

Transfer of moisture through the unsaturated zone in the tropical forest using the neutron probe

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ABSTRACT: Knowledge of moisture content is crucial in assessing spatial and temporal movement of water through the unsaturated zone. Moisture storage is also important for monitoring the soil water balance and for validation of water balance models. The purpose of this work was to determine and analyse moisture content profiles at point locations in the unsaturated zone of a lateritic soil around Nsimi, south of Cameroon. Neutron probe has been connected to a set of tensiometers in an area of 60 ha. A comparative study between a site covered with vegetation and a site uncovered was conducted to assess the influence of vegetation in the process of moisture transfers. The results showed that the spatial distribution of moisture profiles varied according to the site and the texture of the soil, with in general increasing of moisture from the surface horizon toward the deeper layers. The mean values of moisture varied from $\theta_m = 0,397 \text{ cm}^3/\text{cm}^3$ on barren site, against $\theta_m = 0,429 \text{ cm}^3/\text{cm}^3$ in vegetation. Values of suction were generally strong in surface and at depth, but weak in the intermediate layers.

Keywords: Barren soil; Calibration; Lateritic soil; Neutron probe; Tensiometer

INTRODUCTION

The sustainable management of a natural ecosystem requires knowledge of different processes that are involved. The unsaturated zone plays a very important role in infiltration, deep percolation or recharge, water balance and the drainage systems because it is in this interface that exchanges of water, pollutants and microorganisms into the ground water or the atmosphere occur (Braun *et al.*, 1997; 2005; Thais, 2004). The study of soil water must be addressed both in quantity and in terms of energy. Several methods are available for determining the moisture content of the subsurface zone: gravimetric methods, neutron thermalization and time domain reflectometry (Dalton, 1992; Healey and Cook, 2002). Although the first method leads in reshuffle of the soil, it is generally used as a standard for the other ones (Evet, 2004). Since the last few decades, the neutron probe has been widely used in Europe and America for determining the moisture content of the soil (Pourrut and Camus, 1970).

It is convenient, fast, simple and it enables the instantaneous and continuous moisture measurement on the same point without disturbing the ground. However, this technology is rarely used in Sub Saharan Africa (Olivry and Sircoulon, 1998). Important work on the transfer of water in the unsaturated zone has been conducted in the past on this site using gravimetric methods (Fih, 1999). Disturbance of soil and non-recurrence of tests are the major disadvantages of this method (Fares *et al.*, 2004). The concern is how to track variation in soil moisture on daily basis while respecting the soil structure. The major difference between this work and those already made at the site include the use of neutron probe that does not require the disturbance of soil and the possibility of continuous determination of moisture in the ground at fixed points. The method uses the real dry bulk density of soil, for determining the volumetric moisture content. The calibration of neutron probe is a very important task of this work. The objective of this study was to determine and analyze the moisture profiles in the unsaturated

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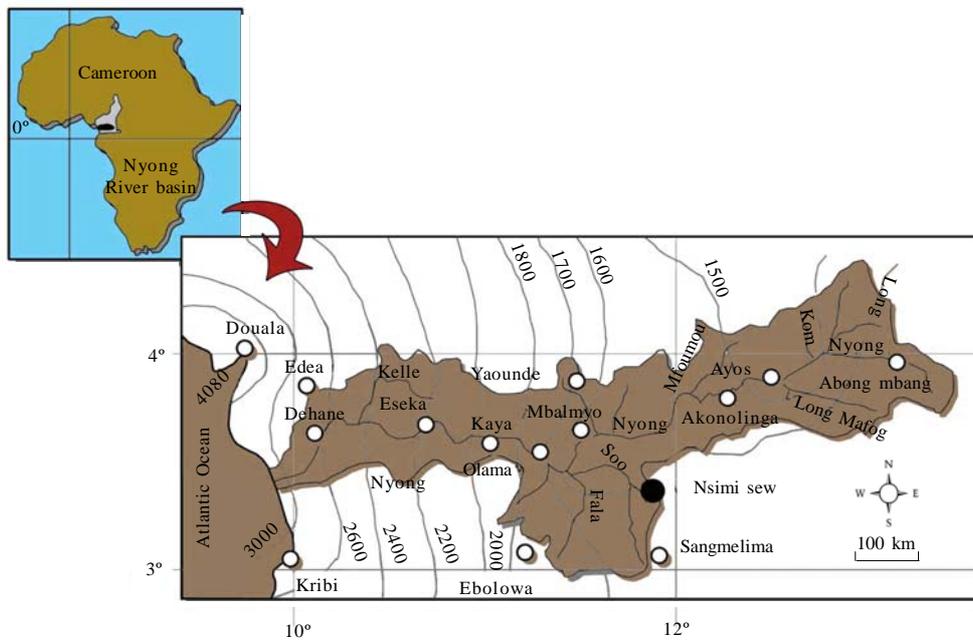
MATERIALS AND METHODS

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Depth	Lateritic soil section	Horizons	Clay (%)	Silt (%)	Sand (%)	Stone (%)
0 m		Humiferous layer	46.95	2.05	95	0
		Loose clay-rich	64.22	8.21	27.52	0
5 m		Indurated ferruginous clay	21.81	3.41	14.11	60.67
10 m		Saprolite	24.09	30.71	40.80	4.4
35 m		Granitic bedrock	-	-	-	-

Fig. 2: A simplified lateritic soil section of the Nsimi watershed developed on a granitic bedrock. This vertical section shows different pedological horizons and their principal granulometric classes (Yene Atangana *et al.*, 2003)

Gravimetric method

When laying access tubes for neutron moisture probe depth, soil sample were taken at intervals of 10 cm. The collected samples were packed with aluminum foil and then weighed (h_w). They were then dried at 105°C in an oven for 48 h and weighed again (d_w). The weighted moisture content is given by the following equation:

$$w = \frac{h_w - d_w}{d_w}$$

and the volumetric moisture was obtained from this equation:

$$\theta_v = da.w$$

Where, θ_v : volumetric moisture content (cm^3/cm^3); W: weighted moisture (g/g); Da: bulk dry density of the soil.

Neutron moisture probe

A neutron moisture measuring probe using a sealed mixture source of radioactive americium 241 and beryllium with an activity ranging from 0.4 to 1.9 gigabecquerels was used to measure the soil moisture content. Two hard aluminum tubes of 2 m each were implanted at two locations: one on barren area (B.S.) and another on vegetated area (V.S.). Measurements

were made sequentially, leaving the probe at a depths Z (respectively at 15, 25, 35, 45, 55, 65, 75, 85, 95, 105, 115, 125, 135, 145, 155, 165, 175, 185 and 200 cm) for a period $\Delta t = 65$ s and registering the number of counts N. The probe was then lowered with an incremental of $\Delta z = 10$ cm and the same operations were repeated up to the base of the tube. In addition, to take account of the possible neutron drift, relative count values (β) were obtained from the equation:

$$\beta = N/E,$$

Where, E is the counting in the water in a container. Four measurements were performed per week. The calibration of the neutron probe was made by comparing the gravimetric measurements made during implementation of the access tubes and neutron counts measured by the probe (Reichardt *et al.*, 1997). For every layer, a calibration curve was prepared using:

$$\theta_v = a.\beta + b$$

Where, a and b refer respectively to the slope and the intercept of the regression line obtained while plotting $\theta_v = f(N)$ and θ_v is the volumetric moisture (Evet, 2003).

By integrating the calibration equations following the depth, one gets the amount of water stored on the site at each measurement. The extrapolation of these

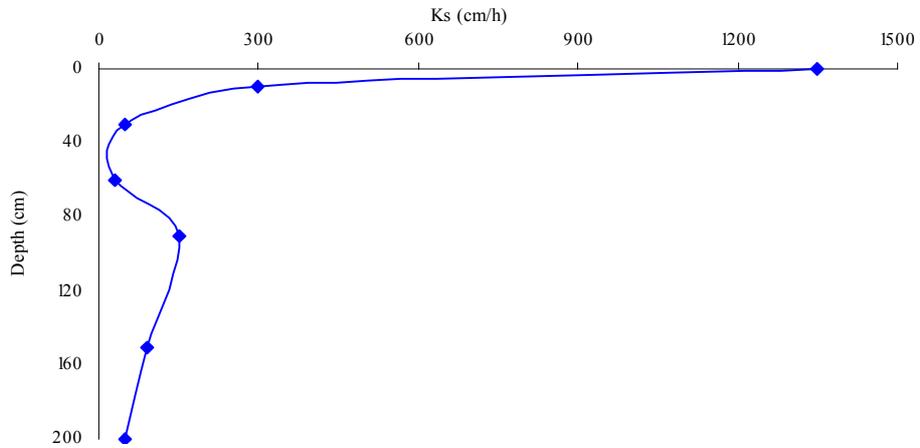


Fig. 4: Variation of the coefficient of permeability at saturation with depth. One can notice the important decrease of the permeability from the surface to 40 cm depth (Tienjo, 2007)

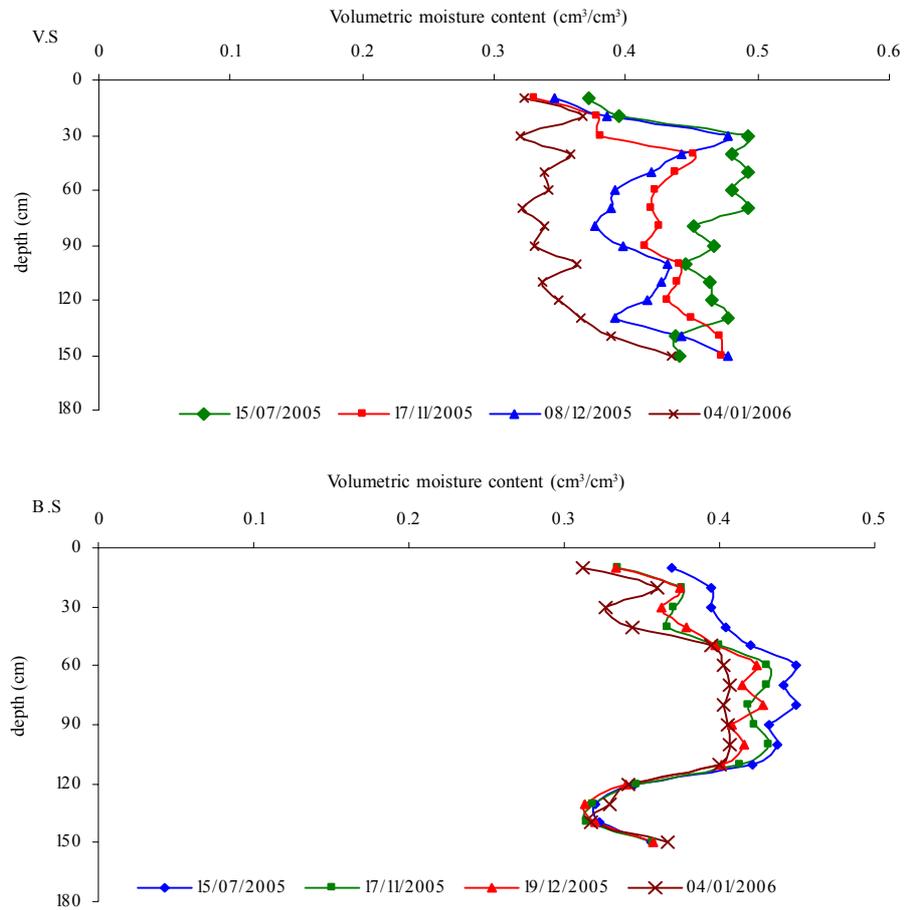


Fig. 5: Soil moisture profiles (V.S and B.S). These profiles show the influence of the vegetation on the aerial distribution of soil moisture content

depth of the neutron probe could allow the possibility of measuring ground water recharge at depth where ground water is present. For this purpose, Maréchal *et al.* (2008) suggested an integrated approach coupling hydrogeological to geochemical monitoring.

Kinetics of moisture movement

The measurement carried out during October 2 and 9, 2005 had provided information for evaluating the behaviour of soil moisture profiles following the precipitation events. Between these two dates, 46.5 mm of rainfall had been recorded. It was observed that there was a superposition of the two profiles on barren site, for the 0-40 cm depths and beyond 110 cm and an enhancement (5 %) in moisture in the 40-110 cm zone after the precipitation. As the runoff was negligible and evapotranspiration limited, the increase in moisture content at depth 40 cm was probably due to infiltration

(Fig. 6). A similar increase in moisture content was also observed on the vegetated site. In addition, it was observed that the moisture front (moving at variable speed of 5 to 26 cm/d), had moved deep into the soil on barren land. The presence of vegetation showed a significant influence on soil moisture content, as well as moisture movement. The variable residence time of water within the soil, creating an alternation of reducing and oxidizing conditions, affects soil chemistry, structure and lateral extension of the soil patterns (Temgoua *et al.*, 2005).

Tensiometric measurements

Tensiometric profiles showed a marked and more individualized behaviour at the vegetated site (Fig. 7). The profiles showed a continuous draining of moisture within the soil. The barren site showed a linear progression, with higher moisture content at the

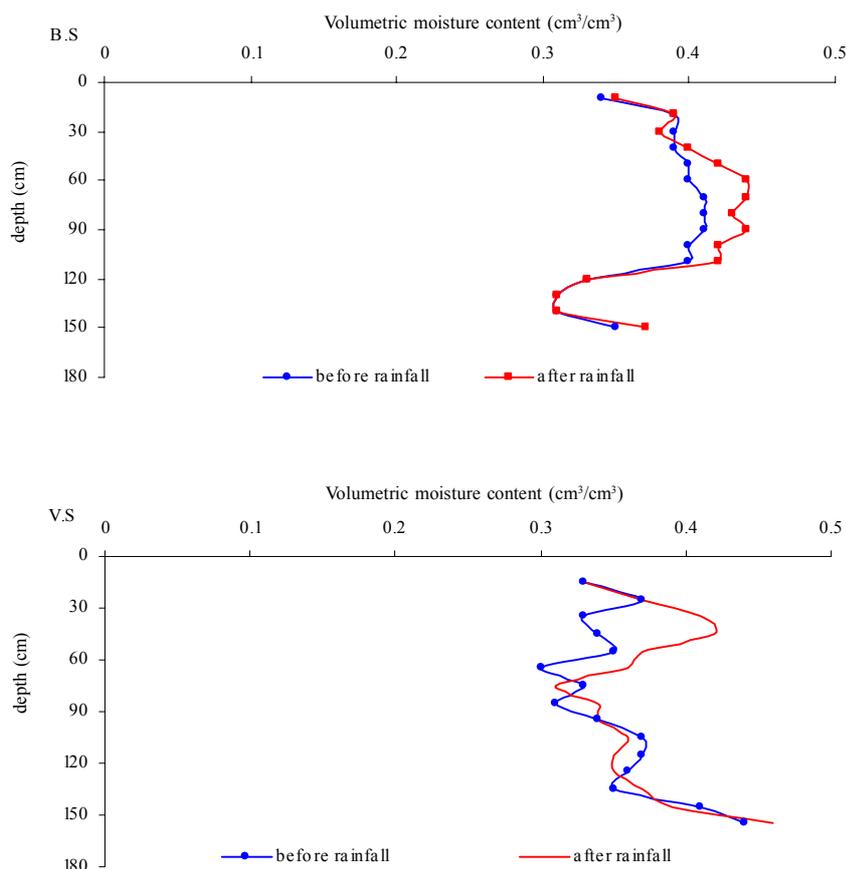


Fig. 6: Moisture profiles before and after rainfall (V.S and B.S). These profiles illustrate that enhance in soil moisture content after precipitation is greater in vegetated area compare to barren area

Moisture transfers through the unsaturated zone

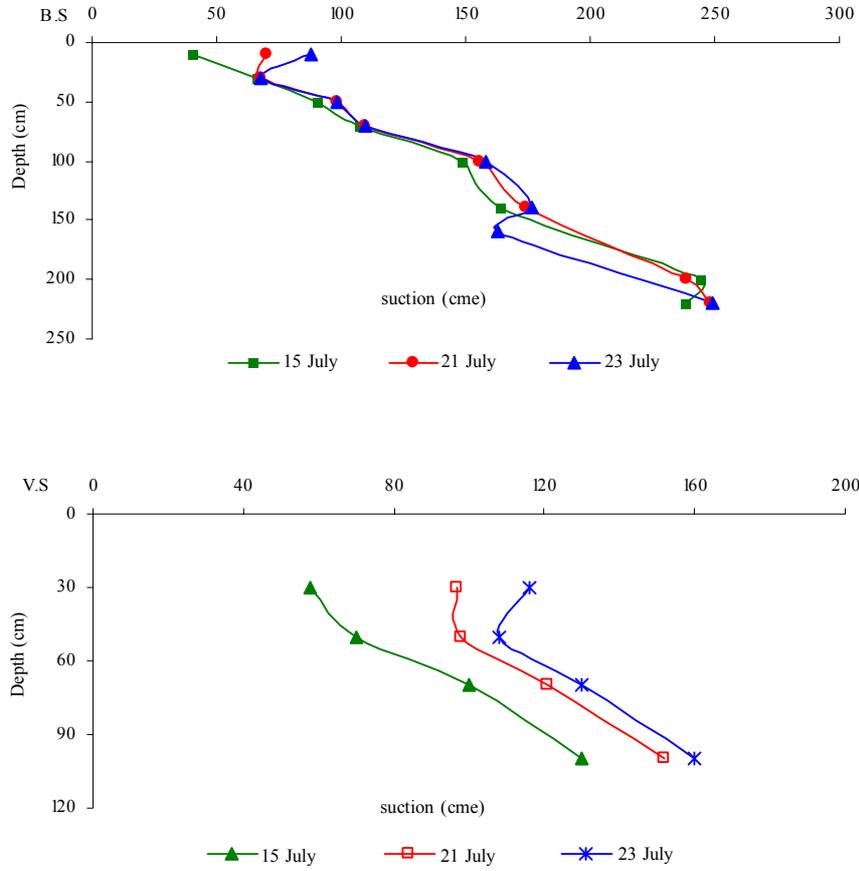


Fig. 7: Tensiometric profiles (15, 21 and 23 July 2006). The profiles (B.S and V.S) show a continuous draining of moisture within the soil with depth

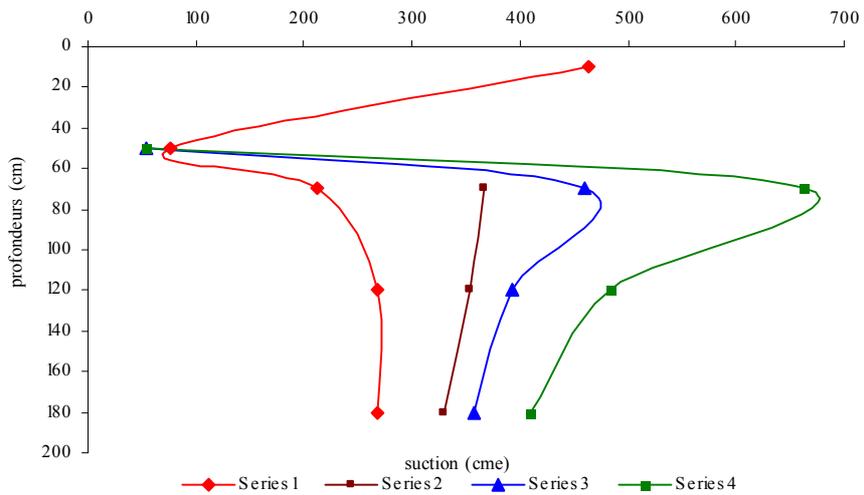


Fig. 8: Tensiometric profiles before rainfall (2, 19 and 23 August) and after rainfall (2 September). This figure illustrates the influence of rainfall on the soil suction value

surface and a gradual decrease with depth. A more detailed study of these variations at identical depths showed that the moisture content in vegetative site have always been at higher level than those in barren site at depth up to 180 cm. These are in conformity with the neutron moisture probe results and confirm that these two methods (tensiometric and neutronic) are adequate for taking moisture measurements. The influence of rainfall was very significant on vegetative site profiles (Fig. 8). The rains received before the last transactions were recorded on July 26 and August 23. This means that the profiles of August 2 and 19 took place during dry period. It was observed that the soil was very dry at the surface and slightly at lower depth on August 2. The drying up of layers of subsurface however continued over time. It was also observed with rainfall on August 23 and September 2 that there was switching of profiles on the surface, but a continuous and gradual drying at lower depth. This meant that the moisture front had not yet reached the layers at lower depth. There was a delay in moisture or drying on the two sites and the delay was more significant as the series of previous rainfall events were more distant .

CONCLUSION

Measurement of moisture content using moisture probe in the soils at the test site were accurately estimated using noninvasive method. The application of neutron thermalization in the study shows excellent promise for monitoring spatial and temporal variability in moisture content in a soil profile. The results indicated that the spatial distribution of profiles was influenced by vegetative cover and soil type. Although the surface moisture content was generally low, it has been noted a gradual increase in moisture content up to 110 cm depth in the both sites. The suction values were relatively strong in surface, strong in the intermediate layers and weak at depth. Although suctions were varied and moisture content different from one site to another, it was found that the soils of forest areas were quite wet and retained the moisture up to certain depth with time, particularly to the sites deprived of vegetation. However, it is suggested that the investigation depth of the study must be expanded to assess the possibility of measuring ground water recharge at depth where ground water is present.

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