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GEOTECHNOLOGY TO DETERMINE THE DEPTH OF ACTIVE ZONE IN EXPANSIVE SOILS IN KIBAHA, TANZANIA

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ABSTRACT

Considerable distress to lightly loaded engineered structures in various parts of the coast of Tanzania is due to development of heave and swelling pressure in the active zone of expansive clay soils. The active zone is the region of soil near the surface in which the water content varies due to precipitation and evapo-transpiration. Even though the soil may have the potential to shrink and swell below the depth of active zone, volume changes will not take place because the water content of the soil is constant. Because the water content distribution does not change with time below that zone, the soil should be either stabilized or removed down to that depth or the foundation must extend to a depth that exceeds that of the active zone. A logical soil investigation needs to be carried out by an appropriate geotechnology to determine the depth of active zone based upon the site specific soil conditions that are dependent on the water content in the soil at the specific site in question. To monitor the water content changes with depth, samples from different open pits at earmarked intervals and depths within 100-hectare section in Kibaha were analysed. Based on the moisture content variation with depth, the depth of the active zone ranged between 1.5 m and 2.0 m.

KEYWORDS: Depth of active zone, soil water content, soil profile and heave/shrinkage

INTRODUCTION

Investigation of the depth of the active zone, sometimes referred to as the zone of seasonal fluctuations, is very crucial in construction on expansive soils. The importance of the active zone is to determine the soil depth above which changes in moisture content/soil suction and soil heave/shrinkage may occur due to changes in environmental conditions. This is so imperative because the potential for damage from expansive soils is limited to the upper zone of the soil in which seasonal changes in moisture content take place (Hamilton, 1977; Chen, 1988; and Day, 1999).

Soils above the depth of active zone experience wide variations in water content while those below this depth do not experience changes in moisture content and thus do not contribute to soil expansion. Below the active zone, the soil may have the potential to shrink and swell but no volume change because of the constant moisture content. The deeper the active zone, the larger the region over which soil expansion takes place. Therefore, the depth of the active zone is very important in controlling the expansive potential of the soil profile.

The active-zone depth can be determined by plotting the natural moisture content vs. the depth of the soil profile over several seasons (Figure 1). This means that the active zone concludes the depth at which the foundation can be placed without fear of shrink-swell effect. It is therefore imperative to find out the depth of the active zone for exercising the option of removing soil down to the depth of the active zone. Otherwise, it may be necessary to use other soil stabilization procedures and/or special design and construction methods for foundations depending on local soil conditions. On the other hand, the hypothetical difficult alternative is to prevent the soil's moisture from changing. Despite the importance of the active zone to a wide variety of building on expansive soils, information about depth of it has rarely been collected in a systematic and standardized fashion in the case study area.

OBJECTIVES

The objectives of this study are:

1. To trace the vertical seasonal changes in soil moisture contents in both wet and dry profiles in order to locate the depth to constant moisture (depth of active zone).
2. To ascertain the depth of active zone by carrying out a comparative suction experimental investigation in both wet and dry profiles

LITERATURE REVIEW

The movement of moisture status in soil profiles in a season can be equally used to locate the active zone (Prakash and Sarma, 1990 and Aubeny and Long, 2007). Figure 1 illustrates the different profiles (initial dry profile and wet profile) to locate the depth of active zone. The wet initial profile is gotten at the peak of the wet season while the dry initial profile occurs at the peak of the dry season. The water contents in wet profile and dry profile decrease and increase respectively as the depth increases and finally merge at equilibrium profile (Day, 2000). On the other hand, the suction in profile increase and decrease respectively as the depth increases to join together at equilibrium profile (Snethen, 1980; Wray, 1984; and Bell et al., 1986). The equilibrium pore water pressure profile is located at the depth of active zone where both wet initial profile and dry initial profile coincide and move in tandem (Lucian, 2008). Under equilibrium conditions, the water contents in both dry and wet profiles are in balance (Terzaghi et al., 1996 and Lucian, 2008).

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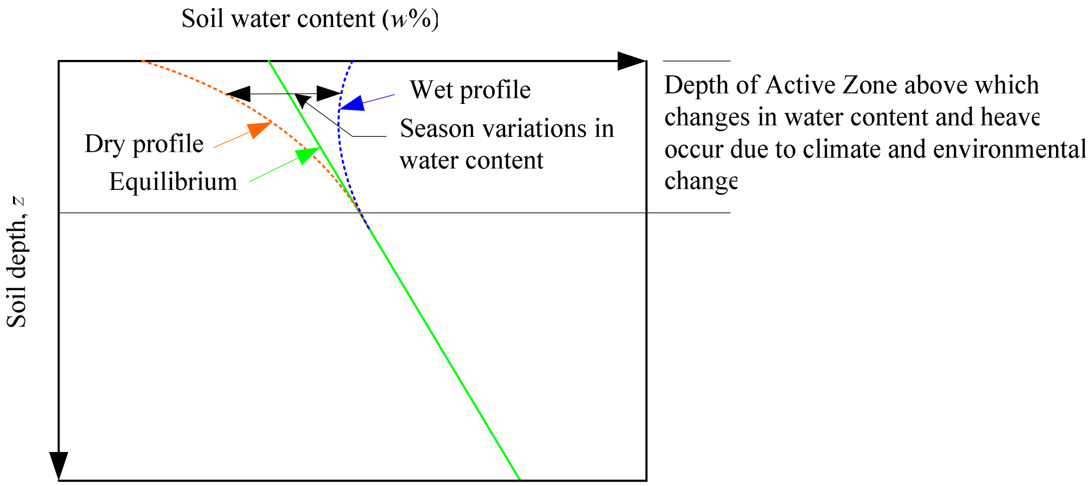

Figure 1: Suction variation with depth to locate the Depth of Active Zone (Lucian, 2008)

Geology

Kibaha is located in semiarid areas of the Coastal Plain of Tanzania, which is underlain largely by overconsolidated clays and poorly cemented sands to a depth of several metres. Nearly all soils of the area consist of clay, associated with moderate amounts of sand. Soil characteristics in the coastal plain of Tanzania are strongly influenced by parent material, including sediments filling of fluviatile and alluvial deposits that comprise clay, calcareous sandstones, limestones, marine marls, shells, mud, organic materials and conglomerates of late Mesozoic and early Cenozoic (Mpanda, 1997). Therefore, the soils have significant amounts of expansive smectite (montmorillonite) minerals, resulting in shrink/swell potential. The higher degree of concentration of smectite is obtained from sediments of marine marls and shells (Lucian et al., 2007 and Lucian, 2008). Generally, the soil is described more specifically as dark brown to grey with lenses of sand and pebble gravel. Surface soil is very dry throughout and very hard especially during the dry season. The soil profile is of moderate to low permeability with decreasing clay content and plasticity with increasing depth (Lucian, 2008).

Climate

The area being in the tropical zone experiences two distinct seasons a year, the wet and the dry, separated by two short transition periods. The wet season is characterised by a distinctive bimodal pattern of rainfall distribution; both long rains and short rains. The long rains are generally expected to fall between March and May and the short rains to fall between October and December. The Dry season is in June – August and January – February. June is the coldest month with the temperature approaching 20℃ whereas September is the hottest month with the temperatures exceeding 30℃ and long hours of sunshine (Lucian, 2008). Generally, the geological and climatic changes in the coast of Tanzania are the controlling factors of the formation of smectite clay minerals in certain materials which are causing ground heave problems. It is postulated that, smectite favours conditions of pronounced dry seasons alternating with less pronounced wet seasons (Singer, 1984)

Soil Ground Condition

Desiccation is a common phenomenon in the case study area during the periods of drought. The desiccation produces a network of fissures or popcorn texture (Figures 2) in hot season followed by rill and gully erosion (Figure 3) during rainy season, which are potential plains of weakness. Furthermore, these soils are susceptible to tunnelling or piping failure. The soils become sticky and very slippery, and unimproved roads in the area are virtually impassable during the heavy rainy season. Likewise, the rill and gully erosion becomes very plastic when wet and hard when dry.

The groundwater table is well below the active zone. The supposition is supported by a number of studies carried out repeatedly for the past 11 years by the researcher in the same area (Lucian, 1996; Lucian et al., 2006[1]; and Lucian, 2008). However, the deep groundwater has little or nothing to do to do with the swell of the soils.

Figure 2: Expansive soil in Kibaha showing cracks (Lucian et al., 2006[1])

Figure 3: Rill and gully in a Soil from Kibaha (Lucian et al., 2006[1]).

MATERIALS AND METHODS

It is evident that trends of active-zone thickness at larger scales may differ significantly from those occurring at smaller scales. In general, the active zone responds consistently in response to environmental and interannual climatic changes. However, at reasonable scales the trends are spatially and temporally variable in consistency with contemporary climate (Lucian, 2009). It is from this fact that both disturbed and undisturbed samples were collected within a short distance (a 100 ha study plot) from 20 open trial pits down to the depth of 3m within a period of long rainy season in April and dry season in September 2006. The profiles were sampled at vertical interval spacing of 0.5 m throughout the depth of each pit on a seasonal basis of 2006. To ensure continuity of the curves, the readings were taken frequently enough so that the change from one reading to the next was very slight. Thereafter, the collected samples were wrapped numerous times in wrapping papers and aluminium foils, logged and carefully transported to the laboratories at Dar es Salaam Institute of Technology (DIT) and Ardhi University (ARU) for testing to determine moisture content.

RESULTS

Depth of Active Zone

Because the maximum drying and wetting of the soils occured in September and April respectively, soil samples were collected during the two months of 2006 from different pits at earmarked depths. Table 1 presents some results of the variation of water content with depth from randomly selected pits determined by filter paper method. Suction profiles for four different sites are given in Figure 4. As it is evident from the Figure, the depth of active zone ranged between 1.5 m and 2.0 m, below which moisture fluctuation were found to be small for almost all pits. As was expected for the area in the semi-arid region of the tropical zones, water contents typically increased with depth to the point where the difference in moisture contents was insignificant. The suction profiles gave a snapshot of moisture variations in the profile at the explicit time the samples were retrieved.

Table 1: Variation of Water Contents with Soil Depth for few samples

Depth (m)	Moisture Content (%)							
Depth/Samples	Sample 02		Sample 07		Sample 12		Sample 19	
	Sept.	April	Sept.	April	Sept.	April	Sept.	April
0.3	11.8	19.5	9.9	23.1	11.5	22.7	13.1	24.5
0.5	12.4	16.8	11.4	22.1	12.7	21.0	13.2	21.2
1.0	14.0	17.6	12.3	19.2	14.5	18.3	15.6	19.7
1.5	14.5	15.1	16.5	19.9	17.5	18.9	15.7	17.9
2.0	16.1	16.2	18.2	20.0	18.7	19.8	17.3	18.2
2.5	15.8	16.4	19.4	20.9	18.5	20.5	19.2	20.3
3.0	15.6	16.3	19.9	21.1	18.6	20.0	19.7	20.9

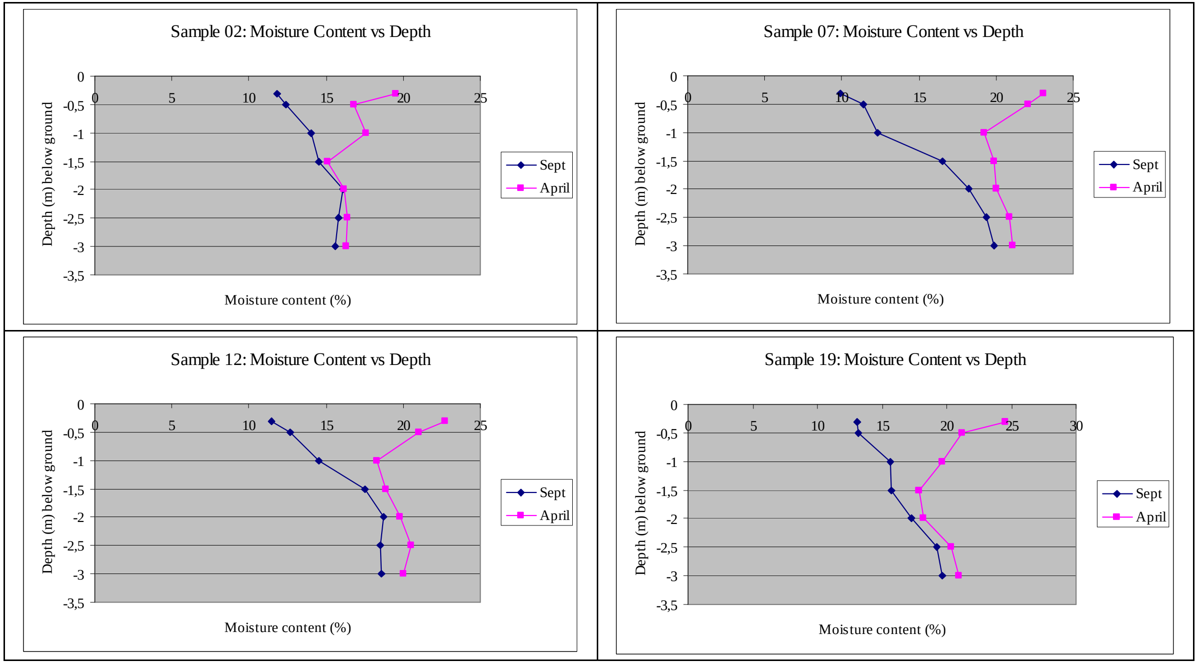

Figure 4: The variation of natural water contents with depth of soil for four samples

Active Zone Validation Using the Suction Values

A comparative suction experimental study was undertaken to locate the depth of active zone. Like soil moisture content, soil suction may be used on its own for the prediction of depth of active zone. Soil suction can be defined as the intensity or free energy level of water that the soil attracts (Fredlund and Rahardjo, 1993; Bulut et al., 2001; Ridley et al., 2003; and Sreedeep and Singh, 2006). The increase in moisture content is usually associated with the decrease in suction toward a value of zero. On the other hand, the corollary of decrease in soil moisture is the increase in the suction of the soil. The total soil suction comprises two components namely osmotic and matric (capillary) suctions as shown by equation 1. Matric suction reflects the forces emanating from interactions between the pore water and the soil solids. Osmotic suction represents the effects arising from the presence of dissolved solutes (Edil and Motan, 1984).

Total suction $h_t = h_0 + h_m$ ……………(1)

(assuming gravitational and external pressure effects are negligible)

where h_0 is the osmotic suction and

$h_m = (h_a - h_w)$ is the matric suction

h_a = pore-air pressure

h_w = pore-water pressure

The suction is calculated either in log kPa ($\log_{10}(|$suction in kPa$|)$ unit system or in pF ($\log_{10}(|$suction in cm of water$|)$ units. The two systems are approximately related by suction in log kPa = suction in pF-1 (Bulut et al., 2001). The formulae for determination of suction in log kPa as well as pF are summarized in Table 2. Suction is zero in soils whose moisture is in balance with the free water and greater than zero in soils above the ground water level. The maximum value of suction is reached at about pF = 7 corresponding to clay dried in an oven at 110℃ (Trevisan, 1988).

In general, suction data stimulate the expected sequence of the moisture change in the profiles. Like in the previous analysis, the depth of active zone ranged between 1.5 m and 2.0 m from the upper surface of the zone (Table 3 and Figure 5). The equilibrium suction at the depth of active zone ranges between pF 4.5 and 5.1. The fact that the groundwater table is deep in the area, the located depth of active zone is governed by the climatic changes rather than the water table depth. The results are in close agreement with the suction value of pF 6.0 for dry soil in equilibrium with the atmosphere reported by Russam and Coleman (1961). Moreover, the results conform to the criteria that the first point at which the total suction does not dissipate more than 0.08 $\log_{10}$|mm| suction units per meter with depth indicates the depth of the moisture active zone proposed by Lytton (1997). Similarly, according Masia et al. (2004) the active depth is taken equal to the depth at which $u_{\max} - u_{\min} = 0.1x\Delta u_{0.25}$ where $u_{\max}$ and $u_{\min}$ are maximum and minimum soil suction against depths, and $\Delta u_{0.25}$ is suction range (pF) at depth $z = 0.25$ m to ensure better representation of the surface suction. In this study, $\Delta u_{0.3}$ was used.

Table 2: Filter paper calibration relationships

Filter Paper	log kPa $(\log_{10}(\lvert \text{suction in kPa} \rvert)$	pF $(\log_{10}(\lvert \text{suction in cm of water} \rvert)$
Schneider and Schuell No. 589-WH	$\lvert h \rvert = 5.4246 - 8.247w$ $R^2 = 0.9969$ $(1.5 < \lvert h \rvert < 4.15)$	$\lvert h \rvert = 6.3662 - 8.2414w$ $R^2 = 0.9899$ $(h > 2.5pF)$

Table 3: Variation of Total Soil Suction with depth

Depth (m)	Total Soil Suction in pF							
	Sample 02		Sample 07		Sample 12		Sample 19	
	Sept.	April	Sept.	April	Sept.	April	Sept.	April
0.3	5.394	4.759	5.550	4.462	5.418	4.495	5.287	4.347
0.5	5.344	4.982	5.427	4.545	5.320	4.636	5.278	4.619
1.0	5.212	4.916	5.353	4.784	5.171	4.858	5.081	4.743
1.5	5.171	5.122	5.006	4.726	4.924	4.809	5.072	4.891
2.0	5.039	5.031	4.866	4.718	4.825	4.734	4.940	4.866
2.5	5.064	5.015	4.767	4.644	4.842	4.677	4.784	4.693
3	5.081	5.023	4.726	4.627	4.833	4.718	4.743	4.644

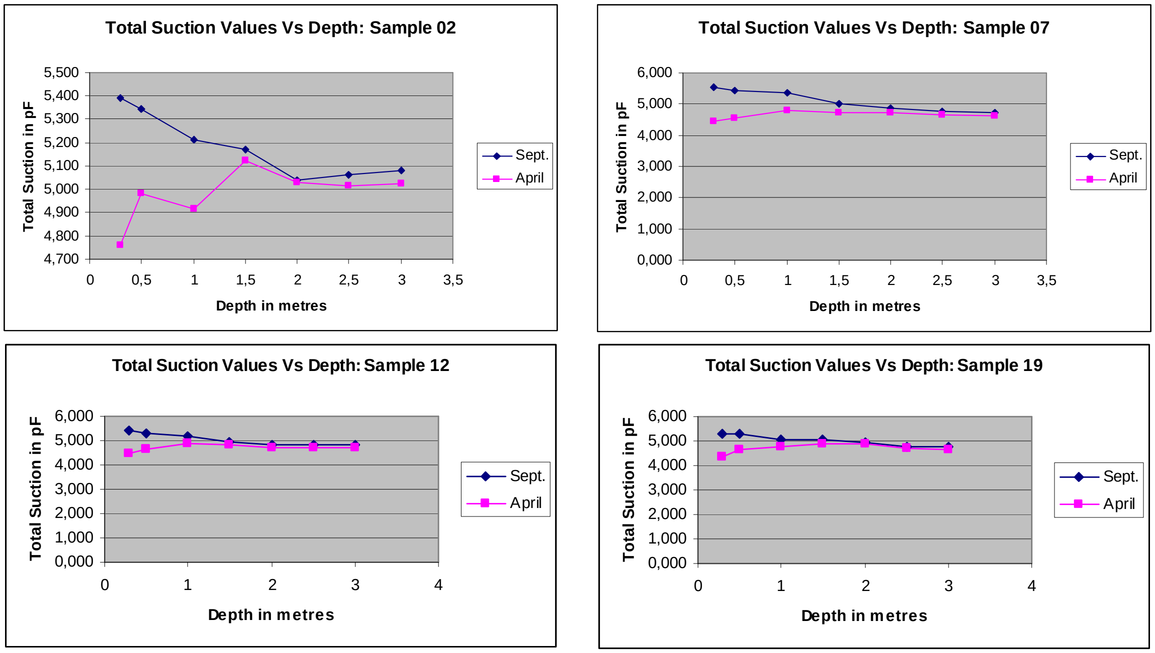

Figure 5: Suction profile with depth to locate the active zone

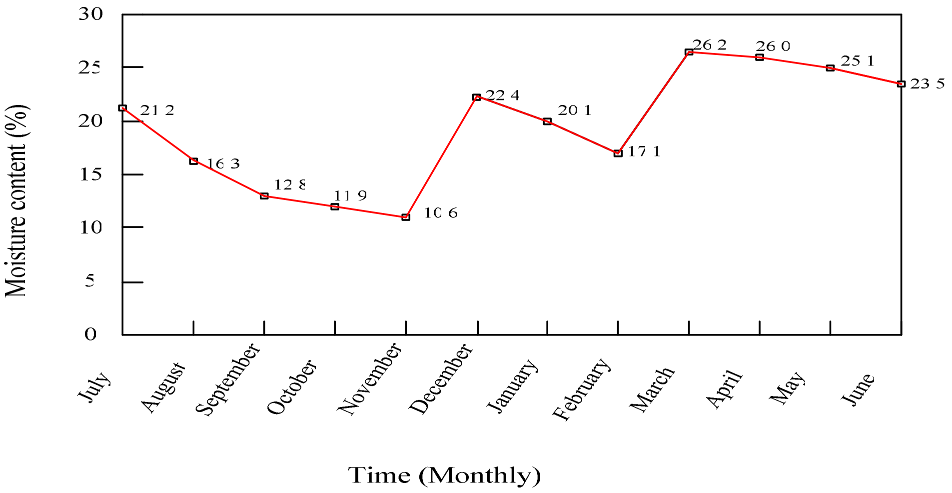

Figure 6: Spatial moisture content variation as function of time at 1 m depth.

Data Validation Using Yearly Spatial Variation in Moisture Contents

In order to asses the statistical structure of the spatial variation of the moisture content in typical close profiles at one site (Roman Catholic Church in Kibaha), measurements were made at a depth of 1.0 m from the ground level during the period of January to December 2006. The samples were taken on the 15th of each month, starting from 15th January 2006 and ending on 15 December 2006. The variations in moisture content for the period are shown in Figure 6. During the extreme dry period in September, the moisture content dropped to about 10.6%, depicting a dry soil. After the heavy rain in March, there was abrupt increase in moisture content up to approximately 28.2%. Generally, the soils exhibit drastic spatial variation of the moisture content in the study area. The rapid increase in moisture content is associated with critical expansion of soils. Based on the moisture data, the maximum swell is likely to take place in March and April and moderate swell in December. The maximum shrinkage takes place between September and November. It implies that the moisture content data taken in September and April accurately represent the two extreme periods of maximum drying and wetting. Figure 6 ratifies Figures 4 and 5, thus desiccation is more intense towards September and the wetter section appears in April.

DISCUSSION

Identification of the depth of active zone based on accurate plots of moisture variation with depth has yield substantial results. Before the structure is constructed, the soils above the depth of active zone should be removed and replaced with non-expansive soils to depth and width sufficient to assure stable moisture content in the active zone. The removed soils shall not be used as either fill or stabilization materials.

Another feasible solution is to stabilize the upper portion (active zone) with resin, lime, ash, pozzolana, cement or lime treatments. These treatments are effective techniques of expansive soil properties alteration that boost up their shear strength while inhibit their shrink and swell potential at the same time

Other authors (Nelson and Miller, 1992; Noe et al., 1997; Weston, 1980; and Lucian et al., 2006[2]) advocate maintenance of stable water content around the structure in question. This can be achieved by paving the perimeter of the building, using cut off walls to the perimeter of the building and by constructing buried impermeable membranes around the building. Theoretically, if the moisture content does not change, the volume of the clay soil will not change and therefore swell does not take place. However, these approaches are not a panacea on earth for moisture elimination; rather they just assist in minimising ongoing moisture movement.

CONCLUSIONS

The technique of moisture content determination has been used at multiple sites to characterise the depth of active zone and it has proved to be a valuable monitoring method providing data to locate the active zone. It is evident from the results that the depth of the active zone is very shallow and extends to about 1.5 m below the ground surface. The active soils encountered above the active zone depth are subject to moisture related volume changes. The state of the active soils is likely to change considerably with increase in moisture contents resulting into some upward movement. This phenomenon could potentially damage the structures on the soils unless substantial damage is avoided by incorporating appropriate geotechnical engineering design and measures. In a nutshell, the depth of active zone calls for complete replacement before the foundation is laid. Nevertheless, where soil replacement proves expensive, soil stabilization with resin, fly ashes and paper sludges, lime, pozzolana, cement and other cementitious materials might be thought. In case of heavy building construction, piles or piers should be used to transmit the load of the building to the deeper depth (below 1.5 m) of nonexpansive horizons. Apart from soil replacement, another solution is to prevent the soil's moisture from changing.

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