CONSIDERATION OF WATER RETENTION IN SOIL USING RETC AND EXPERIMENTAL DATA

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Abstract

Unsaturated expansive soils are found throughout the world. Shrinking and swelling of the soils in response to water content change, which is one of the most common geotechnical causes of damage to civil engineering structures, is a worldwide phenomenon. The annual cost of damage to highway embankments and buildings is estimated in many billions of dollars worldwide. The cost associated with damage due to soils is more than double those of floods, hurricanes, tornadoes and earthquakes.

Determinations of unsaturated soil parameters using experimental procedures are time consuming and difficult. In recent years, the soil water characteristic curve (SWRC) has become an important tool in the interpretation of the engineering behavior of unsaturated soils.

This paper presents experimental results of SWRC and SWRCs plotted by the proposed models in RETC have been compared. A computer code, called as RETC in which several models given on the establishment of SWRC have been investigated. Physical and mineralogical features of a soil, taken from Mertekli village of Siran District of Gumushane City (Turkey), have been determined. SWRCs, belong to the clay named as Siran-1 clay, have been estimated for different ratios of additive materials of lime and cement. "Filter paper method" has been employed to estimate the SWRC in the laboratory. The best fit for SWRC for the experimental data has been found.

Key words: Retention curve code (RETC), Soil water retention curve (SWRC), Unsaturated soils, Soil suction.

Introduction

Expansive soils are found in almost all parts of the world. However, the problems caused by expansive soils are usually associated with areas of arid and semiarid climate. Because in these areas changing of climatic conditions over the year from wet to dry and vice versa, in these areas, cause moisture change within unsaturated soils near the surface and, consequently, changes in volume and surface elevations. The performance of structures supported on shallow foundations residing on unsaturated soils is largely dependent on moisture movement and its distribution in the supporting soils. Therefore, if moisture movement and its distribution in the unsaturated soil mass are predicted accurately then the soil volume change and the performance of shallow foundations resting on the soil can be reasonably estimated. Moisture changes in expansive soils might caused by different sources such as climate, vegetation, and ponded water. The process of mass flow through unsaturated soils is very complex and difficult to describe quantitatively due to the changes of unsaturated soils properties with the changes in soil suction [1].

Geotechnical engineering community have long recognized that expansive soils may result in considerable distress and consequently cause severe damage to overlying structures, particularly to low-rise buildings and buried lifelines. Numerous reports of expansive soil problems and related damages have been documented in different countries [2].

Determinations of unsaturated soil parameters using experimental procedures are time consuming and difficult. In recent years, SWRC has become an important tool in the interpretation of the engineering behavior of unsaturated soils [3]. A fundamental soil property SWRC, sometimes called as *soil water characteristic curve, SWCC,* [4] has been employed for modeling water and solute movement in a soil mass. It shows the relationship between matric suction of soil and its volumetric water content. SWRC can also be described as the relationship between water and air as the soil de-saturated. Unsaturated soils consist of more than two phases so that the natural laws governing their behavior are changed. Specification of a soil water retention curve is necessary for most efforts at modeling soil water behavior [5]. SWRC is key information for unsaturated soils properties, was used in numerous investigations [6], [7]. Satisfactory predictions of shear strength functions can be made for the unsaturated soil after a reasonable estimate of SWRC is obtained [8]. Unsaturated hydraulic conductivity and moisture contents are determined by SWRC [9]. A large number of theories have been developed to study the effect of spatial variability of what on flow and transport in unsaturated zones as well as saturated zones [10], [11], [12], [13], [14], [15], [16], [17]. Many models have been proposed to estimate SWRCs of soils by a number of researchers [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29]. Each of these models requires several parameters of a soil such as air entry value, saturated water content, residual water content etc. Thus, some experiments are still needed to be performed since the parameters above must be known in order to use the models. Also, SWRC has been described by numerous mathematical functions [5]. RETC (RETention Curves) is a computer code uses the parametric models of Brooks- Corey and van Genuchten to represent the SWRC and the theoretical pore-size distribution models of Mualem and Burdine to predict the unsaturated hydraulic conductivity function from observed soil water retention data.

In fact, SWRC is often used to determine the unsaturated hydraulic conductivities. Both of the hydraulic properties (saturated and unsaturated states) are essential for modeling water flow and estimating soil water content, or water availability. However, the standard laboratory and field procedures that are used to determine the soil water retention curve are tedious and time consuming. This is particularly true if numerous samples are required to characterize the spatial variability of a field or watershed. For these reasons, several methods have been proposed to estimate the SWRC from simpler soil properties. These attempts have employed various techniques, including multiple regression analysis, similar-media scaling, and physico-empirical models. Each of these methods has inherent advantages and disadvantages. Functions given by Brooks-Corey (1964) and van Genuchten (1980) have been most widely adopted to describe SWRCs.

RETC uses the parametric models of Brooks-Corey and van Genuchten to represent the SWRC and the theoretical pore-size distribution models of Mualem and Burdine to predict the unsaturated hydraulic conductivity function from observed soil water retention data. A non-linear least-squares parameter optimization method is used to estimate the unknown coefficients in the hydraulic models. The model incorporates menu-driven data entry. This retention curve model for soil water includes the executable and source codes.

In this study, soil water retention curves, belong to the clay named as Siran-1, have been estimated for natural state and different proportion of lime and cement additive state of soil by using "filter paper method". Also, soil water retention curves of Siran-1 clay have been plotted by computer software named as RETC and these curves have been compared with those of in literature.

Material and Method

Siran-1 clay, taken from Mertekli village of Siran District of Gümüşhane City, has been used (Fig.1). Siran-1 clay plain (with no additive materials), and with additive materials of cement, and lime, is used to examine the proposed models given in RETC. Basic soil properties are measured experimentally in soil mechanics laboratory. Soil suction measurements have been performed by the filter paper method. The method provides reasonable accuracy for large variations of soil moisture conditions and requires minimal equipment.

Computer Code RETC

RETC is a computer code that can be used to estimate soil water retention curve, and hydraulic conductivity of unsaturated soils [30]. In the computer code, Brooks-Corey, and van Genuchten models are used in order to estimate SWRCs. The code allows users to use four parameters if only soil water retention curve is preferred to be established. One of the parameters is residual water content (θ_r), which is the maximum amount of water in a soil that will not contribute to liquid flow because of blockage from the flow paths or strong adsorption onto the solid phase [31]. Second parameter is saturated water content t (θ_s), sometimes also referred to as the satiated water content, denotes the maximum volumetric water content of a soil. The last two parameters are called shape factors of α□and n.

There are three new features in RETC. First one is a direct evaluation of the hydraulic functions when the model parameters are known. Second a more flexible choice of hydraulic parameters to be included in the parameter optimization process. Finally, the possibility of evaluating the model parameters from observed conductivity data rather than only from retention data, or simultaneously from measured retention and hydraulic conductivity data.

Soil Properties

The Siran-1 clay, used in the experimental work, was taken from Mertekli village of Siran District of Gumushane City, Turkey. Physical properties of Siran-1 clay with no additives are seen in Table 1. X-ray diffraction analysis, differential thermal analysis, and grain size distribution curve of the soil have been determined. By these tests, it has been found that the soil has expansion characters namely Ca-smectite, and illite. Some physical properties of Siran-1 clay are natural density: 19.2 kN/m^3, dry density: 13.5 kN/m^3, natural water content: 42.5%, coefficient of permeability: 1.3x10^{-9} m/s. Plastic properties of Siran-1 clay with additive materials are also determined and given in Table 1. These types of soils are called as swelling soils or expansive soils [32].

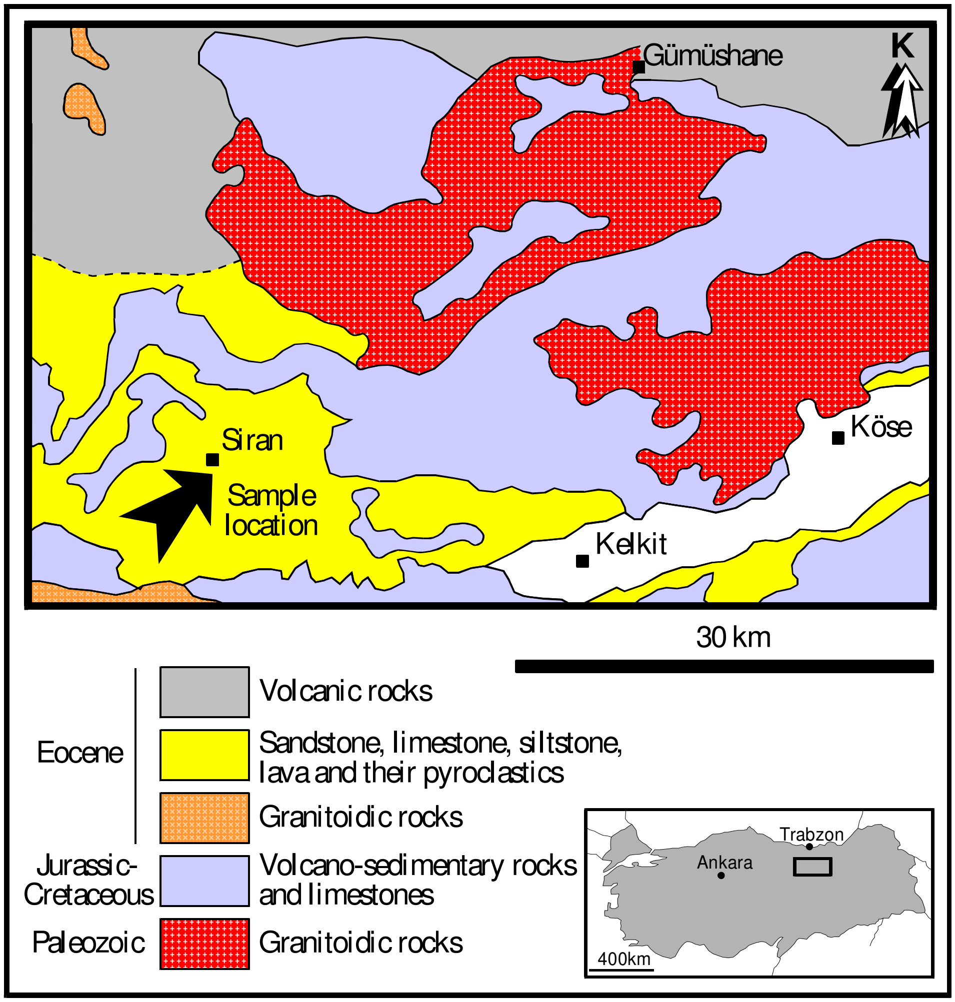

Figure 1. Sample Location

Properties of Additive Materials

Components of the additive materials lime and cement are seen in Table 2. Physical properties of the Siran-1 clay with additive materials are also given in Table 1.

Table 1. Some properties of Siran-1 clay with additives

Specimens	Grain density (kN/m^3)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Siran-1 clay (no additives)	23.7	104.8	56.72	47.58
4% lime	23.8	99.5	74.30	25.20
7% lime	23.9	82.6	65.97	16.60
11% lime	24.0	79.7	64.40	15.30
4% cement	24.0	97.2	46.50	45.70
8% cement	24.2	101.7	73.00	28.70
12% cement	24.4	83.7	58.25	25.50

Table 2. Properties of the additive materials

Chemical analysis (%)	Lime	Cement
CaO	72.0	49.2
MgO	2.6	1.4
SiO_2	1.8	30.3
Al_2O_3	1.7	8.4
Fe_2O_3	1.7	2.9
SO_3	_	2.4
Other	_	2.5
Heat loose	21.9	2.9
Free lime	_	1.6
Mechanical analysis (% pass)		
Sieve 950	99	100
Sieve 900	_	99.7
Sieve 4700	_	95.5
Sieve 4900	90	_

Filter Paper Method Used in the Experiments

Soil suction is one of the most important parameter describing the moisture condition of unsaturated soils. The measurement of soil suction is crucial for engineering applications in unsaturated soils. The filter paper method is a laboratory test method [33], and it is inexpensive and relatively simple. The filter paper method is used as an indirect means of measuring soil suctions. The advantages of the method include its simplicity, its low cost, and its ability to measure a wide range of suctions. The results show that measurement of both the components of suction using the filter paper method is simple and useful in engineering analysis [34]. Both total and matric suction can be measured with the filter paper method. The working principle behind the filter paper method is that the filter paper will come to equilibrium with the soil either vapor flow or liquid flow, and at the equilibrium, the suction value of the filter paper and the soil will be the same. If the filter paper and the soil are not in direct contact, then only total suction is measured. However, if the filter paper and soil are in intimate contact, then only matric suction is measured. In this study, matric suction of Siran-1 clay was measured by the filter paper method in which Whatman No. 42 filter paper is employed.

Measurements

The filter paper method was employed to measure suction values of Siran-1 clay since the method is inexpensive, the results can be taken in a short time, and no need to special equipment when compared to the other methods. Also suction value range is larger than the other methods to measure soil suction values. Soil suction measurements of the clay taken from the region Siran have been done as it is described in ASTM D 5298-94. The soil suction measurements have been done with the increased water contents of Siran-1 clay. In the tests, filter paper Whatman No. 42 has been employed. The specimens in the jars have been stayed seven days in order to have water content equilibrium between the specimens and filter paper. Then, mass of the filter papers are measured using an electronic balance that has a sensitivity of 0.001 gr. After calculation of volumetric water contents of the filter papers, the calibration curve is used to estimate the matric suction of each of the specimens. Estimated matric suction values versus volumetric water contents of Siran-1 clay with no additive materials are plotted as seen in Fig.2.

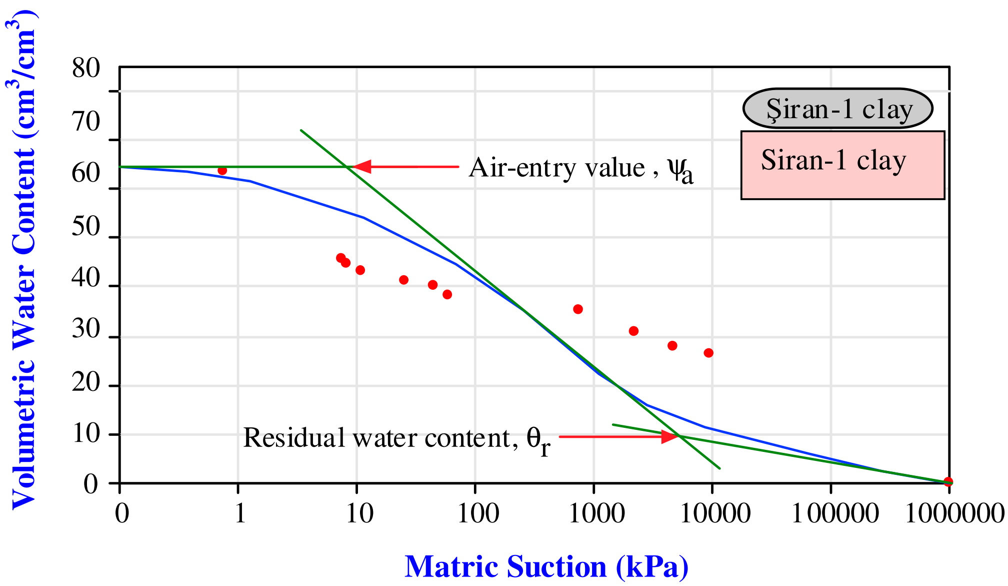

Figure 2. The relationship between volumetric water cont and matric suction of Siran-1 clay with no additives

The residual water content (θ_r) and matric suction (ψ_r) of Siran-1 clay have been estimated as 10% and 8475 kPa, respectively. On the other hand, air entry value is found to be 9 kPa in Fig. 2. Also, estimated matric suction values versus volumetric water contents of Siran-1 clay with, 4%, 7%, and 11% lime added are seen in Fig.3a, 3b and 3c, respectively. On the other hand, SWRCs of Siran-1 clay with 4%, 8% and 12% cement added are seen in Fig. 4a, 4b and 4c, respectively. When the shapes of the SWRCs that are plotted for 4% lime added (Fig 3a.) and 4% cement added (Fig.4a) specimens are compared to one another, it is observed that the changes of soil matric suction is not much for 4% cement added specimens but 4% lime added specimens have a larger changes on soil matric suction. Figs.4a to 3c show that cement additive makes soil not sensitive to matric suction in terms of volumetric water contents between 10% and 60% whereas lime added specimens are more sensitive for same range of volumetric water content. Similar results are seen when Figs.3b and 3b, 2c and 3c are compared. It is also observed that the changes of soil matric suction are limited between 10% and 45% of volumetric water contents of cement added specimens. Sharp changes of volumetric water contents are more visible for cement added specimens when compared the changes for lime added specimens (Figs.3a, 3b, 3c, 4a, 4b, 4c).

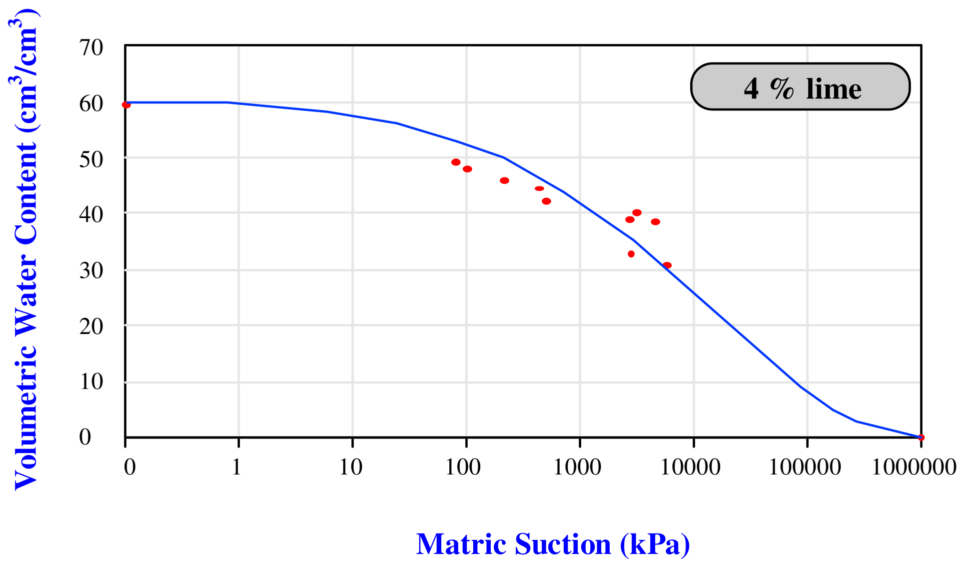

Figure 3a. SWRC of 4% lime added specimen

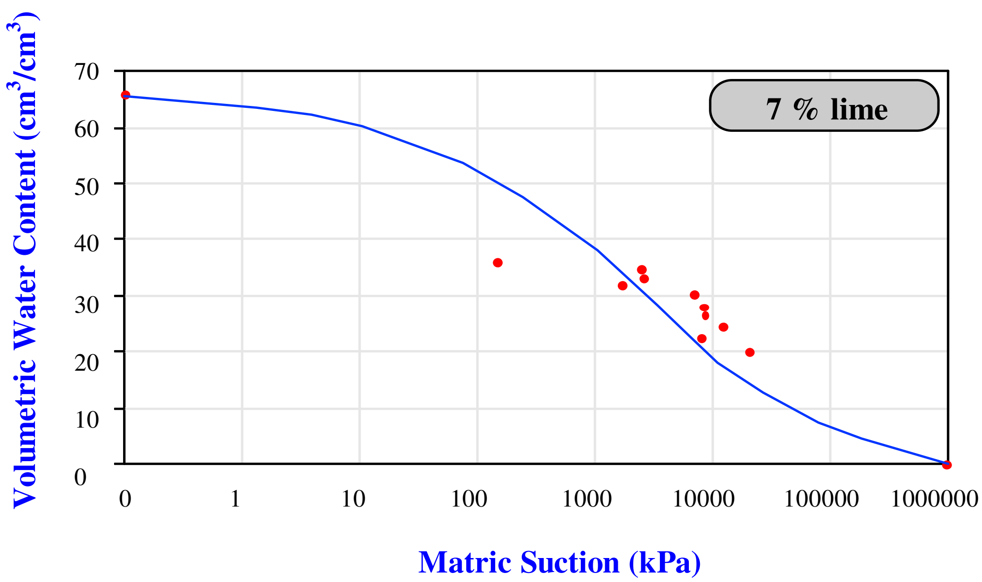

Figure 3b. SWRC of 7%lime added specimen

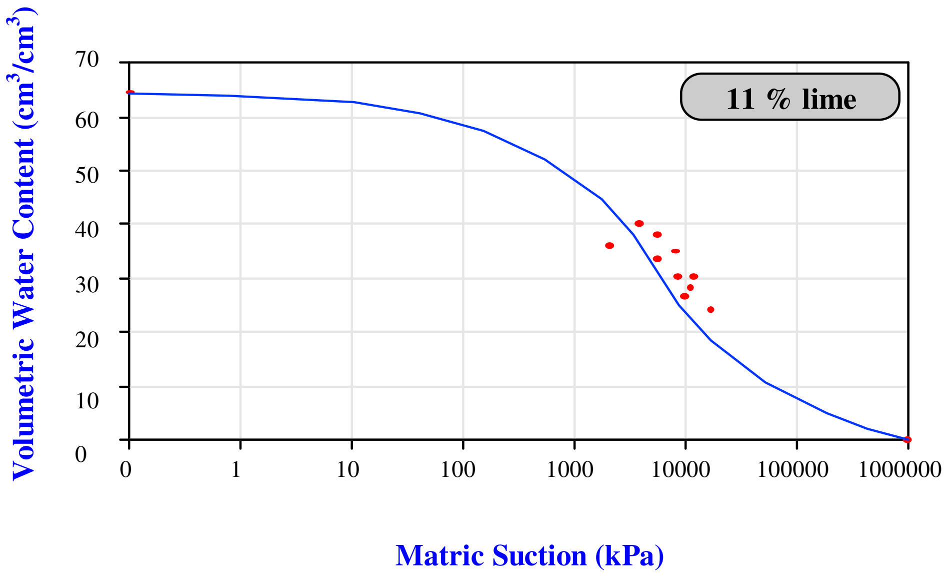

Figure 3c.SWRCs of 11%lime added specimen

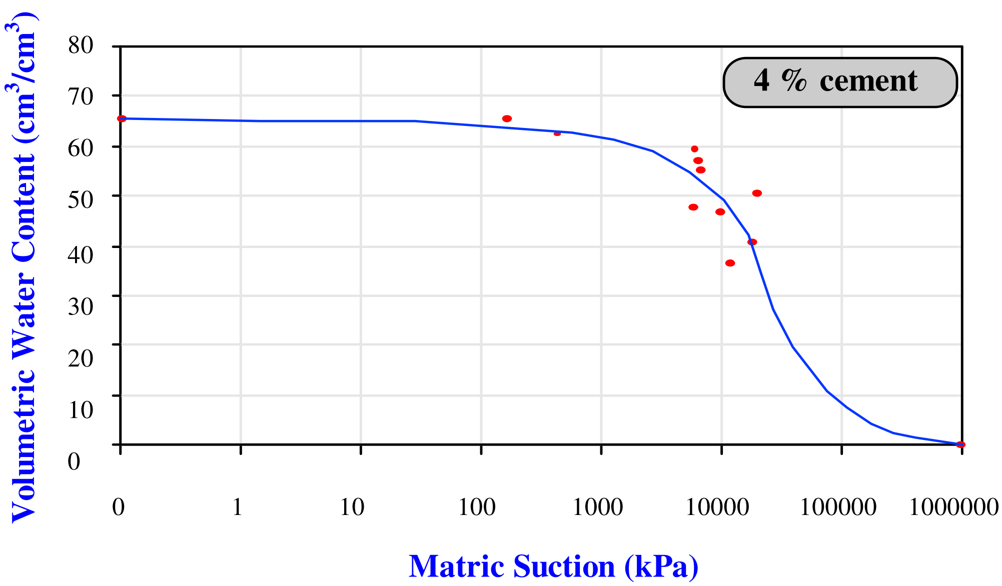

Figure 4a. SWRC of 4% cement added specimen

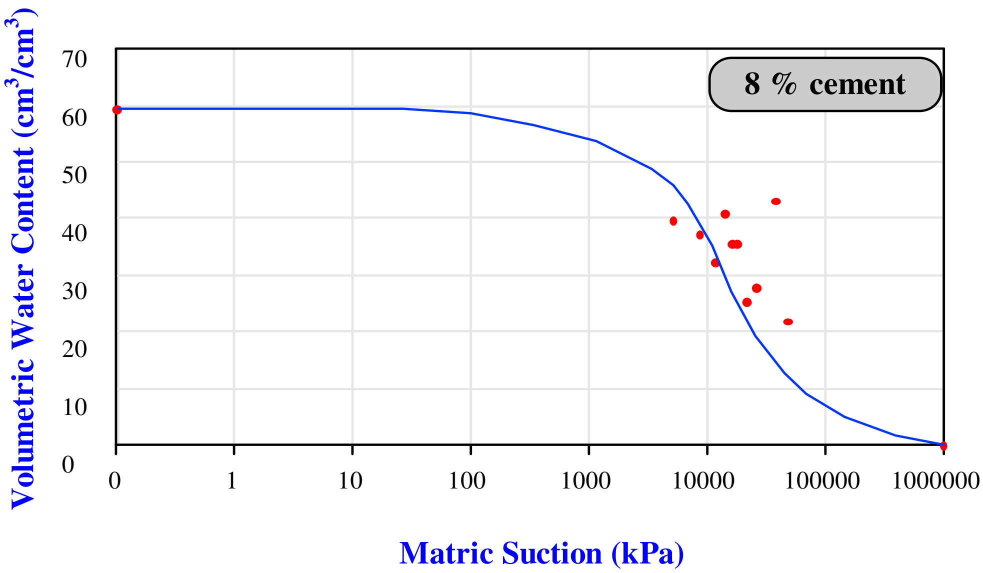

Figure 4b. SWRC of 8%cement added specimen

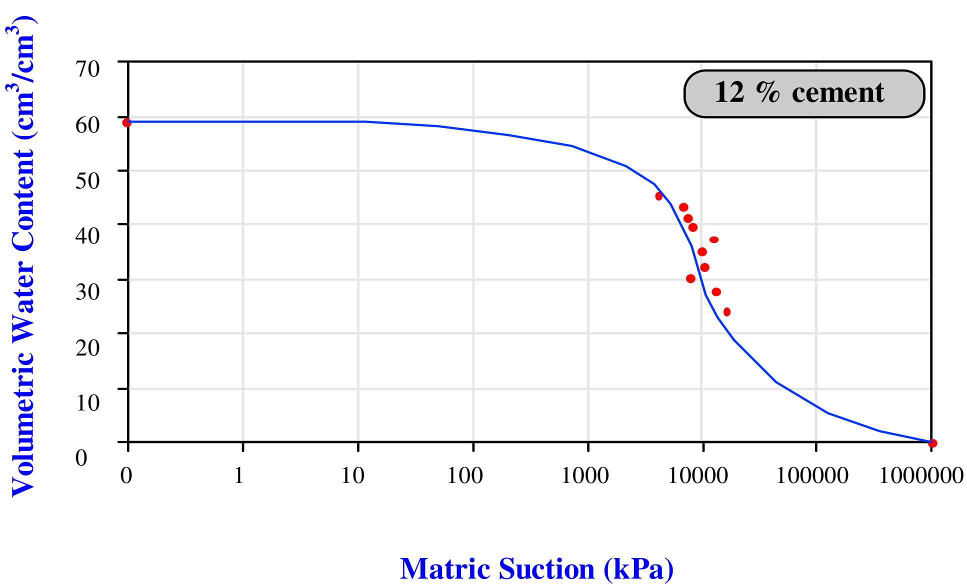

Figure 4c. SWRC of 12%cement added specimen

Results and Discussion

The SWRC in RETC computer code is represented by the equations of van Genuchten (vG) or Brooks-Corey (BC), while hydraulic conductivity function is formulated in terms of the statistical pore size distribution models of Mualem and Burdine. Inspection of effective saturation of the soil shows that the SWRC contains five parameters. These parameters are the residual water content (θ_r), the saturated water content (θ_s), and the shape factors α, n, and m. Evaluation of the experimental data has been done by RETC computer code. The relationship between volumetric water content and soil matric suction of Siran-1 clay is seen in Fig. 5. The relations have been plotted for two models of Brooks-Corey and van Genuchten, which use the Burdine and Mualem's unsaturated hydraulic conductivity functions.

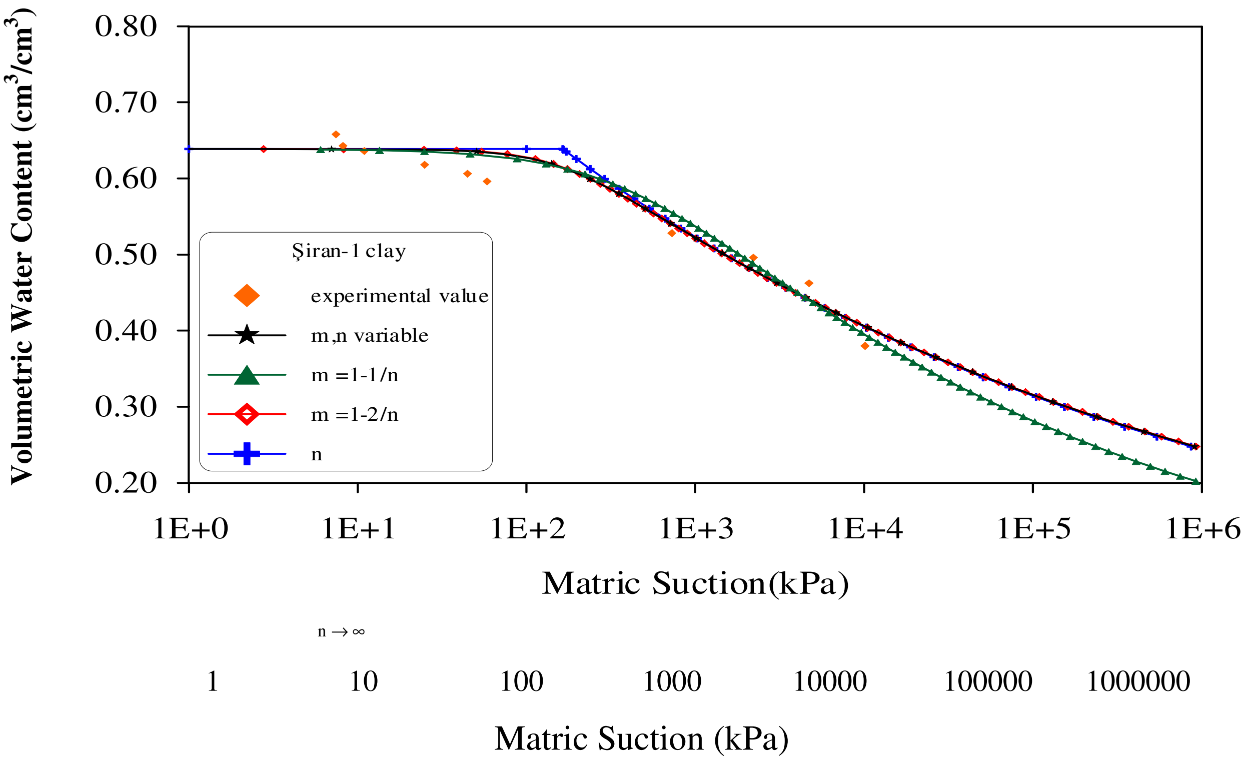

Figure 5. SWRC of Siran-1 clay plotted by RETC code

The equation of BC, (n→∞) and the equation of vG, with the variables m and n (m=1-2/n) give similar results. However, the SWRC estimated by the equation of vG with the limited variables m and n (m=1-1/n) has given a little bit different values over a soil matric suction value of 10000 kPa comparing the other equations, the SWRC fits the experimental data observed in this study. The BC equation for Touch silt loam produces an unacceptable fit whereas the vG equation with restricted m, n values produces results which are essentially identical to those for the general case when m and n are independent [30].

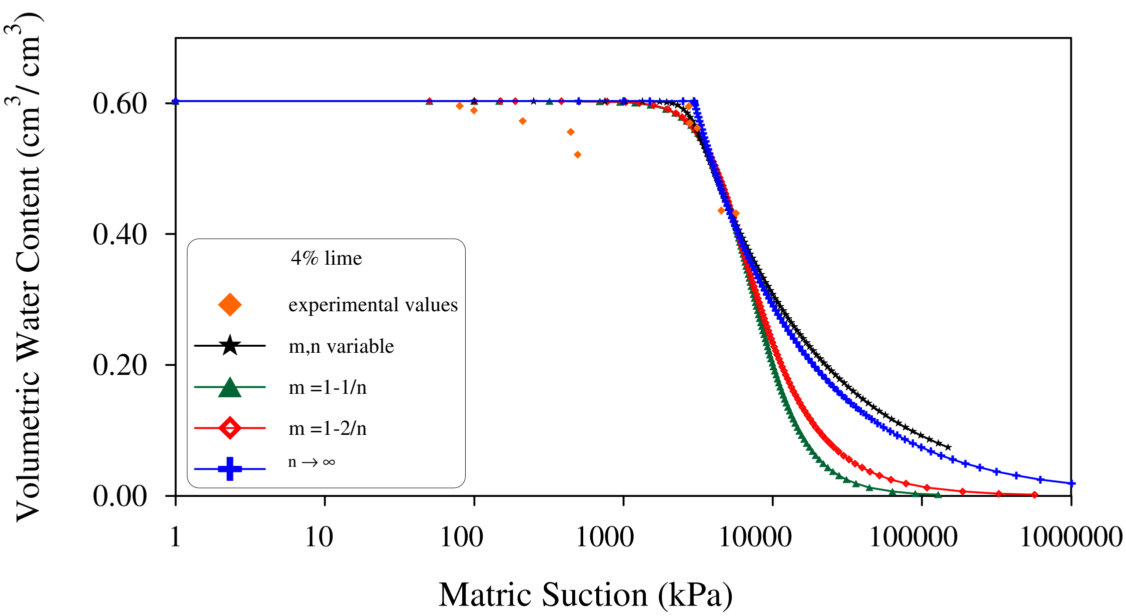

Figure 6a. SWRC of 4%lime added specimen plotted by RETC code

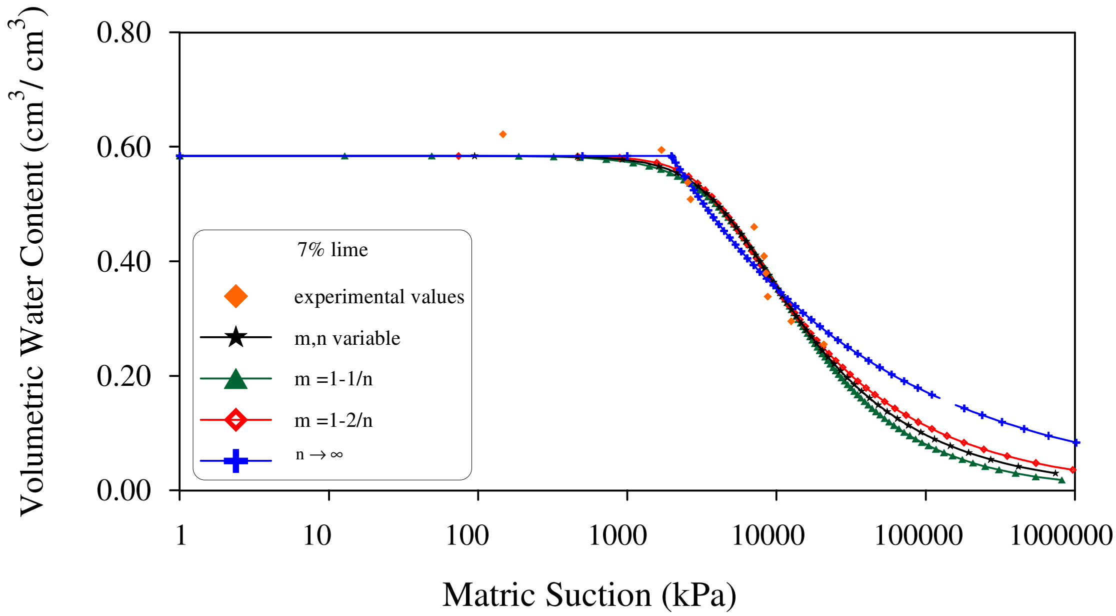

Figure 6b. SWRC of 7%lime added specimen plotted by RETC code

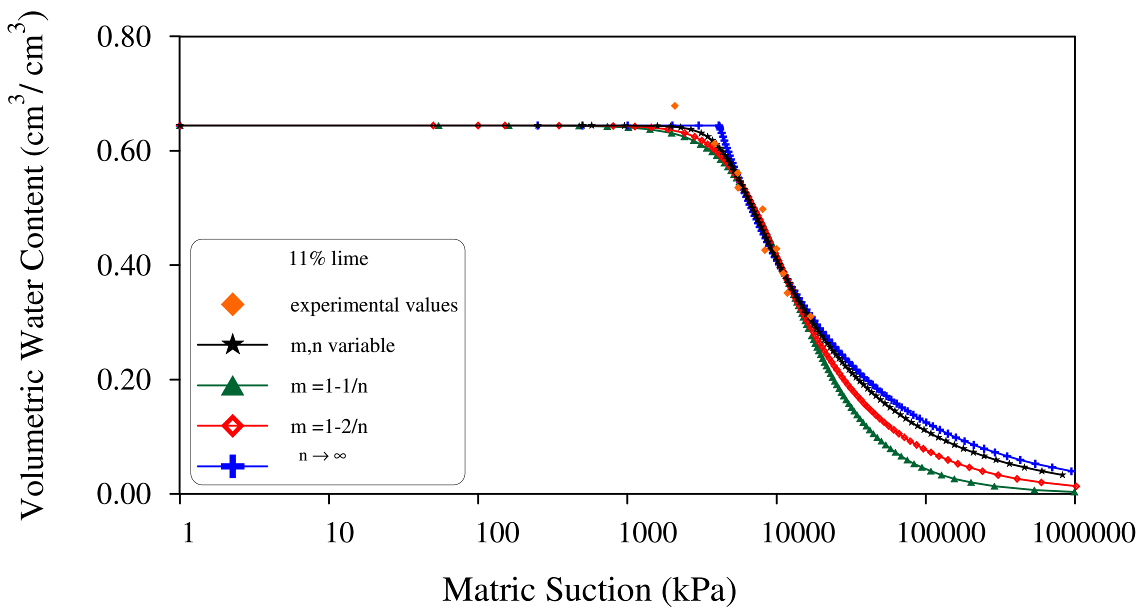

Figure 6c. SWRC of 11%lime added specimen plotted by RETC code

Figure 6a, 6b, and 6c show that the relationship between the experimental data and SWRC that is plotted by RETC code. The SWRC is strengthened with increased additive ratios at lime added specimen. At 4% lime added specimen, SWRCs of vG with limited variables m,n and BC($n \rightarrow \infty$) are separated in two groups (Fig.6a). At 7% lime added specimen, the SWRCs are different from the experimental results and the other SWRCs (m=1-1/n and m=1-2/n). On the other hand, at 11% lime added specimen, general ways of curves are suitable not only for experimental data but also with each other. Difference among the SWRCs is due to definitively case for low volumetric water contents. Similar case, experimental data and results, which obtained by Hunks et al., (1962) were appeared for SWRC plotted by RETC [30]. At lime added specimens, experimental data and SWRCs have shown contrast when matric suction is over 10000kPa. In addition to the both SWRCs estimated by vG and BC are similar to one another and SWRCs are fit into experimental data at matric suction below the value of 10000 kPa (Fig.6a, 6b, and 6c).

Figure.7a shows that at 4% cement added specimen, SWRC of BC is unfit SWRC of vG with limited variables m, n (m=1-1/n and m=1-2/n). Besides the SWRCs of vG are identical to each other, it is disappeared with decreasing volumetric water content.

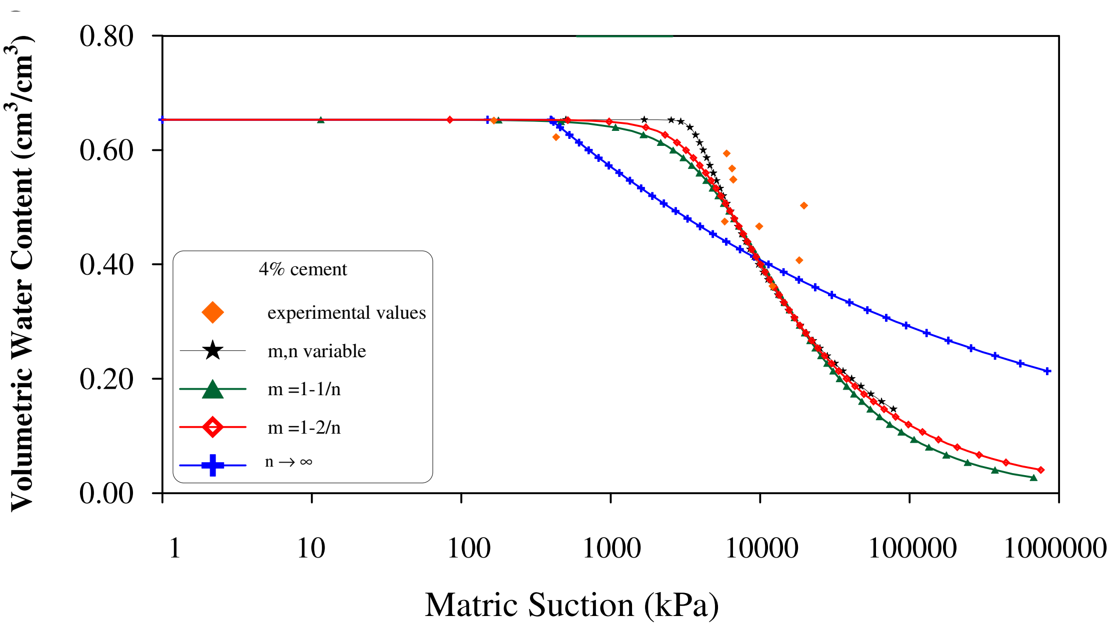

Figure 7a. SWRC of 4% cement added specimen plotted by RETC code

At 8% cement added specimen, although SWRCs have small differences comparing to each other, they have acceptable fit respect to SWRCs, which plotted by lime added specimens. Experimental data are illustrated in Fig.7b. For volumetric water contents between 25 and 55 percent, SWRCs estimated using equations BC and vG are acceptable. While volumetric water content is decreasing, SWRCs go away from each other but ways of curves have continued similarly. This case is shown parallel with SWRC of GE sands plotted by RETC code determined by King (1965) (van Genuchten *et al*.,1991). Figure 7c shows that BC at 12% cement added specimen with vG in which m, n are independent, is exactly fit. For vG with limited variables m, n is unacceptable. Similar experimental data of welt clay loam, which obtained by Jenson et al. (1967) were evaluated similarly (Van Genuchten *et al.,* 1991).

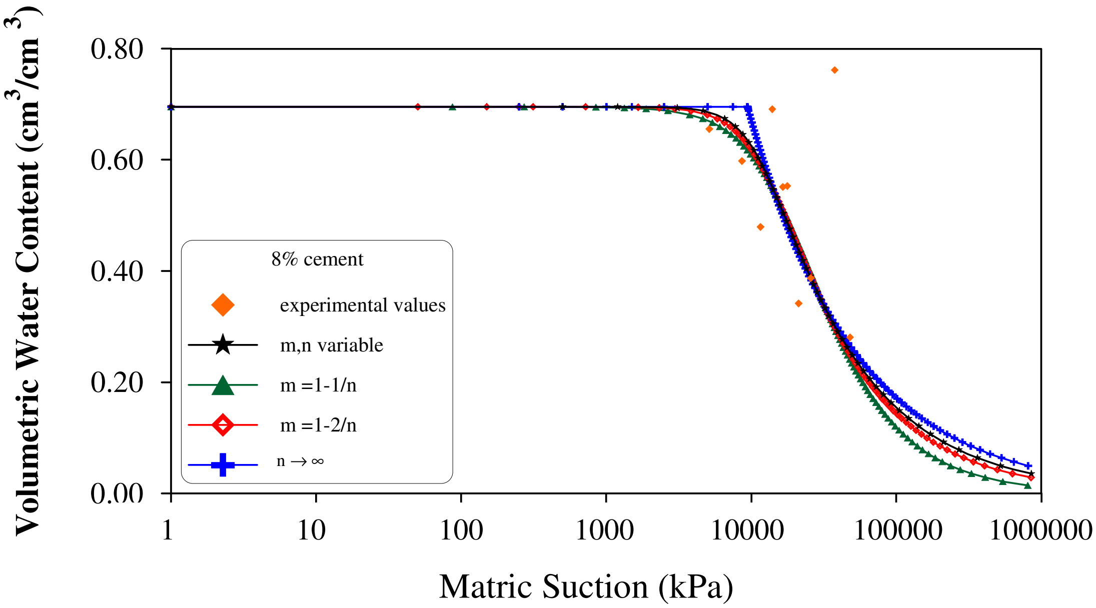

Figure 7b. SWRC of 8% cement added specimen plotted by RETC code

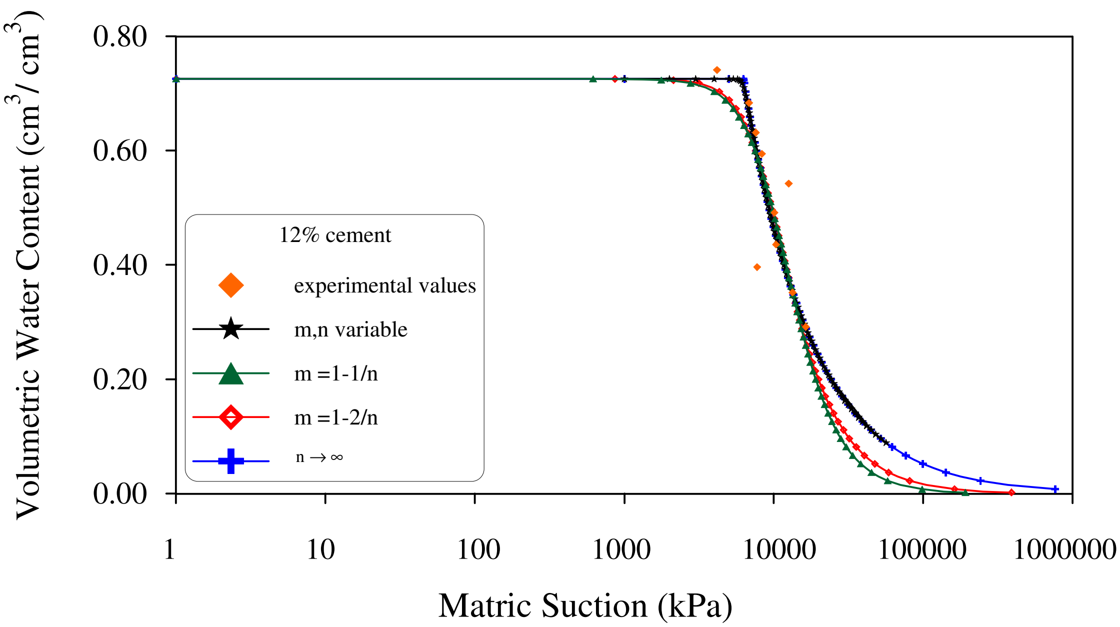

Figure 7c. SWRC of 12% cement added specimen plotted by RETC code

Conclusions

In this study, soil water retention curves (SWRCs) of Siran-1 clay with no additive and with lime and cement additives in different ratios have been estimated in the laboratory and the experimental results are compared with the models given in RETC computer code, and following conclusions are reached. The best fit is found to be the equation of vG with the shape factors of m and n with dependable values of m=1-1/n. The residual water content (θr) and matric suction (ψr) of Siran-1 clay have been estimated as 10% and 8475 kPa, respectively. The SWRCs are strengthened at increased additive ratios at lime added specimens. Differences among the SWRCs are due to definitively case for low volumetric water contents. The equation of Brooks-Corey (BC), ($n \rightarrow \infty$) and the equation of van Genuchten (vG), with the variables m and n (m=1-2/n) give similar results. However, the SWRC estimated by the equation of vG with the limited variables m and n (m=1-1/n) has given a little bit different values over a soil matric suction value of 10000 kPa comparing the other equations, the SWRC fits the experimental data observed in this study. Sharp changes of volumetric water contents are more visible for cement added specimens when compared the changes for lime added specimens.

It is known that the filter paper method has ability to measure a wide range of suctions. However, measurement sensivity decreases because of the wide range. In spite of this situation, filter paper method is recommended for its simplicity and its low cost in this study. The method provides reasonable accuracy for large variations of soil moisture conditions and requires minimal equipment.

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