International Journal of Physical Sciences Vol. 4 (12), pp. 784-795, December, 2009
Available online at http://www.academicjournals.org/ijps
ISSN 1992 - 1950 © 2009 Academic Journals

Full Length Research Paper

Measurements of apparent electrical conductivity and water content using a resistivity meter

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Accepted 5 November, 2009

Measurement of soil water content (Wn), a major interest in many disciplines which requires collection, analysis and interpretation of soil data, may be expensive and time consuming. One way to reduce the cost of it is to measure the soil apparent conductivity (ECa) and to correlate with soil volumetric water content. However, the influences of soil properties such as salinity, porosity, structure, pH and clay content might be significant effect on ECa variation. Therefore, to understand the influence of different properties on the ECa, we studied the relationships between ECa and Wn, with respect to salinity, porosity, pH, and clay content in two engineered covers located in the Umuttepe and Alikahya Regions. Soil ECa measurements were conducted at 142 points in the Umuttepe and 260 points in the Alikahya engineered covers in September 25 and 27, 2007. At the same time soil samples were collected to a depth of 0.3 m from each site of measuring points in both engineered covers to determine the soil properties. pH values were measured at each of the measuring point *in-situ*. Soil ECa readings were correlated with Wn, salinity, porosity, pH, and clay content. Regression analysis yielded R^2 values of 0.811 and 0.819 for Wn versus ECa for the Umuttepe and Alikahya engineered covers, respectively. Weak relationships were determined for ECa and salinity (R^2 =0.008 for Umuttepe, and 0.0168 for Alikahya), porosity (R^2 =0.0016 for Umuttepe, and 0.0087 for Alikahya), pH (R^2 =0.0403 for Umuttepe, and 0.0051 for Alikahya) and for clay content (R^2 =0.1211 for Umuttepe, and 0.0465 for Alikahya).

Key words: Water content, resistivity, conductivity, Kocaeli, Turkey.

INTRODUCTION

Examining of soil water content which is probably the most easily identified soil property is an essential matter for agricultural arrangement. Information about water content in near-surface soil is vital for estimating land-atmospheric interaction, water balance, infiltration, and deep percolation or recharge. The information acquired from surveying is crucial for optimizing crop yields, accomplishing high irrigation efficiencies, minimizing lost yield due to salinization and waterlogging, and planning irrigation scheduling. Soil electrical conductivity is a function of clay content, water content and salinity (Rhoades et al., 1989, Kurtulus et al., 2009). Therefore, soil conductivity measurements have the potential for assessing these properties in field variation.

Electrical conductivity measurements of soil have long been used to identify soil properties in the geologic and environmental areas. Sheets et al. (1995) measured EC in New Mexico over a 16 month period, and determined a linear relationship between electrical conductivity and soil water content. Grisso et al. (2007) discussed the use of soil EC measurements, relation between EC and specific soil properties that affect crop yield, such as topsoil depth, pH, salt concentration and water-holding capacity; Ristolainen et al. (2005) examined temporal variation in soil electrical conductivity; Johnson et al. (2005) showed that apparent electrical conductivity mainly depends on soil texture, soil water content and water holding capacity in non-saline soils; Rhoades et al. (1976) reported that the electrical conductivity increases with increasing clay and water contents. Several different techniques to measure soil electrical conductivity are available including four electrode sensors ((Roy and Apparao, 1971; Dalton et al., 1984; Sudduth et al., 1998; Nemdahl and Greve, 2001). Soil electrical conductivity can depend on various soil properties including soil water content, soil salinity, cation exchange capacity (Sheets and Hendrix, 1995;

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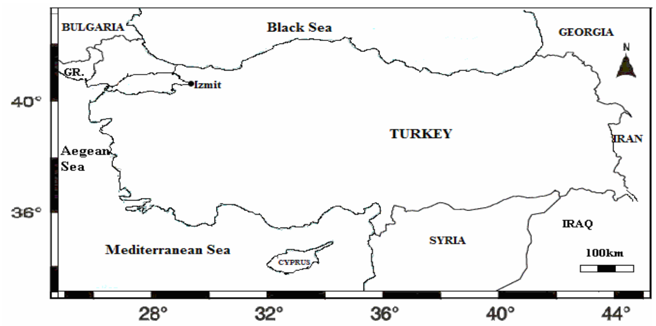

Figure 1. Location map of investigation area.

(a)

(b)

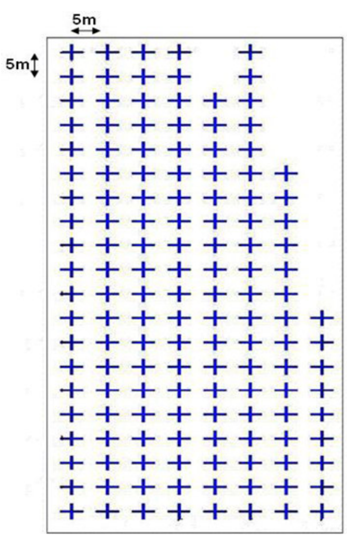

Figure 2 a, b. Engineered cover in Umuttepe, b) shape and measuring points of the engineered cover.

Agadzo et al., 2003; Rhoades, 1993; Eric et al., 2006; Halvorson and Rhoades, 1976; Rhoades and Corwin, 1981), soil particle size distribution (Sudduth et al., 2005) and management practices (Johnson et al., 2001).

Topsoil depth of claypan soils has been proposed as an important soil quality indicator (Kitchen et al., 1999). Research in Missouri has established direct, within-field calibrations between ECa and the topsoil above a subsoil claypan horizon (Doolittle et al., 1994, Kitchen et al., 1999). Most recently geo-referenced ECa measurements have been correlated to associated yield-monitoring data with the mixed results (Eigenberg et al., 2002; Jaynes et al., 1993; Corvin and Plant, 2005). The Veris was used in ECa measurements by Lund et al. (1999) and Sudduth et al. 1999). Soil electrical conductivity technology was applied for precision agriculture (Barker 1989; Lund et al., 2001; Mueller, 2004; Shaw and Mask, 2003; Corvin and Plant, 2005; Clay et al., 2005).

The purpose of this study is to examine whether the apparent electrical conductivity can be used to estimate the water content in the upper 1.4-2.0 m of the soil profile over two engineered covers in the Kocaeli Region.

Site description

The investigation engineered covers are located in Izmit-Kocaeli, NW of Turkey (Figure 1). Two investigation engineered covers were selected for investigation. One of them with the dimensions of 45 x 105 m is located in the Umuttepe Region 10 km north of Izmit (Figure 2a and b), and other one with the dimensions of 30 x 200 m is located in the Alikahya Region NE of Izmit (Figure 3a and b).

Geology of investigation areas

The Akveren formation is developed in the Umuttepe Region to a sequence of mainly white, thin to thick-bedded, calcareous to limy mudrocks and limestone. The basal section of the Akveren formation is characterized by different and laterally interchanging rocks, lying directly on the Triassic rocks: (1) yellowish gray-weathering, thickly-bedded to massive bioclastic limestone; (2) pink to pale red rudistid patch reefs; (3) light gray to grayish green, and pale red mudrocks, and (4) pale red limestone conglomerate with interlayers of rudistid debris (Ketin and Gumus 1963; Erguvanli, 1949). Investigation holes indicated two layers in this field. The thickness of the first layer is about 1.4 m with the density of 1.90 gr/cm^3 overlying the second layer with the density of 2.20 gr/cm^3.

The Izmit formation of triassic age consisting of gravel, claystone, sandstone, and shale is formed in the Alikahya investigation area. The gravel, sandstone and shale were observed as repeatedly added (Baykal, 1943; Altinli, 1968; Cakır, 1999). Two layers were determined in this field. The first layer with the density of 1.37 gr/cm^3 and the thickness of 1.5-2.0 m overlies the second layer with the density of 1.69 gr/cm^3.

MATERIALS AND METHODS

In order to figure out the apparent resistivity-water content relation, Wenner electrode arrays were applied on both of the engineered

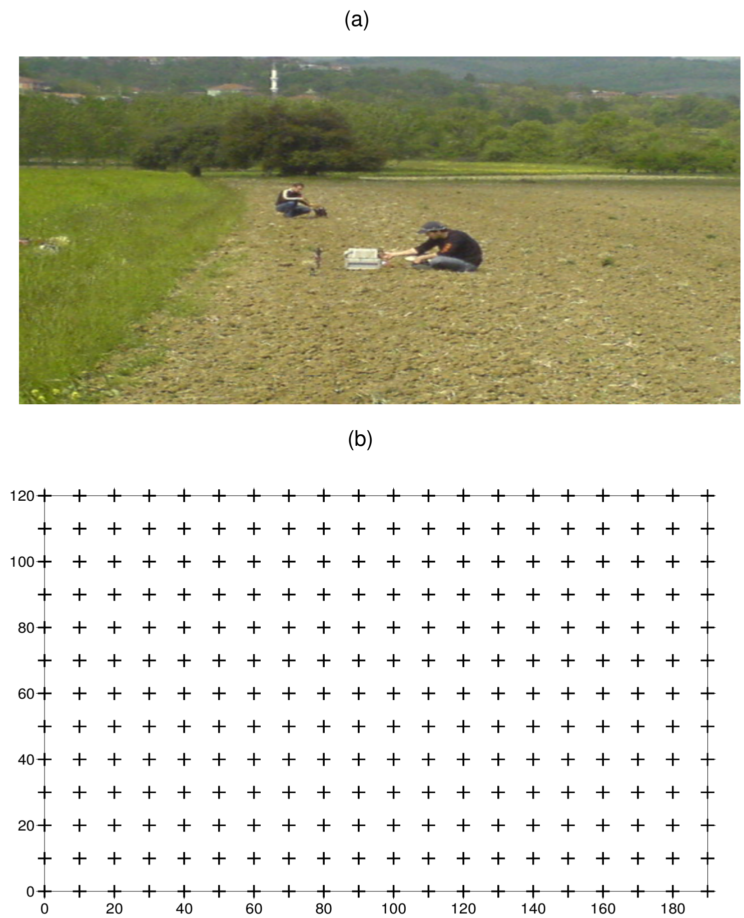

Figure 3. a: Engineered cover in Alikahya, **b:** shape and measuring points of the engineered cover.

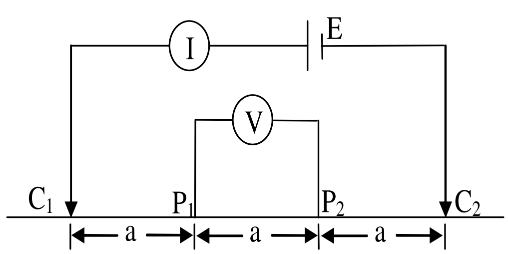

Figure 4. Wenner electrode array.

covers indicated in Figures 2 and 3. Soil samples were collected at 142 points in the Umuttepe and 260 points in the Alikahya engineered covers to a depth of 0.3 m and sent to laboratory immediately to find out water content, atterberg limits, porosity, grain size distribution. pH and salinity values were measured in the fields *in-situ*.

Apparent electrical conductivity measurements

Resistivity measurements were conducted using Wenner electrode array (Figure 4). This array uses four electrodes equally spaced along a line.

The outer electrodes (C_1 and C_2) serve as the current electrodes and the inner ones (P_1 and P_2) as potential electrodes. Soil resistivity at site was determined by injection current into the ground through current electrodes measuring the resulting voltage difference at two potential electrodes. The apparent resistivity value was calculated from the current (I) and voltage difference (ΔV).

$$\rho_a = 2\pi a \frac{\Delta V}{I} \quad (1)$$

Where; ρ_a is the apparent resistivity (ohmm) and a is the electrode spacing. The apparent electrical conductivity (ECa) was obtained inversing the apparent electrical resistivity:

$$\sigma = 1/\rho_a \quad (2)$$

Where σ is the apparent electrical conductivity (mhom^{-1}). The electrode spacing of 1.5 m was used during the resistivity measurements. The resistivity measurements were performed at the points separated 5 m in the Umuttepe engineered cover and 10 m in the Alikahya engineered cover (Figures 2 and 3). The apparent electrical conductivity maps of Umuttepe and Alikahya engineered covers are demonstrated in Figures 5 and 6. The ECa values are

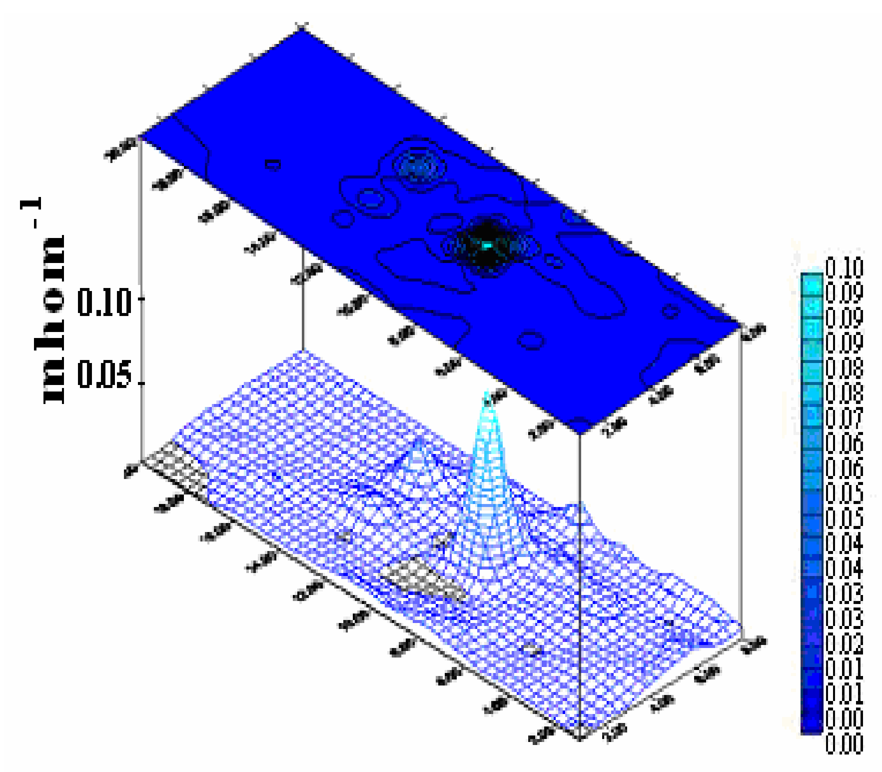

Figure 5. Apparent electrical conductivity (ECa) map of the Umuttepe engineered cover

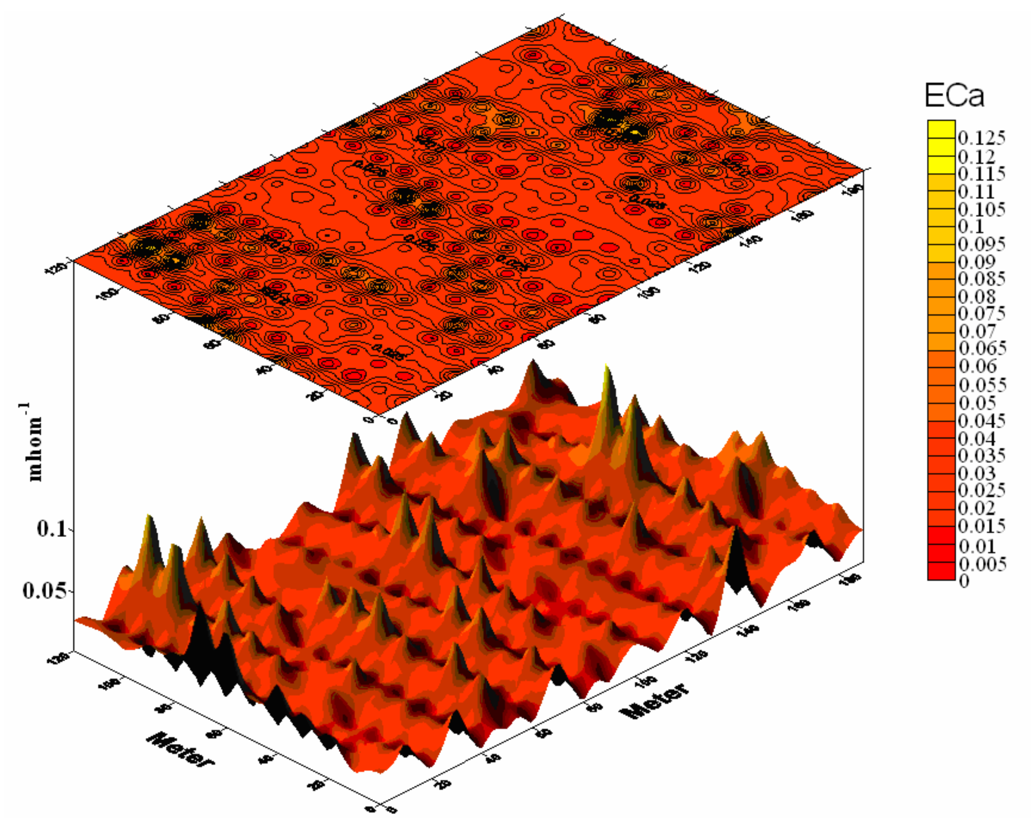

Figure 6. Apparent electrical conductivity (ECa) map of the Alikahya engineered cover.

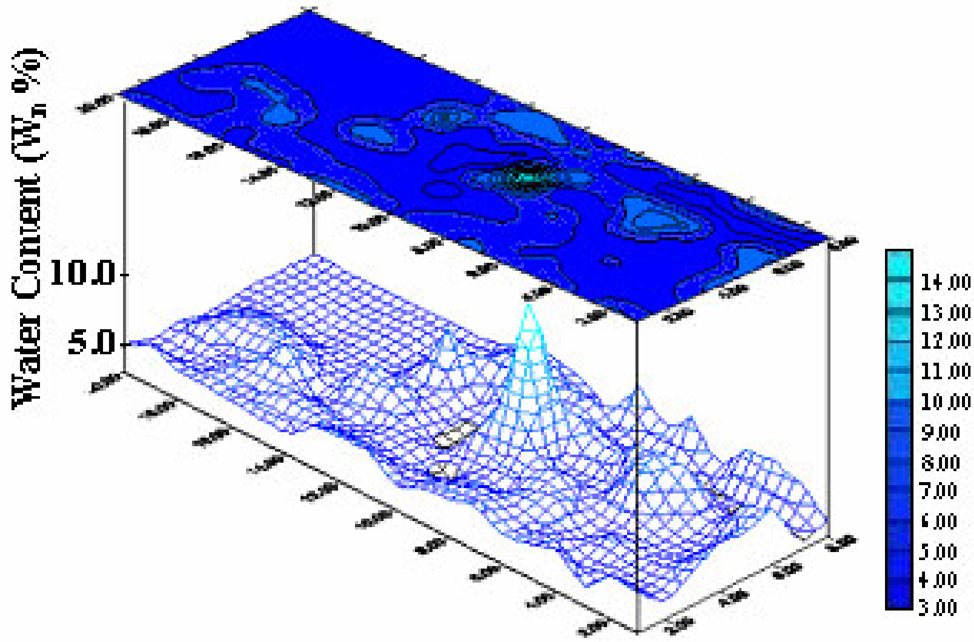

Figure 7. Water content map of the Umuttepe engineered cover.

ranged between 0.00281 and 0.0379 $mhom^{-1}$, and 0.0013 and 0.13 $mhom^{-1}$ in the Umuttepe and Alikahya engineered covers.

Determination of water content

The soil samples collected from the measuring points of the engineered covers of Umuttepe and Alikahya (Figures 2b and 3b) were analyzed for water content with the oven method in our laboratory. The water content is the ratio, expressed as a percentage, of the mass of pore water in a given mass of soil to the mass of dry soil solids. First of all, weight of the empty sample jars were recorded, and after placing the soil samples in the jars, the weight of them were measured. The jars and the store were capped at room temperature untill they were ready to proceed. When they were ready, they were placed in 105^0C oven and dried for 24 h. After allowing them to cool, their weights were measured. The water content was then determined from the the ratio of the weight of water to the weight of the solids in a given mass of soil sample. The water content maps of the engineered covers are shown in Figures 7 and 8. It can be observed from Figures 5, 6, 7,and 8 that the elevated Wn values almost corespond to the high ECa measuring points. Simple regression analysis was performed between Wn and ECa values of the Umuttepe and Alikahya engineered covers. The relations between Wn and ECa for the Umuttepe and Alikahya engineered covers are shown in Figures 9 and 10. Very good correlations were detected between Wn and Eca with the correlation coefficient of R^2=0.811 and R^2=0.819 in the Umuttepe and Alikahya engineered covers, respectively. It can be observed from Figures 5 and 6 that the ECa values are more stable in the Umuttepe engineered cover producing a maximum around the middle of the field than that of the Alikahya engineered cover showing more scattering in the area.

Determination of salinity

ECa of soils has long been used to asses soil salinity (Archie, 1942; Gupta and Hanks, 1972; Rhoades and Invalson, 1971). A linear relationship exists between ECa and the salinity of the soil.

Soil salinity was measured *in-situ* using the Field Scout soil EC probe which permits direct measurement of salts in soils. The probe of the instrument was inserted 0.3 m of depth in the engineered covers. Relation between salinity and apparent electrical cunductivity of the Umuttepe and Alikahya engineered covers are given in Figures 11 and 12. Weak relations were obtained between salinity and ECa with the correlation coefficient of R^2 = 0.0385, and R^2=0.0769 for the Umuttepe and Alikahya engineered covers. Salinity values increase slightly with increase in ECa in both engineered covers.

Determination of porosity

Porosity of the soil samples were determined using saturation method. For this aim, the beakers were first filled to the same level with the soil samples. Then the water was poured into the beakers until it reaches the top of the soil samples. Porosity was determined by dividing the volume of water that was poured into the soil by total volume of the sample.

$$n= (V_{void}/V_{total})x100\% \quad (3)$$

Where; n, porosity; V_{void}, void volume; V_{total}, total volume. Relations between porosity and apparent electrical conductivity of the Umuttepe and Alikahya engineered covers are given in Figures 13 and 14. Regression analysis indicated very weak correlations between porosity and ECa values with the correlation factor of R^2=0.0769, and R^2=0.121 for the Umuttepe and Alikahya engineered covers. Porosity increases slightly with increase in ECa in both fields.

Determination of atterberg limits

The atterberg limits are a basic measure of a fine-grained soil consisting of the liquid limit (water content at which the soil passes

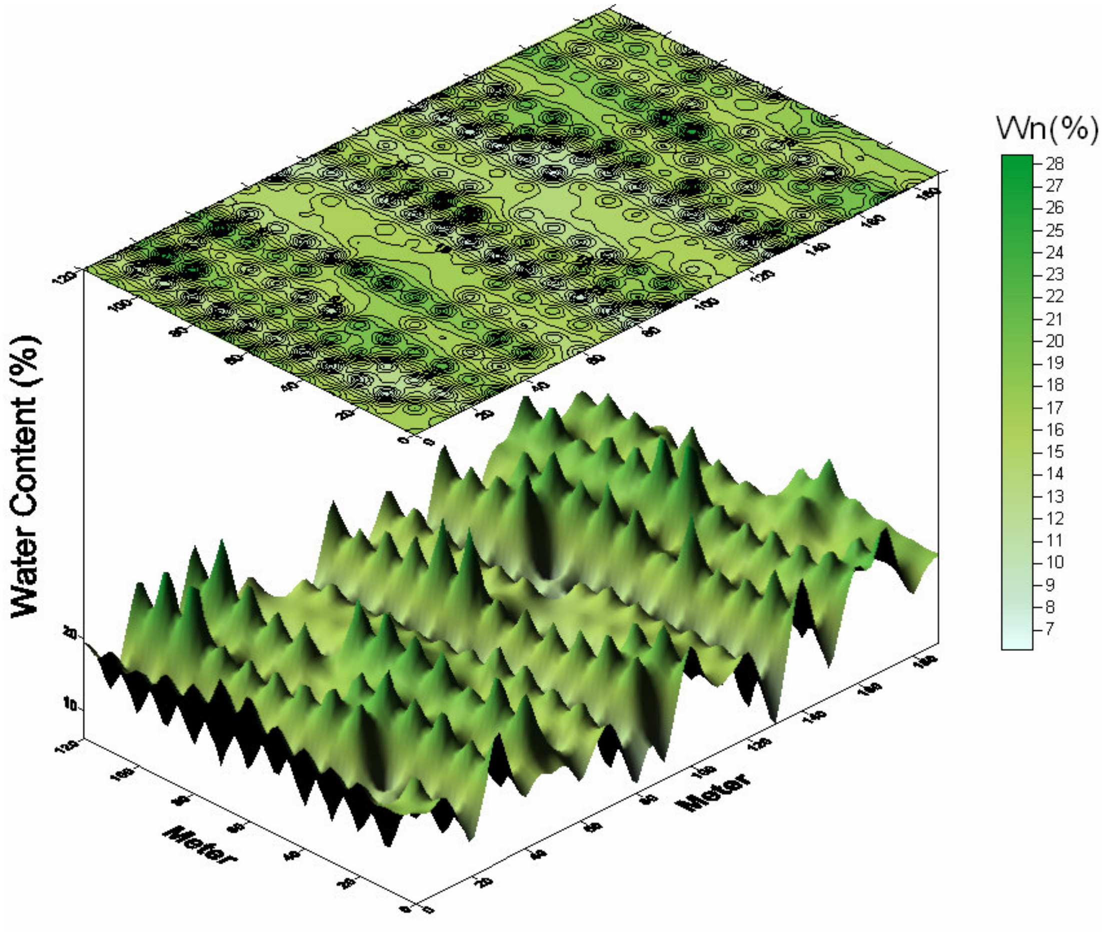

Figure 8. Water content map of the Alikahya engineered cover.

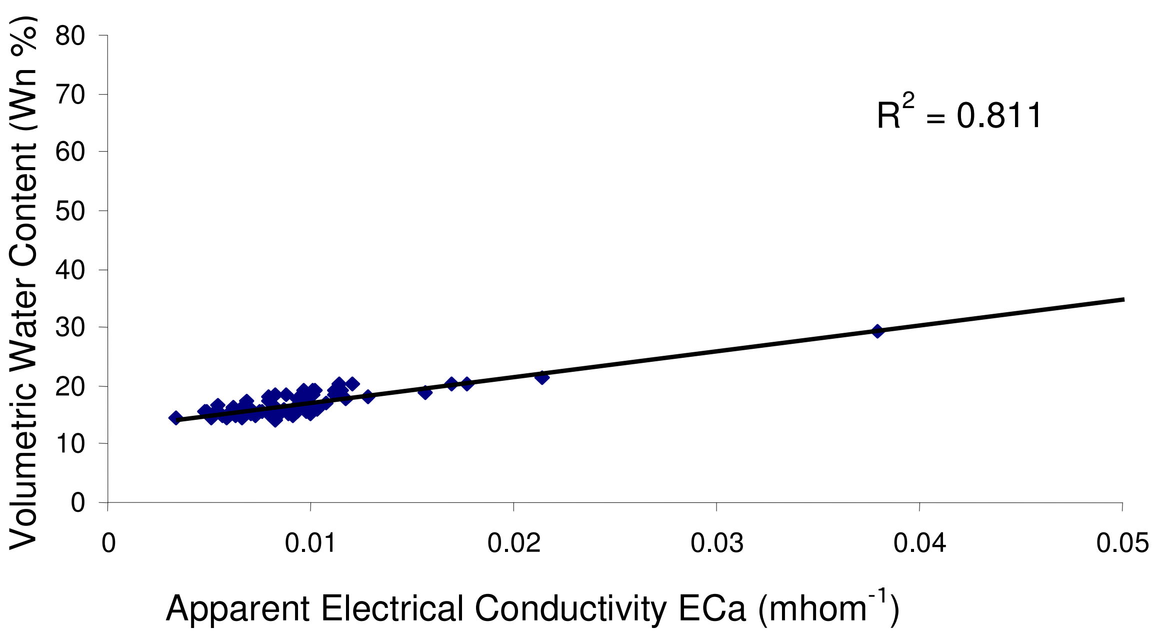

Figure 9. Relation between water content and apparent electrical conductivity of the Umuttepe engineered cover

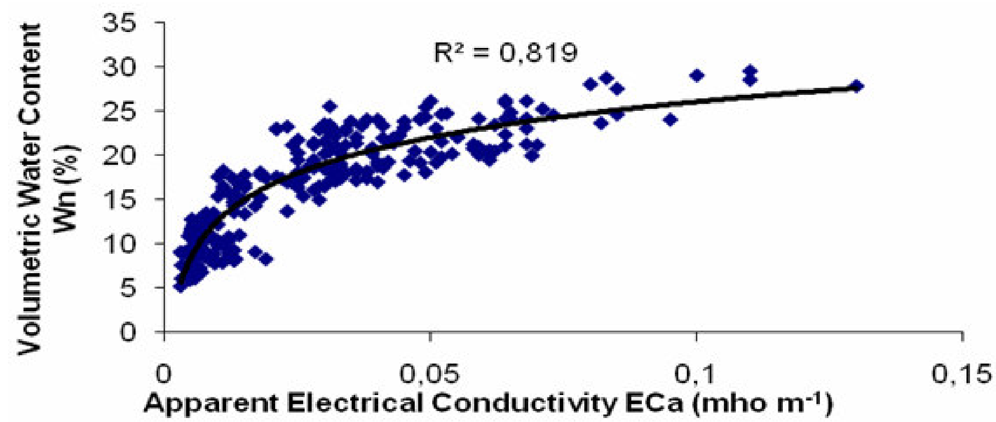

Figure 10. Relation between water content and apparent electrical conductivity of the Umuttepe engineered cover.

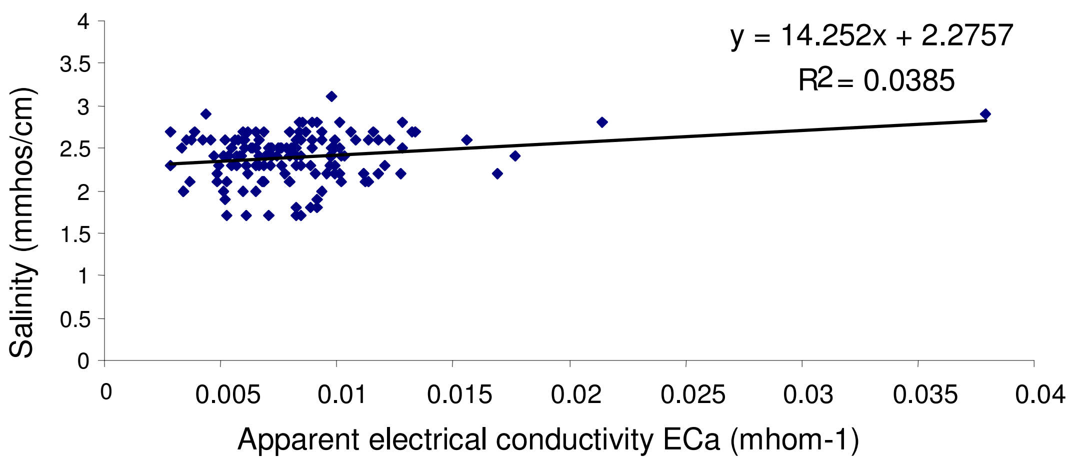

Figure 11. Relation between salinity and apparent electrical conductivity of the Umuttepe engineered cover.

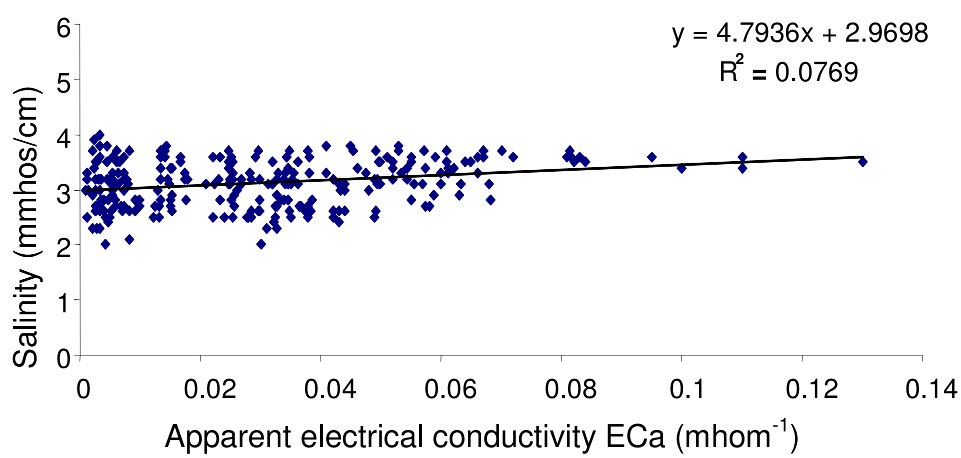

Figure 12. Relation between salinity and apparent electrical conductivity of the Alikahya engineered cover.

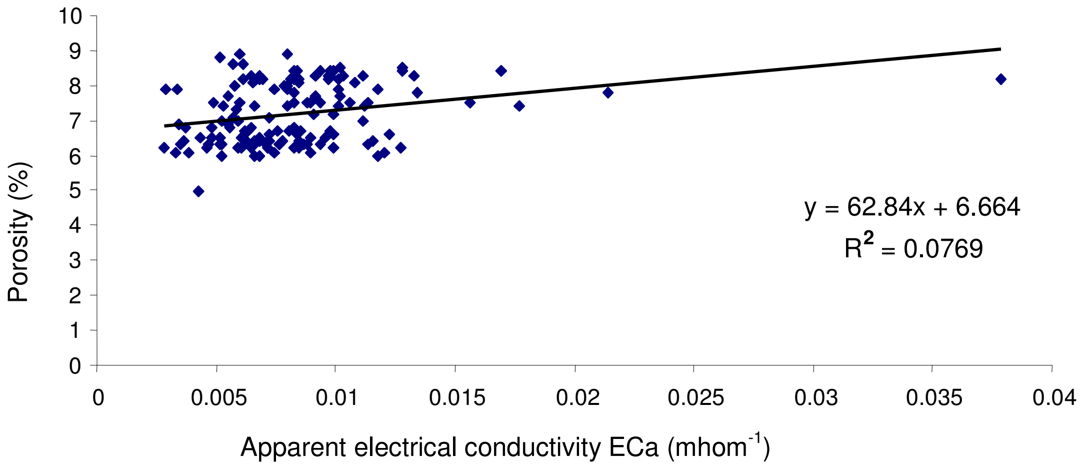

Figure 13. Relation between porosity and apparent electrical conductivity of the Umuttepe engineered cover.

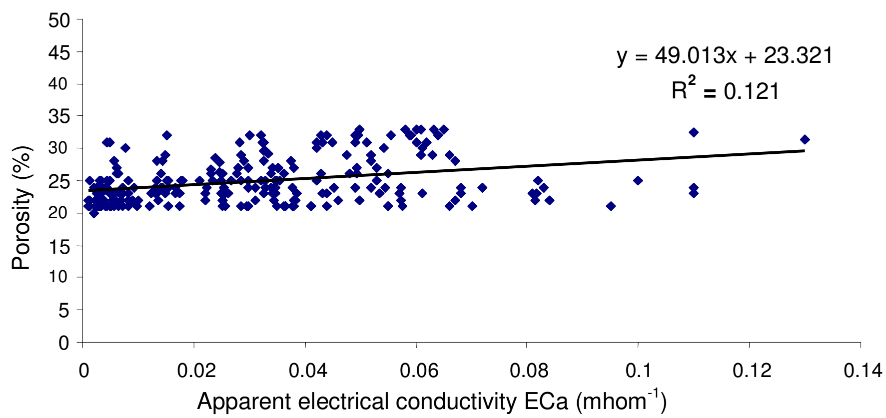

Figure 14. Relation between porosity and apparent electrical conductivity of the Alikahya engineered cover.

Table 1. Atterberg limits and soil properties of engineered covers.

Properties	Umuttepe engineered cover	Alikahya engineered cover
Liquid Limit (LL)	25-35 %	37.14-46.1 %
Plastic Limit (PL)	18-23 %	17.58-23.45 %
Plasticity Index	19-25 %	16.89-24.95 %
Compression index (Cc)	0.28-0.40	0.24-0.33
Consistency Index (Ic)	0.40-0.80	0.28-1.21
Soil Class	CL	CL-CG-SC

from the liquid to plastic state), the plastic limit (water content atwhich the soil passes from the plastic to semi-solid state) and the shrinkage limit (water content at which the soil passes from the semi-solid to the solid state). Laboratory testing (ASTM, 2000b) is required to determine the atterberg limits. The water content was measured gravimetrically then converted to a volumetric basis using bulk density samples. The atterberg limit values of Umuttepe and Alikahya engineered covers are given in Tables 1 and 2.

Determination of grain size distributions

A suitable sieve size for the aggregate of soil samples was selected and placed in order of decreasing size, from top to bottom, in a

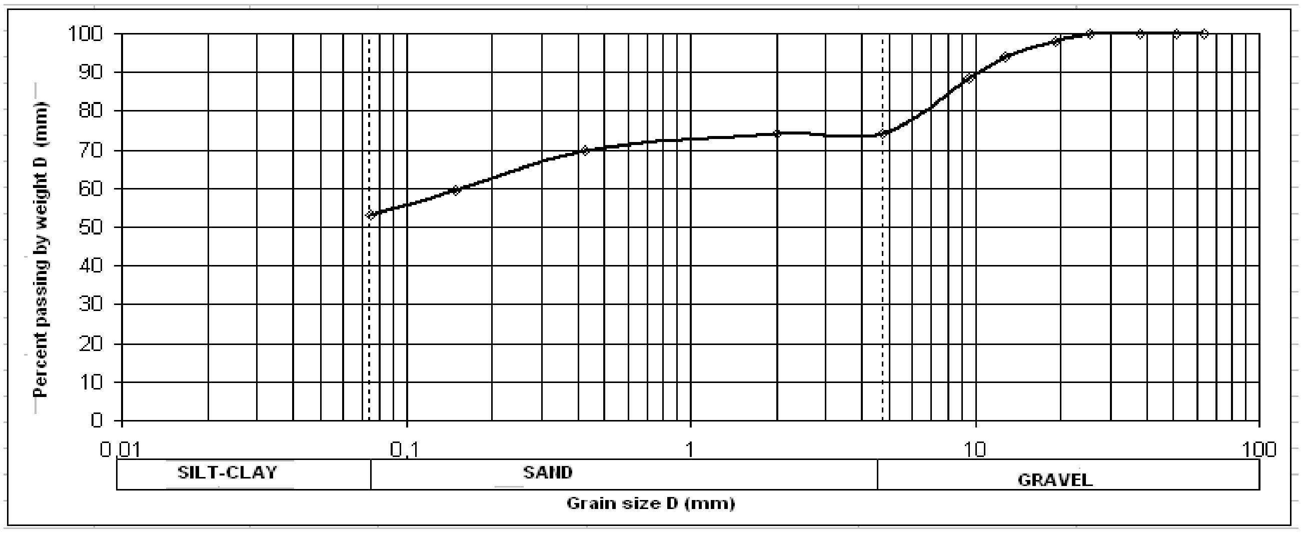

Figure 15. Gronulometry curve of sample collected at measuring point number 10 in the Umuttepe engineered cover.

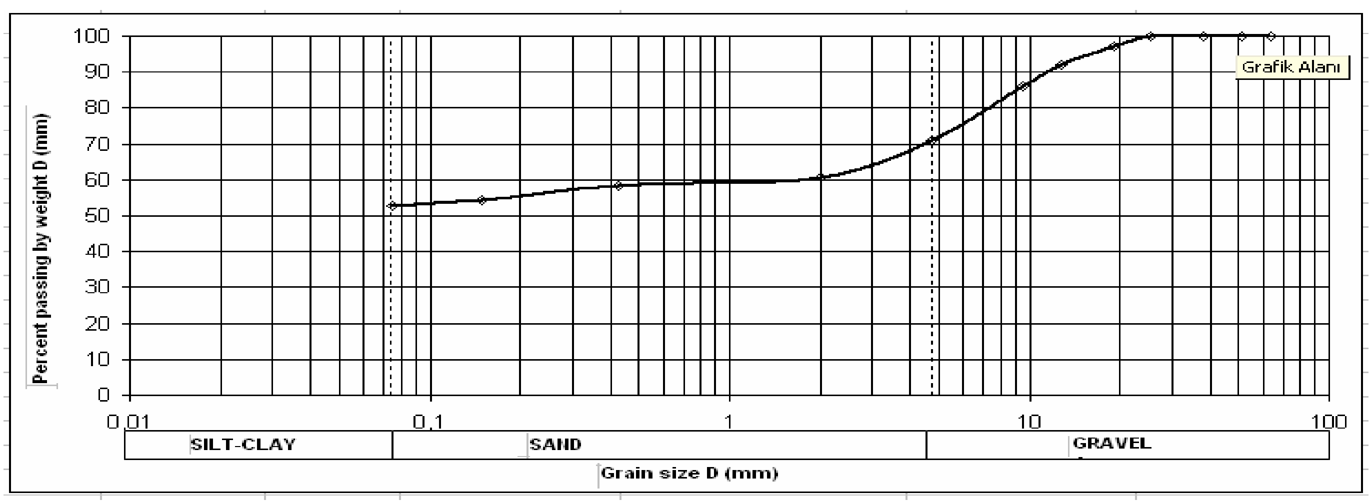

Figure 16. Gronulometry curve of the sample collected at measuring point number 28 in the Alikahya engineered cover.

mechanical sieve shaker. A pan should be placed underneath the nest of sieves to collect the aggregate that passes through the smallest. The entire nest is then agitated, and the material which has diameter is smaller than the mesh opening pass through the sieves. After the aggregate reaches the pan, the amount of material retained in each sieve is then weighed. A sample of granulometry curve is given for the Umuttepe and Alikahya engineered covers in Figures 15 and 16. The grain size distribution values of the engineered covers are given in Tables 2 and 3.

Determination of pH values

pH values of the Umuttepe and Alikahya engineered covers were measured *in-situ* using the Rapitest Soil pH Meter. The pH values of the engineered covers were measured just pushing the metal probe into wet soil and note the pH level on the display. The pH values of Umuttepe and Alikahya engineered covers are shown in Figures 17 and 18. The pH values slightly increase in Umuttepe but

Table 2. Particle size distribution of the Umuttepe engineered cover.

Gravel %	Sand %	Clay %
0-10	20-30	70-90

Table 3. Particle size distribution of the Alikahya engineered cover.

Gravel %	Sand %	Silt/clay %
13.72-33.75	16.93-35.1	31.92-57.91

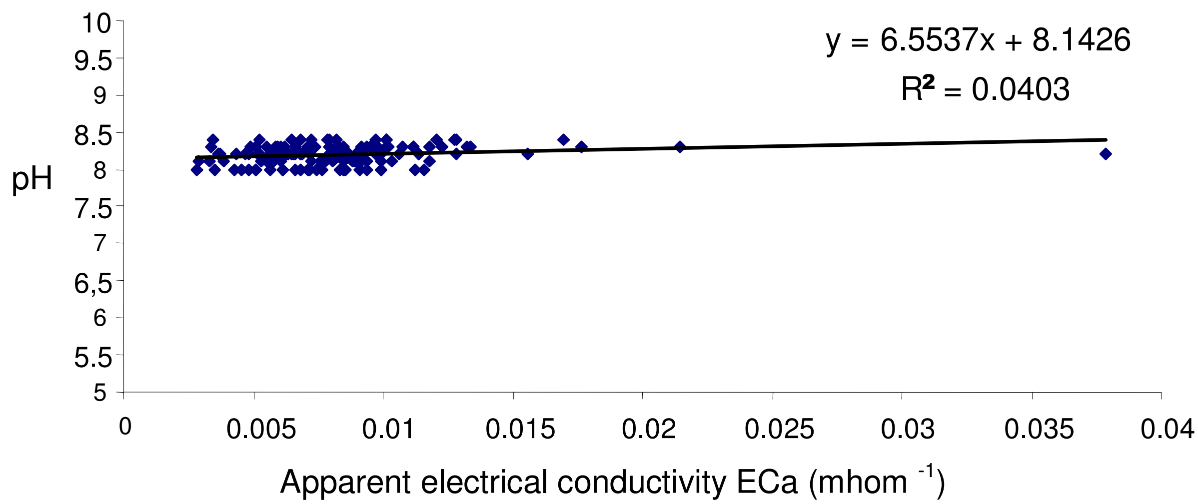

Figure 17. Relation between pH and apparent electrical conductivity of the Umuttepe engineered cover.

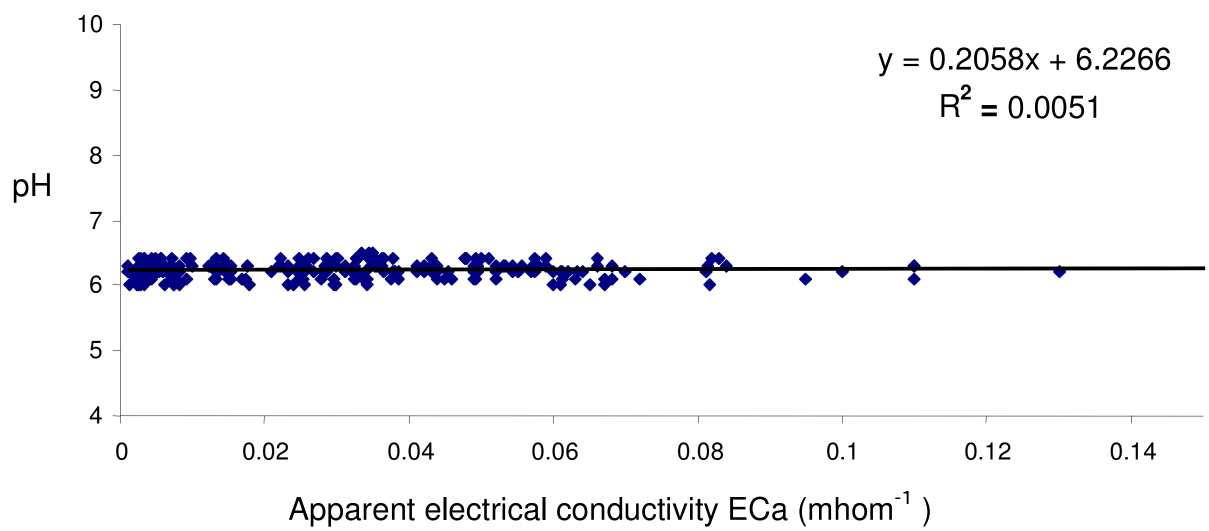

Figure 18. Relation between pH and apparent electrical conductivity of the Alikahya engineered cover.

decrease in Alikahya engineered covers. In both areas, the correlation between pH and ECa is very weak.

Determination of clay content

Clays greatly impact ECa because of their exchangable cations and the water film associated with them. However, there was little relationship between surface clay content and ECa (McNeill 1980). Clay content of each soil sample was determined by seive analysis. The relations between clay content and apparent electrical resistivity of the Umuttepe and Alikahya engineered covers are shown in Figures 19 and 20. Clay percent tends to increase slightly in ECa in both areas. However, the correlations of clay percentage and Eca is weak (R^2 = 0.1211 for Umuttepe, and R^2 = 0.0465 for Alikahya), and the effect of clay content on ECa can be considered negligible in these engineered covers.

RESULTS AND DISCUSSION

The spatial variability of soils was analyzed more easily with ECa because ECa was measured quickly from the surface with little or no soil disturbance. Thus, the influence of soil structure on $EC_{a,}$, which could be especially significant near the soil surface, was examined in two investigation engineered covers located in the Umuttepe and Alikahya Regions of Kocaeli City.

The investigation into the relationships amongst water content, porosity, salinity, pH, clay content and electrical conductivity led us to conclude that the electrical conductivity is a function of water content, porosity, salinity and clay content.

The electrical conductivity showed a good correlation

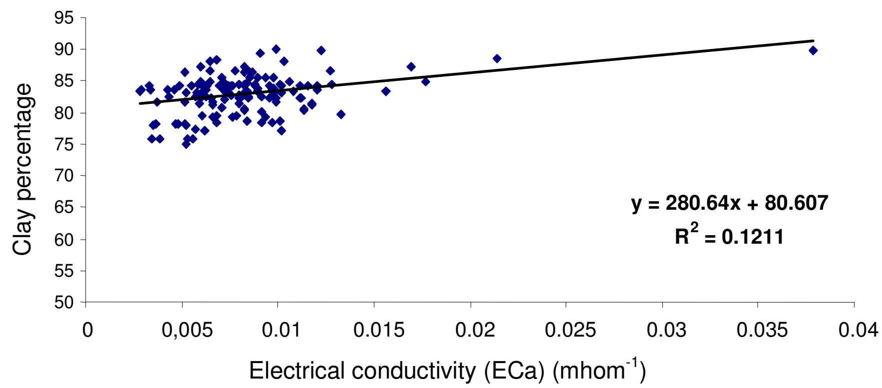

Figure 19. Relation between clay percentage and apparent electrical conductivity of the Umuttepe engineered cover

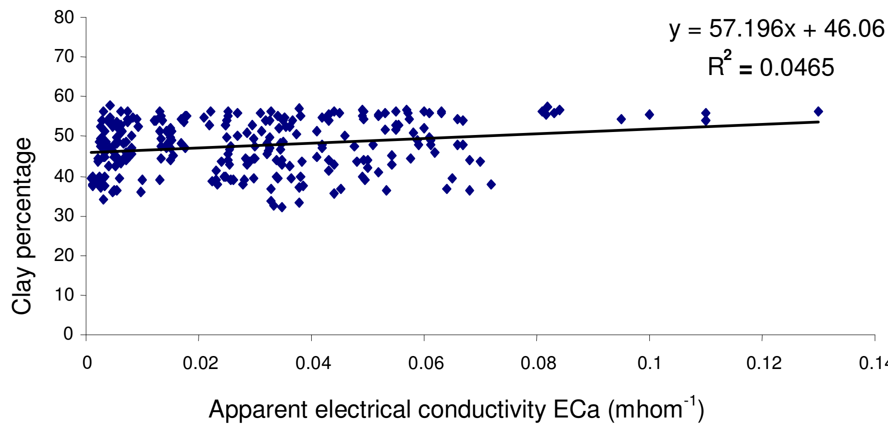

Figure 20. Relation between clay percentage and apparent electrical conductivity of the Alikahya engineered cover.

within the water content in the Umuttepe engineered cover with the correlation coefficient of R^2 = 0.811, and in that of Alikahya with the correlation coefficient of R^2 = 0.819

Clays greatly impact on EC_a because of their exchangeable cations and the water film associated with them (McNeill, 1980); however, there was little relationship between surface clay content and soil EC_a. Very weak correlations were determined with the correlation coefficient of R^2 = 0.1211 for the Umuttepe and R^2 =0.0465 for the Alikahya engineered covers. There was, however, a relationship between soil EC_a and depth to clay increase, consistent with other research studies (Doolittle et al., 1994; Sudduth et al., 1999) that related EC_a to depth of claypan.

Apparent electrical conductivity of soils has long been used to assess soil salinity. As stated by Archie (1942) and shown in several studies (Gupta and Hanks, 1972; Rhoades and Ingvalson, 1971), a linear relationship existed between EC_a and the conductivity of the soil solution in saline soils. We obtained weak correlations between salinity and EC_a with the correlation coefficient R^2 = 0.0385 for the Umuttepe and R^2 = 0.0769 for the Alikahya engineered covers. The salinity slightly increases with increase in EC_a in both engineered covers.

The variations in porosity over the investigation fields were correlated weak with the EC_a with the correlation factor R^2 = 0.0769 for the Umuttepe and R^2 =0.121 for the Alikahya engineered covers. The best fit lines tend to slightly increase with increase in EC_a for both fields. Soil EC_a readings were compared to soil pH values, but could not determine any relationships with pH most likely because the ranges of pH within the engineered covers were small.

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