Use of Neutron probe and Tensiometry techniques in determining water characteristics of the two soil types

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Characterisation of soil water, in particular water flow dynamics is fundamental in assessing the environmental implications to soil management. Soil water characterisation was assessed by measuring soil water content and soil water potential in a draining profile of sandy and loamy soils. Mercury manometers and Neutron probe meter were connected to a 1.2 m high metal-reinforced container filled with soil samples, to simultaneously measure soil water potential and volumetric water content, respectively. Soil water contents (SWC) were found to decrease monotonically with time, with a rapid decrease in the first 50 hrs of free drainage in both soils. Sandy soil was more prone to huge losses of water than loamy soil attributed to numerous large drainable pores in sandy soil. An appreciable difference of SWC in the upper layer (SWC= 0.22 cm^3/cm^3) and the bottom layer (SWC= 0.35 cm^3/cm^3), in the case of loamy soil was attributable to its poor drainage properties.

Key words: Soil water content; water potential; soil water characteristic; mercury manometer; neutron probe.

1 INTRODUCTION

Simultaneous measurements of soil water potential and soil water content are essential in predicting direct water flow and soil water characteristic curves of soils [13, 14]. Moreover instrumentation techniques involving soil water content and soil water potential devices have been used, and still remain valuable tools for researchers and scientists in routine field measurements, although measurement of these properties is usual tedious and often difficult [9, 3]. These techniques are widely applied in many research fields involving routine measurements [8] and soil-water-plant relationships, water flow dynamics [3, 8]. For example, measurements of soil water potential can be used to address questions such as where and how fast water will flow in the unsaturated zone and how much is available to plants [11]. Further soil water content-water potential profile data for determining the flow direction of water are limited [14] and hence the ability to measure higher flow rates for small quantities of water is a limiting factor for many physical observations [15].

Generally, a combination of several methods exists for field measurements, but in most field experiments, water potential is measured with tensiometer connected with mercury manometer while volumetric water content are determined by neutron moderation or scattering techniques and Time Domain reflectrometry (TDR) methods [4, 7, 11, 13]. These methods suffer from a number of limitations resulting to the magnitude of flow rates as well as the smoothness of the resulting 'noisy' data [15]. For instances disadvantages of field estimation of soil water characteristic data are due to considerable time and effort involved and the relatively small range of water potential that can be measured with tensiometer [1, 4]. Similar observations were made by Hutchison [8]; Butters [3] and Libardi [10] in their experimental designs employing simultaneous use of water flow and tensiometry measurements. Many methods have spatially distributed measurement sensitivities, averaging a property of interest over sample volume [6] and these problems may arise due to the sensitivity of a measuring meter especially in the wetter profile. For example water content measurements using neutron probe has proven to be spatially sensitive than other devices such as capacitance probes [6].

The present study was to undertaken to determine soil water characteristics using soil water content and water potential measurement techniques in draining sandy and loamy soil profiles.

2 MATERIALS AND METHODS

2.1 Experimental set up

Water content and water potential measurements were carried out using a drainage profile experiment for two distinct soils; sandy and loamy soils. Disturbed samples of sandy and loamy soils were filled into two metal-reinforced containers, each with a cross-sectional area of 1 m^2 and depth of 120 cm (see Figure 1.). Holes were drilled in the sides of the container for positioning mercury manometer cups while the neutron probe access tubes were installed to measure water content. Holes at the bottom allowed water to drain freely under gravity. The containers were also shielded against wind in order to prevent evaporation while the soil surface was covered by plastic sheets to maintain a constant temperature during the experiment. The container samples were water flooded until water ran out through the outlet to ensure uniform distribution of water.

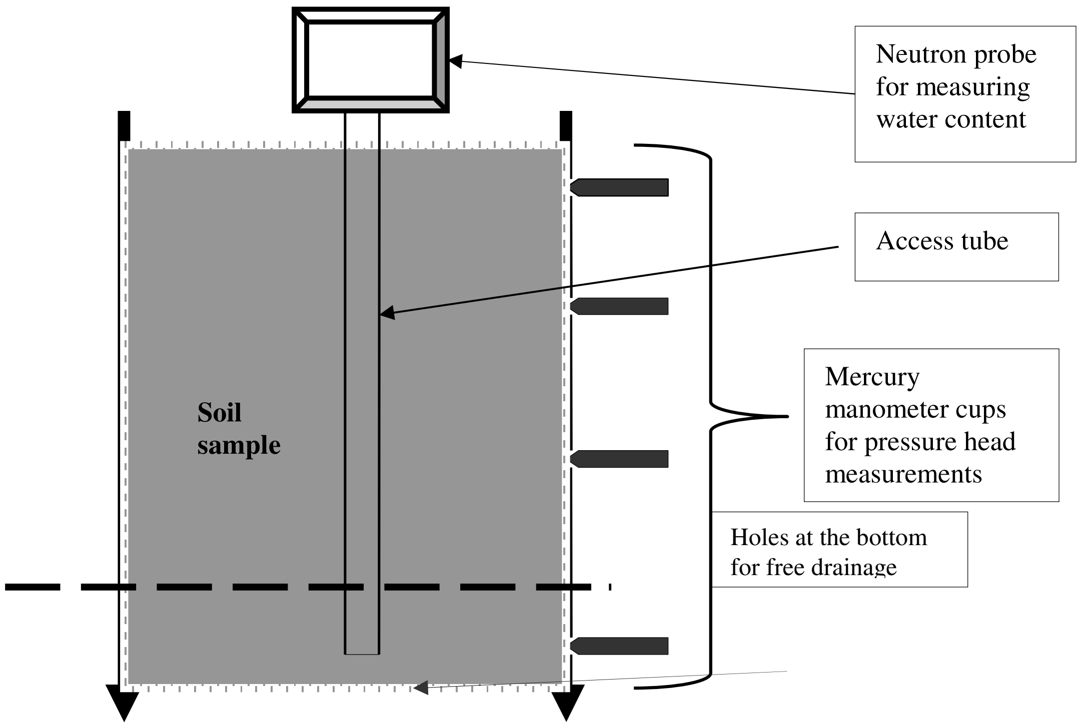

Figure 1. Schematic diagram showing experimental set up (note: container depth = 120 cm, width = 100 cm and crossectional area = $1 m^2$).

Soil water content and water potential were measured simultaneously during gravity drainage at selected depths following flooding samples with tap water. The initial readings were recorded immediately after flooding at small time intervals to account for the relatively faster drainage at the initially high water contents especially for sandy soils. Subsequently the time intervals were increased to more time intervals until the end of the experiment.

2.2 Soil water potential measurements with mercury manometer

Tensiometer ceramic cups with mercury manometers were installed horizontally and sealed into the holes drilled in the sides at the following depths; 15, 25, 35, 45 and 55 cm. These were tilted slightly upwards to enable air to escape from the system. The cups were connected to a mercury reservoir and the system was flushed with de-aerated water to minimise air-entry into the system. Holes of comparable sizes with the tensiometers were made to ensure good contact between tensiometer cups and soil to provide rapid adjustment to changes in soil water status. The water potential at selected depths were computed according to [4] for; $h = -12.6l + z_1 + z_2$, where h is the water potential in the ceramic cup (cm), l is mercury column length (cm), z_1 is the depth of tensiometer cup below soil surface (cm), and z_2 is the height of mercury level above soil surface (cm).

2.3 Water content measurements with neutron probe

Neutron hydroprobe (*model 503DR*) access tubes were installed in depths similar to the mercury manometers (see Figure 1). Theoretically neutron probe measurements involves the use of neutron scattering phenomenon in which hydrogen atoms thermalises fast moving neutrons and electrons. These fast neutrons are emitted by a radioactive source (e.g. americium beryllium, helium) and are slowed down by hydrogen atoms (sources of water in the soil, hence, changes detected in neutrons are attributed to soil water). The thermalised neutrons are counted by a probe sensor (a neutron detector).

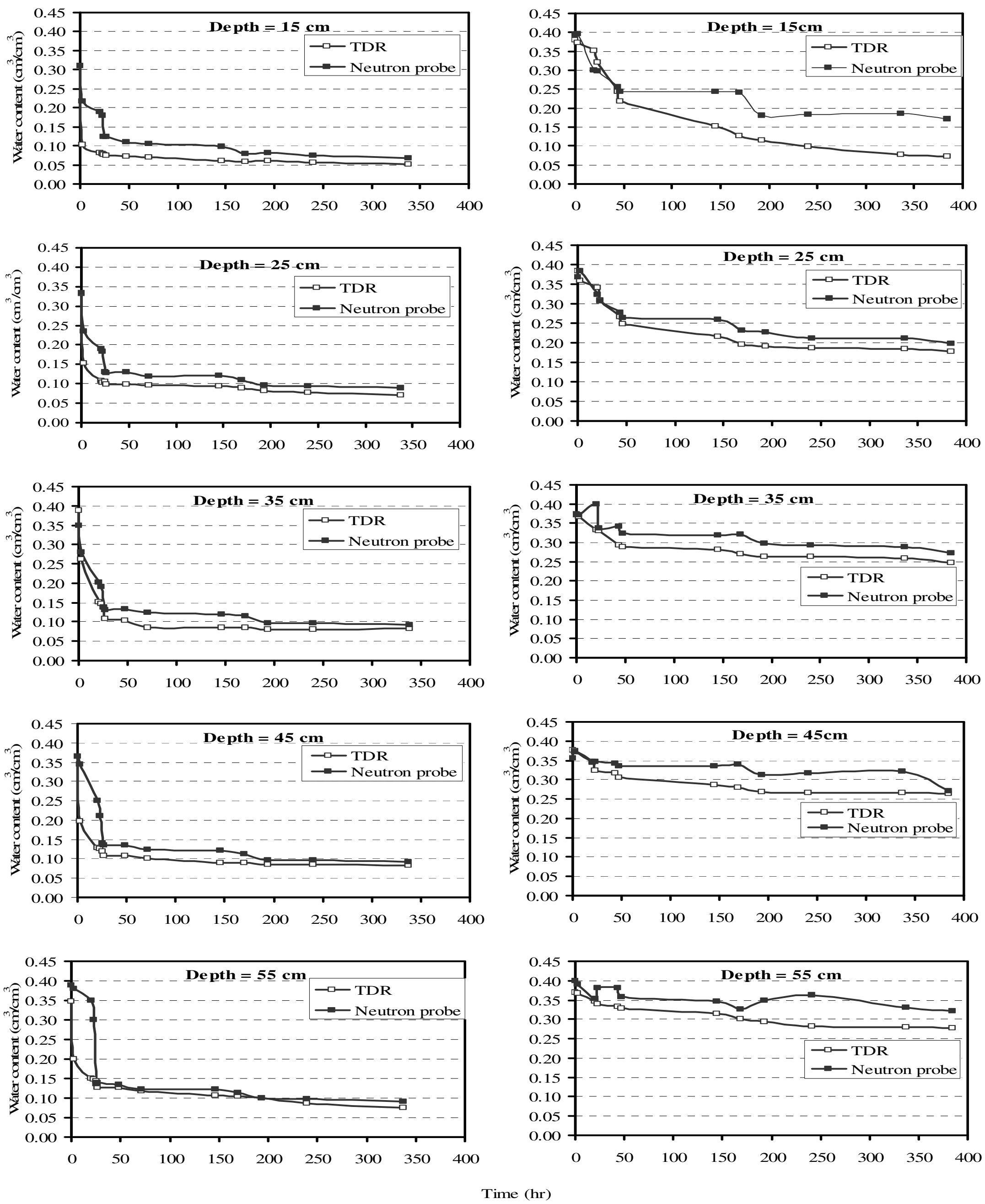

Figure 2. Soil water content as a function of time for various depths as measured by TDR and neutron probe

The neutron probe measurements were calibrated for each depth using the following generalised linear relation [7] for; $SWCv = a * RCR + b$, where SWCv is volumetric water content; RCR is relative count rate and, a and b are calibration coefficients. This linear model of this relationship varies according to the soil type. The calibrations were done for wetter and dry phases of water content and their depth calibration relations are presented in Table 1. In view of this, the TDR soil water contents were measured for comparison with neutron probe and effective evaluation of the two methods. However the evaluation has shown that water content by neutron probe over estimated the TDR by upto 20% (Figure 2). In spite of this, neutron probe data was used in the analysis and this is because it still offers better cost-effective measurement data owing to the relatively high cost of the TDR equipment set coupled with high maintenance costs [12, 11].

Table 1. Calibration of neutron probe water content for selected depths

Depth (cm)	Calibration/regression equation	a	b
	Sandy soil		
15	SWCv = 0.246*RCR – 0.080	0.246	– 0.080
25	SWCv = 0.234*RCR – 0.077	0.234	– 0.077
35	SWCv = 0.244*RCR – 0.094	0.244	– 0.094
45	SWCv = 0.265*RCR – 0.124	0.265	– 0.124
55	SWCv = 0.300*RCR – 0.192	0.300	– 0.192
	Loamy soil		
15	SWCv = 4.405*RCR + 0.320	4.405	0.320
25	SWCv = 3.879*RCR + 0.353	3.879	0.353
35	SWCv = 5.434*RCR + 0.248	5.434	0.248
45	SWCv = 5.149*RCR + 0.286	5.149	0.286
55	SWCv = 4.402*RCR + 0.467	4.402	0.467

n.b. SWCv is volumetric water content, RCR is relative count rate and, a and b are calibration coefficients

3 RESULTS AND DISCUSION

3.1 Redistribution of soil water during drainage

Figures 3a and b show the water content profile distribution following flooding of sandy and loamy soils, respectively. Generally water content decreases with time after flooding depending on drainage properties of soils. During the initial stage (upto 24 hours) drainage changes or changes of water content with time were quite high especially for sandy soil associated with relatively higher pore drainability. However there is also a general increase of soil wetness with depth, with loamy soil showing some remarkable changes in the water content. This water profile distribution pattern has implications in the assessment of the plant water use efficiency or the rate of soil water depletion. For example, cowpea may exert a lower suction or water potential and hence smaller water uptake as compared to sorghum and sunflower [2].

3.2 Dynamics of water flow

Figure 4 shows the soil water content (SWC) profile for a draining profile as measured by the neutron probe, and generally shows a monotonic decrease of water content with time reflecting a draining profile. The faster drainage in the sandy soil is reflected by the sharp drop in water content with time, while in the slower draining loamy soil there was a slower response in the changes. The results also demonstrate that free drainage occurred in the first 50 hrs for both soils, suggesting the predominance of macropore-flow in the wetter profile regime and subsequently the flow was subjected to the matric forces, as reflected by relatively slow drainage especially after the 250 hrs drainage. However under the matrix controlled flow, for example at upper layers after 250 hr drainage, the loamy soil still retained more water (SWC = 0.18 cm^3/cm^3) than sandy soil (SWC = 0.07 cm^3/cm^3) associated with numerous capillary pores in the loamy soil. The limited water flow for sandy soil especially after 250 hrs has overall implications to the water availability and uptake by plant roots.

Interestingly the results also show a 'mirror image' in the flow pattern in the case of loamy soil between 225 and 350 hrs of drainage for depths D_15 (shallowest) and D_55 (deepest), with each layer losing water at the same rate. The losses on the upper layer are attributable to capillary rise, especially that the soils exhibited no self-mulching features during drying. The flow dynamic patterns have also revealed that the sandy soil is more prone to huge losses of water (after 250 hrs of drainage) attributed to numerous large pores in sandy soil. An appreciable difference of SWC in the upper layer (SWC= 0.22 cm^3/cm^3) and the bottom layer (SWC= 0.35 cm^3/cm^3), for loamy soil was attributable to its poor drainage properties.

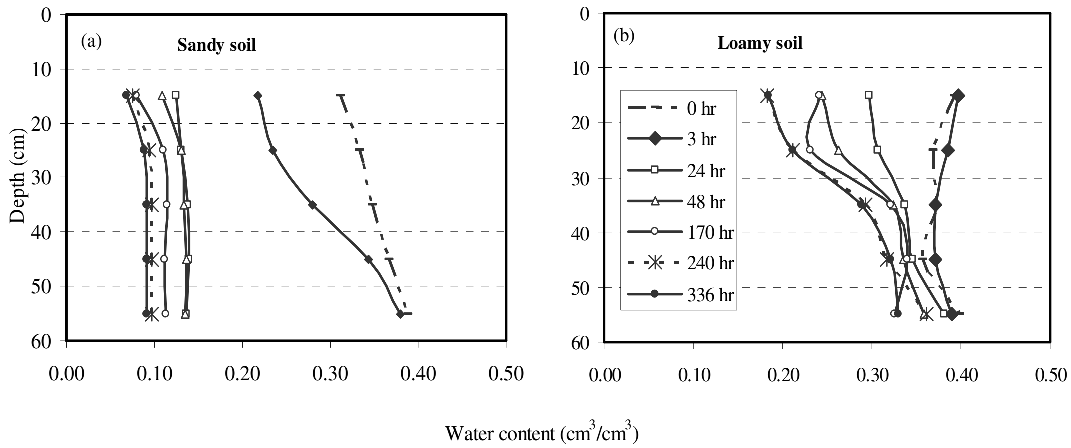

Figure 3. Water content profiles during redistribution following flooding of (a) sandy soil and (b) loamy soil. The time variable in hours (hr) refers to time elapsed since start of free drainage

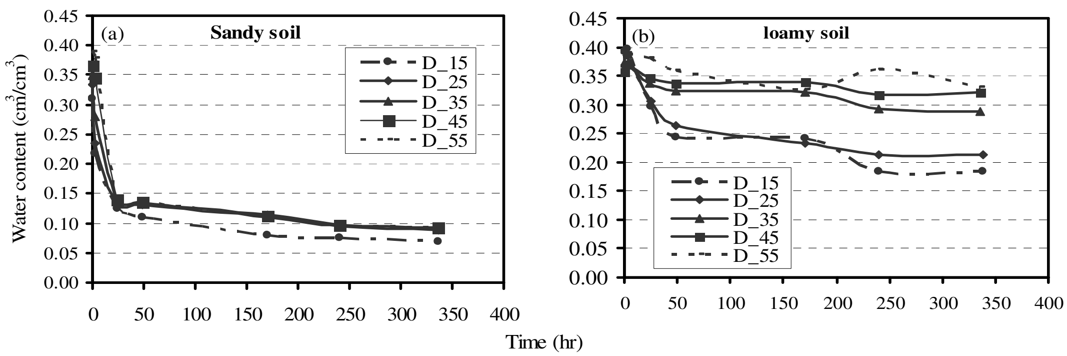

Figure 4. Water content as a function of time for a draining profile for different depths D (cm): (a) Sandy soil and (b) Loamy soil

3.3 Soil water characteristic curve

Data on both soil water potential and water content were plotted to characterise soil water (Figure 5). The results showed better curve fitting for sandy than loamy soil. A decrease of water content of about 70 % and 15 % for sandy and loamy soils, respectively, was observed within a water potential range from 0 to -40 cm. This somewhat rapid decrease in sandy soil following flooding was attributable to its fast drainage and is as reflected by the pattern of water content distribution profile (Figure 3). However the slow response of the loamy soil was associated with its higher amount of clay which essentially will form clay bridges to impede water flow, as demonstrated by the relatively poor curve fitting in loamy soil (regression coefficient r^2 =0.86) compared to sandy soil (r^2 =0.89) in a polynomial plot of water characteristics data. High scatter data accounts for errors associated with the sensitive of the mercury manometer in water potential measurements, especially in the wetter profile, attributed to poor drainage in loamy soil [16].

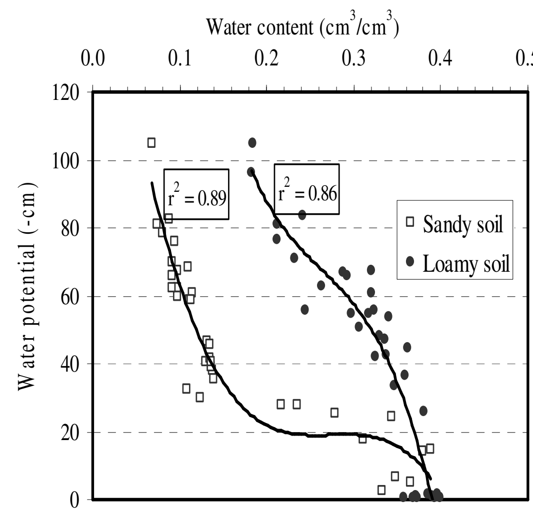

Figure 5. Soil water characteristics for sandy and loamy soils

4 CONCLUSIONS

Soil water contents were found to decrease monotonically with time, with rapidly decrease in the first 50 hrs of free drainae. The flow dynamic patterns have revealed that the sandy soil is more prone to huge losses of water (after 250 hrs of drainage) than loamy soil attributed to numerous large pores in sandy soil. An appreciable difference of soil water content (SWC) in the upper layer (SWC= 0.22 cm^3/cm^3) and the bottom layer (SWC= 0.35 cm^3/cm^3), in the case of loamy soil was attributable to poor its drainage properties. While both soils show similar trend in the soil water characteristic curves, sandy soil was found to more sensitive to changes in soil water potential. For example a polynomial curve fitting of soil water characteristics data resulted in slight better fitting for sandy soil (regression coefficient, r^2=0.89) compared to a loamy soil (r^2=0.86). This difference was associated with the sensitivity of mercury manometer especially in the wetter profile for the slower draining loamy soil. However this analytical information has implications on the effectiveness of the measurement techniques in deriving soil water characteristics, with better results or instrument resolution observed in sandy soil in most cases.

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