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# Seasonal change in thick regolith hardness and water content in a dry evergreen forest in Kampong Thom Province, Cambodia

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ABSTRACT

In dry evergreen forests in Kampong Thom Province, Cambodia, regoliths over 10 m thick are widely distributed. At one study site in an evergreen forest, a 9.4-m-deep soil profile was excavated and certain physical properties, including soil hardness, soil water content, and extent of root systems, were measured in rainy and dry seasons. A new finding was that the evergreen forests used soil water from regolith in the dry season. The root system penetrated more than 9 m into the soil and withdrew soil water. Soil hardness from the surface to a depth of 4 m changed each dry and rainy season from extremely hard to soft. The reason for the change was related to soil texture; the silty soils readily changed their binding power in response to water content. A seasonal change in soil hardness was also observed at other points by penetration tests indicating very hard surface soils to a depth of 4.3 m at the end of the dry season, very soft surface soils to a depth of 1.0 m at the beginning of the rainy season (apparent soil thickness was 4.2 m), and 3.5 m of soft surface soil at the end of the rainy season. Thick regoliths and silty surface soil layers were found to store water and maintain dry evergreen forests in central Cambodia.



## 1. Introduction

Many soil science studies have dealt only with soil and shallow regolith, which typically consists of the upper 200 cm. Recently, however, some soil scientists have sought to understand the long-neglected deep regolith zone, including saprolites of various kinds of rocks, deeply weathered lateritic regoliths, and paleosols in loess. Their objectives have included studying deep regolith (Harris et al., 2005; Wysocki et al., 2005), soil hydrology and environmental quality (Lee and Gilkes, 2005; O'Green et al., 2005; Rabenhorst and Valladares, 2005; Schoeneberger and Wysocki, 2005), deep root systems (Nepstad et al., 1994; Canadell et al., 1996; Tanaka et al., 2004; Bornyasz et al., 2005; Schenk and Jackson, 2005), and geochemistry (McKay et al., 2005; Oh and Richter, 2005; Vepraskas, 2005).

In a study of deep regolith, Harris et al. (2005) noted that important morphologic horizons (e.g., E horizons) were more than 2 m deep in some deeply weathered soils, resulting in inaccurate and disjointed spatial depictions of pedogenic relationships on a landscape scale. Wysocki et al. (2005) argued that thickness of the soil C horizon could exceed thickness of the A and B horizons and contain unique morphological properties. They emphasized that we have to research the subsolum including C horizons as well as A and B horizons to comprehend soil forming and hydrological processes.

With respect to soil hydrology and environmental quality, Rabenhorst and Valladares (2005) found that chemical and mineralogical changes occurred across a sharp, visually detectable boundary at deep horizons (depth >3 m) that have been disregarded in traditional soil science. Schoeneberger and Wysocki (2005) summarized conceptual models for understanding and predicting how water moves in landscapes and in deep regoliths. They also emphasized that vadose zone water flow patterns are modified by pedo- and geo-stratigraphic variation and continuity, and by vegetative consumption.

In connection with deep root systems, Bornyasz et al. (2005) found that evergreen plants with deep, extensive root systems are favored during inherent seasonal droughts in Mediterranean climates where ectomycorrhizal root tips were found throughout the regolith to depths of 4 m. Using empirical models, Schenk and Jackson (2005) predicted that deep roots are most likely to occur in seasonally dry, semiarid to humid tropical regions under savanna or thorn-scrub vegetation or under seasonally dry semideciduous to evergreen forests and that rooting depths are more likely to be deep in coarse- and fine-textured soils, rather than in medium-textured ones. Canadell et al. (1996) found that the maximum rooting depth is 3.7 ± 0.5 m for tropical deciduous forest and 7.3 ± 2.8 m for tropical evergreen forest. Nepstad

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et al. (1994) excavated 36 auger borings in several types of forests in the Amazon and deduced that root systems reach depths of 18 m and they pump water from depths of 8 m in the dry season to maintain evergreen forests. Furthermore, some studies have examined the deep soil layer as a source of water for transpiration (Tanaka et al., 2003, 2004). Simulations have led to the assumption that the rooting system of an evergreen forest in northern Thailand reached depths of 4–5 m. Soil hardness has been measured using a handy dynamic cone penetrometer to determine hardness by depth (Iida and Okunishi, 1983; Onda, 1992). Because measured values are proportional to the bulk density and total porosity of the soil (Yoshinaga and Ohnuki, 1995), this method can be used when the bulk densities of colluvium, saprolite, and bedrock differ.

As mentioned above, we have recognized that deep soils and deep root systems play important roles in some hydrological processes, especially in the monsoon tropics. However, recent studies have not observed root systems in deep soil layers by digging large deep soil profiles and have not obtained physical evidence that evergreen forest trees actually consume water in the dry season. In the Mekong River Basin in Cambodia in tropical monsoon Asia, evergreen forests are widely distributed in flatlands, and the water environment changes drastically between the rainy and dry seasons. Soil thickness and related data for this ecosystem are few (Ohnuki et al., 2007; Toriyama et al., 2007a,b). Thus, the present study has two objectives: 1) to measure certain soil physical properties and root systems on the wall of a deep soil profile (>9 m) in an evergreen forest to understand the role of deep soil layers in water storage and transpiration in Kampong Thom Province, central Cambodia; and 2) to comprehend the mechanisms underlying seasonal changes in soil thickness and soil hardness using a handy dynamic cone penetrometer in the rainy and dry seasons.

## 2. Study area

The study area was in Kampong Thom Province, central Cambodia (Fig. 1). The survey sites were 69–101 m in elevation in a predominantly evergreen forest where deciduous forests and swamp forests coexist in a mosaic-like pattern. The surface geology is Quaternary and consists of river terraces overlaid with sedimentary rocks (Ohnuki et al., 2007). The distributed soils are Acrisols based on the Food and Agriculture Organization (FAO) and WRB classifications (Toriyama et al., 2007b). Over 10 m in thickness soil and regolith are widely distributed (Ohnuki et al., 2008).

Two types of plots were established at the survey sites as follows (Hiramatsu et al., 2007; Tani et al., 2007; Toriyama et al., 2007b). First, a dry evergreen forest plot was established (DEF1: elevation 101 m; soil type: Acrisols): DEF1 consisted of *Dipterocarpus costatus*, *Anisoptera costata*, and *Vatica odorata*. The height of the predominant trees was 30–40 m. Second, a logged dry evergreen forest plot (DEF2: elevation 73 m; Soil type: Acrisols) was established in a dry evergreen forest where tall trees had been selectively-logged. DEF2 also consisted of *D. costatus*, *A. costata*, and *V. odorata* and the height of predominant trees was 30–40 m. DEF1 is located at crest flat (terrace surface) and the elevation is over-10 m higher than adjacent streams, we excluded lateral supply from the streams. The maximum water level of the streams in the rainy season raised less than 1 m from the dry season by megascopic observation. At the DEF1 plot, a deep soil profile was established in 2006. Near the DEF1 plot, we constructed a 60-m meteorological observation tower with an interception observation plot. Using a set of the data of precipitation, evapotranspiration, interception (Nobuhiro et al., 2007; Shimizu et al., 2007; Tamai et al., 2007), shallow soil water content, groundwater level (Araki et al., 2008), runoff characteristics (Shimizu et al., 2007) and deep soil water content and other information; we will construct a model of water balance from −10 m to 60 m in elevation at evergreen forests in monsoon tropics.

## 3. Methods

At the DEF1 plot, a deep soil profile was dug to a depth of 7.6 m in February 2006 and to a depth of 9.4 m in May 2006. After observations along the wall surface of soil color, mottling color, soil texture, gravel content, soil structure, and the amount of roots by thickness, we measured soil water content and soil hardness vertically at 20-cm intervals from −20 to −920 cm (Fig. 2). Water content was measured using a HydroSense device (Campbell Co. Ltd.), and soil hardness was measured with a Push Cone Penetrometer (DIK-5553, Daiki-Rika Co.

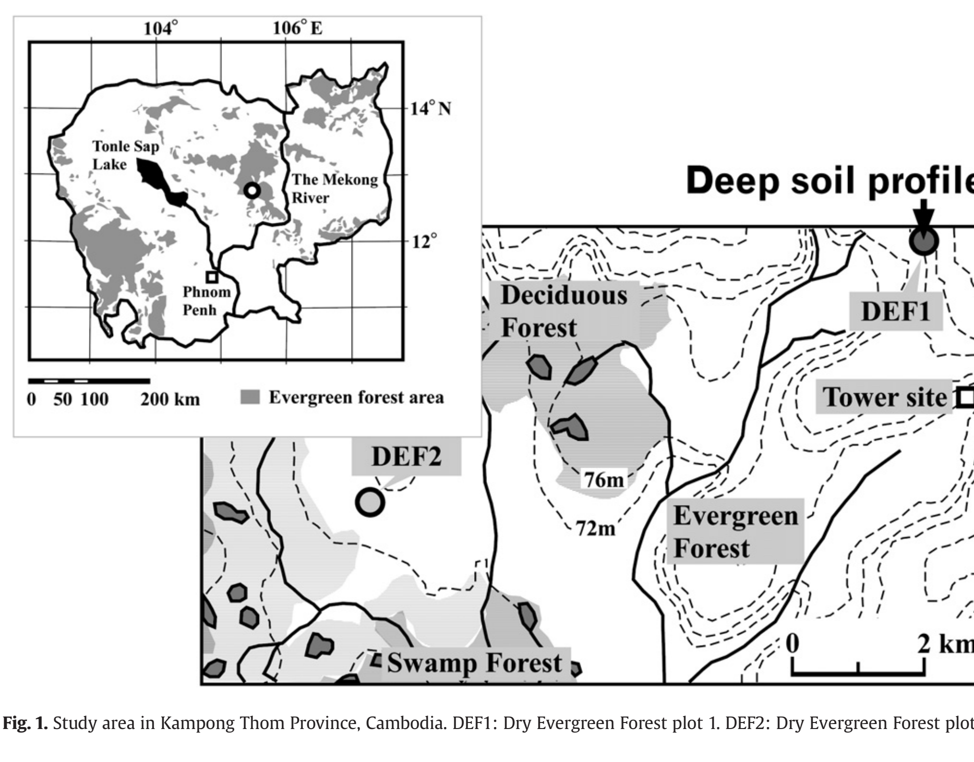


**Fig. 1.** Study area in Kampong Thom Province, Cambodia. DEF1: Dry Evergreen Forest plot 1. DEF2: Dry Evergreen Forest plot 2.