with sparse vegetation. Sedimentation is more marked, so that wide, deep alluvial plains, extensive scree, river terraces and piedmont deposits are encountered. The soil always has coarse and mostly sandy loam to sand and has good depth. Soil contents of moisture, organic matter, organic carbon, N and P are very low. Although this soil suffers from deficiency of the above elements, it is also affected by salinity problems, as well as increasing of pH values.

On the vertical level and through the catenas, the slope and vegetation factors have played the most distinct role in formulation of soil properties. This role has varied from one site to another and also from one attribute to another. Soil properties were examined in relation to the main slope segments (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope) from toe to ridge, and the following results can be reported.

a - Although soil depth does not exceed 50 cm, two distinct thicknesses can be noted; namely, somewhat deeper soil in toe-slopes (44 cm) and foot-slopes (39 cm) and shallow or thin soil in mid-slopes (28 cm), shoulder-slopes (25 cm) and top-slopes (21 cm). These differences in soil depth between slope units, have resulted in due to removal factors (erosion and mass wasting) exceeding deepening and upbuilding factors (interior and surface additions of minerals and organic matter) in mid-slopes, shoulder-slopes and top-slopes.

b - Due to the augmentation of fine fractions (silt and clay), washing of potassium from the upper slopes toward the lower slopes and the high rates of leaching with the reasonable permeability of the soil, particularly after rainfall, in the upper slope units, the soil moisture, potassium (K) and electrical conductivity (EC) increase down-slope (on the toe-slopes and foot-slopes) and decrease in the middle and upper slopes.

c - Little difference can be observed in soil texture classes, organic carbon (OC) and phosphorus content (P) along the slope segments. These results can be attributed mainly to the short distances between slope segments and to increased vegetation density in the upper parts of slopes that reduces migration of fine materials toward the lower parts of slopes and weakness of variation in organic matter and soil texture along the slope segments.

d - Due to the increase of vegetation density, boulders, rocks and washing processes in the upper slope segments, soil organic matter, $CaCO3$ content and pH values decrease along the slope units from the top to the bottom.

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Marei Hussain Al-Qahtani, Ph.D in environmental sciences, Hull university 1998. Associate professor, Department of Social Sciences, Faculty of Arabic and Social Sciences, King Khalid University, Abha, Saudi Arabia. His research interests are in the field of environmental of sciences and pollution.