Some Convincing Evidences of a Deep Root System Within an Interfluve Aquifer of Northeast Thailand

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Abstract. In Northeastern Thailand, dipterocarp forest has been cut massively in recent decades to be gradually replaced by cash crops. The aerial parts of the vegetation were sold or burned while underground parts have been degraded with time on site by microbial activity that converts the plant tissues in organic matter more or less mineralized (humus). A drilling program to implant deep piezometers (> 25 m) allowed (i) to describe and characterize the superficial formations (XRD analysis); (ii) to observe and quantify the presence of root biomass at several tens of meters in depth. Additional analyses (stable carbon isotope, SEM) showed that the deep roots are mainly from tree species and aged less than 60 years. The good state of preservation suggests favourable conditions such as the presence of a renewed deep groundwater.

1. Introduction

The northeast of Thailand (NT) is dominated by a landscape of low hills with elevations ranging from 170 m (lowlands) to 240 m (highlands). The lowlands are managed for rain-fed and flooded paddy rice fields which are nowadays severely affected by salinity. Dipterocarpus forest originally occupied the highlands, but was heavily destroyed during the last half of the twentieth century. Forest area decreased from 70,400 km^2 in 1961 to 21,370 km^2 in 1993, namely from 41% to 13% of the NT area [1]. Intensive deforestation has favoured the development of cash crops such as cassava, sugarcane, kenaf, maize and rubber-tree (Hevea brasiliensis). It is widely accepted that the change in land use has led to a radical change in the hydrological balance within the NT, namely a rise in groundwater due to the increase in deep aquifer recharge, an evapotranspiration decrease of seasonal crops and an extension of the saline contamination in the bottom of slopes and in lowlands [2]. Salinity contamination comes from the artesian rise up of the regional groundwater which is enriched with dissolved salts by flowing through the Cretaceous Maha Sarakham evaporite deposits embedded within siliclastic formations [3], [4], [5]. Studies on the deep roots of tree species are relatively limited because the investigative tools provide limited information [6], [7].

The purpose of this study is to (i) characterize the mineralogy of the superficial formations along an interfluve toposequence within a given watershed; (ii) detect traces of deep root biomass in the geological substrate; (iii) characterize the structure of the deep roots and interpret their origin.

2. Materials and methods

2.1. Study site

The studied watershed has an area of 2 km^2 and is located at about 20 km southwest of the city of Khon Kaen near the village of Ban Nong Tun, Phra Yun district, Khon Kaen Province (16°20'N, 102°44'30"E). The region is subjected to a tropical savannah climate influenced by Asian monsoon and marked by distinct dry season (from November to April) and rainy season (from May to October) with a mean annual rainfall of 1,212 mm and 107 rainy days per year in average [8]. Within the watershed, annual rainfall was 1,310 and 1,958 mm in 2007 and 2008, respectively. According to the Soil Taxonomy [9], soils are classified along a toposequence (3.5% average slope) as Typic Haplustult (upland summit), Arenic Paleustalfs (from upper to lower slope) and Typic Paleustult (toe slope). The soil profile is comprised of a superficial ochre sandy layer overlying a grayish clayey layer. The soil thickness varies from 0.70 m (summit) to 2.5 m (toe slope). The bedrock, probably the parental material, is densely fractured and briefly described as a fine reddish sandstone or siltstone (Figure 1). Clay and silt contents of soils increase with depth ranging from 3 to 28% and from 5.6 to 14.3%, respectively. The sandy and clayey layers locally display iron oxide features which attest bedrock weathering and iron mobility under reduced conditions. Quartz, smectite and kaolinite are the predominant constituents in the clay fraction of soils with some illite and trace amounts of feldspar and goethite. Quartz is the most dominant component in the silt fraction with a small amount of feldspar and traces of goethite. Formation of poorly crystalline kaolinite along the slope may occurred by pedogenesis under an intermediate to poorly drainage whereas a dense clay layer at 50-70 cm depth produced a waterlogging in rainy season [10].

Figure 1. Soil profile along the transect showing the ocher sandy surface horizon (1), the intermediate grayish clayey horizon (2) and the reddish fractured bedrock in depth (3)

2.2. Field work

Deep piezometers were installed in two stages. In April 2007, a drilling campaign was initiated to install eight 12 m deep piezometers along a slope (transect 2) within a rubber tree plantation. The names of the piezometers are respectively PB# (from 1 to 8). After a year of monitoring the groundwater level, some piezometers at the slope top (from PB1 to PB4) did not reach the aquifer as expected.

A second drilling campaign was conducted in June 2008 to reach the deep aquifer which needed to dig up more than 25 m using a rotary worm screw device, two piezometers up to 32 m (PB1K and PB2K near PB1 and PB2, respectively) and a third one up to 26 m (PB5K near PB5). Deep piezometers were base-screened from two meters in order to avoid aquifer mixture and obtain water that represented the actual sub-aquifer (Figures 2 and 3). All piezometers were monitored in time (three times a week) to ascertain the magnitude of groundwater fluctuations.

2.3. Laboratory analyses

During the borehole drilling, disturbed materials were sampled every meter for a total of 90 samples. Root biomass was weighed for each sample. Isotopic measurements (^{13}C and ^{14}C) and scanning electron microscopy (SEM) investigations were performed on selected root samples.

The X-ray diffraction (XRD) analyses of 36 samples were investigated using a Philips PW3020 diffractometer equipped with an applied CuKα radiation operating at 50 kV and 20 mA and a graphite monochromator to record diffraction patterns.

Figure 2. Location transect piezometric along the southern slope of the watershed. In red, the deepest piezometers (length exceeding 25 m); in blue, the shallower piezometers (length of about 12 m)
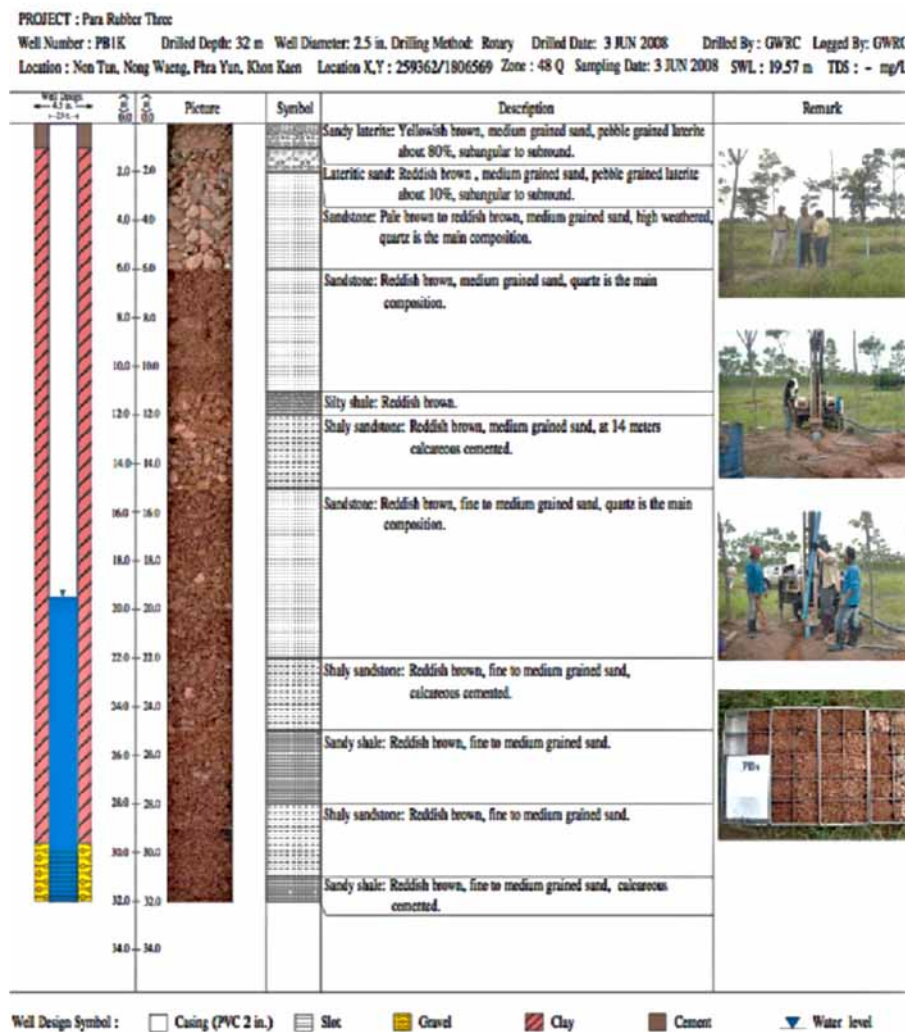

Figure 3. Geological description of the PB1K borehole

C content and ^{13}C isotope composition were determined using an online continuous flow C elemental analyser Flash 2000 HT, coupled with an Isotopic Ratio Mass Spectrometer Delta V Advantage, from Thermo Fischer Scientific. C isotope ratio was defined using the delta notation:

δ sample (‰) = [(R_{sample} - $R_{standard}$)/$R_{standard}$] x 1000

where R is the isotopic ratio ^{13}C/^{12}C R_{sample} and ^{13}C/^{12}C $R_{standard}$, respectively. The results were expressed in δ^{13}C per mil (‰) against the international standard V-PDB (Vienna Pee Dee Belemnite).

δ^{14}C determination was performed on the same root samples than δ^{13}C analyses by Accelerator Mass Spectrometry using Artemis AMS built by NEC (National Electrostatics Corp., Middleton, Wisconsin, USA) around a 3MV Pelletron electrostatic tandem and located in Saclay nearby Paris. The activity of ^{14}C is given in pMC (percent Modern Carbon) according to the international convention [11]. The precision of the measurement (ΔpMC) is ±0.5 PMC. ^{14}C ages are calculated in conventional ^{14}C years before 1950 (or Before Present, BP) according to the international convention [11].

Scanning electron microscope (SEM) investigations were performed using a Zeiss EVO LS15 at 15kV coupled to a INCA 350 Energy Dispersive X-ray Spectrometry (EDX) system from Oxford Instruments for element analysis. Samples were carbon coated prior to analysis.

3. Results and Discussions

3.1. Geology and mineralogy of superficial formations (soil and bedrock)

The well log report for PB1K borehole shows the textural heterogeneity of the geological formations (Figure 3). From the surface to depth, drilled materials are mainly reddish brown and consist of sandstone, shaly sandstone and shale with varying thicknesses. In the upper part, the material is lateritic and sandy. For the two other boreholes, the material description is fairly similar. Only the distribution of layers, their nature and colour slightly vary.

Depth (m)	Clay fraction							Silt fraction	
	Kaolinite	Illite	Smectite	Chlorite	Int 7-10A°	Int 10-14A°	Quartz	Quartz	Feldspar
PB1K									
0-1	tr	x	xx	-	-	-	tr	xxxx	tr
1-2	tr	x	xxx	-	-	-	-	xxx	tr
4-6	tr	x	xxx	-	-	-	-	xx	tr
8-9	tr	x	xxx	-	-	-	-	xx	tr
11-12	tr	x	xxx	-	-	-	-	xx	tr
13-14	tr	x	xxx	-	-	-	-	xxx	tr
17-18	-	x	xxxx	-	-	-	-	xxx	tr
19-20	-	x	xxxx	-	-	-	-	xxx	tr
23-24	tr	x	xxx	-	-	-	-	xx	tr
26-27	tr	x	xxx	-	-	-	-	xxx	tr
29-30	tr	x	xxxx	-	-	-	-	xxx	tr
31-32	tr	x	xxx	-	-	-	-	xxx	tr
PB2K									
0-1	x	x	x	-	tr	tr	x	xxxx	tr
1-2	x	x	xx	-	tr	tr	-	xxx	tr
2-3	x	x	xxx	-	tr	-	-	xxx	tr
5-6	tr	tr	xxxx	-	tr	-	-	xxx	tr
8-9	tr	x	xxx	-	tr	tr	-	xxx	tr
11-12	tr	x	xxx	-	-	-	-	xxx	tr
14-15	tr	tr	xxx	tr	-	-	-	xxx	tr
18-19	tr	tr	xxx	tr	-	-	-	xxx	tr
21-22	tr	xxx	-	x	-	-	-	xx	tr
23-24	tr	xxx	-	x	-	-	-	xx	tr
26-27	tr	xxx	-	x	-	-	-	xxx	tr
29-30	tr	xxxx	-	x	-	-	-	xxx	tr
PB5K									
0-1	x	x	x	-	tr	tr	tr	xxxx	tr
2-3	tr	tr	xxx	-	tr	tr	-	xxx	tr
4-5	tr	x	xxx	-	-	-	-	xxx	tr
5-6	tr	x	xxxx	-	-	-	-	xxx	tr
7-8	tr	x	xxx	-	-	-	-	xxx	tr
9-10	tr	x	xxx	-	-	-	-	xxx	tr
11-12	tr	tr	xxx	-	-	-	-	xxx	tr
14-15	-	tr	xxx	-	-	-	-	xxx	tr
17-18	-	tr	xxx	-	-	-	-	xxx	tr
21-22	-	tr	xx	-	-	-	-	xx	tr
23-24	-	x	xxx	-	-	-	-	xxx	tr
25-26	x	tr	xxx	-	-	-	-	xxx	tr

tr = trace, x = small, xx = moderate, xxx = large, xxxx = dominant
Int 7-10 A° = Interstratified clay mineral between 7 and 10 A° on basal 001 reflection
Int 10-14 A° = Interstratified clay mineral between 7 and 14 A° on basal 001 reflection

Figure 4. XRD determination from three boreholes drilled in superficial formations

Quartz is the major component of the non-clay fraction (silt fraction) with traces of feldspar (Figure 4). Although not determined by XRD, presence of iron oxides such as goethite and hematite is evidenced by the dominant reddish brown color. The predominant minerals in the clay fraction are smectite with a

small amount of illite and traces of kaolinite. In the deeper layers of PB2K borehole, smectite is absent and replaced by illite. Interstratified clay minerals are detected as traces.

3.2. Root biomass

The distribution of root biomass as a function of depth indicates a high amount of root biomass (from 0.1 to 1.8 g 1000g^{-1}) at a depth ranged from 20 m to 32 m, mainly for PB1K and PB2K boreholes, (Figure 5).
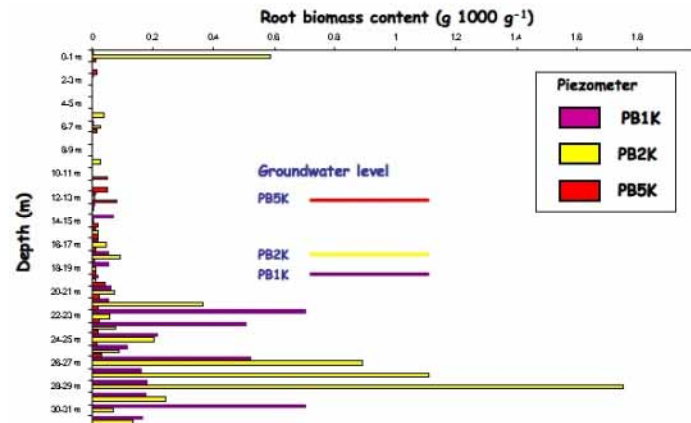

Figure 5. Vertical distribution of root biomass in the deeper borehole; the groundwater level is indicated at the drilling time

3.3. Groundwater location

The deep root biomass appears below the current level of deep groundwater which is about 19 m for PB1K and 18 m for PB2K, as shown in Figures 5 and 6. In terms of elevation, the groundwater level is between 177 m and 179 m above mean sea level (AMSL) and does not seem to change a lot over time (Figure 6). In PB1K piezometer, rapid groundwater level variations were recorded, probably due to infiltration of water through a shallow sandy soil and a very fractured bedrock.
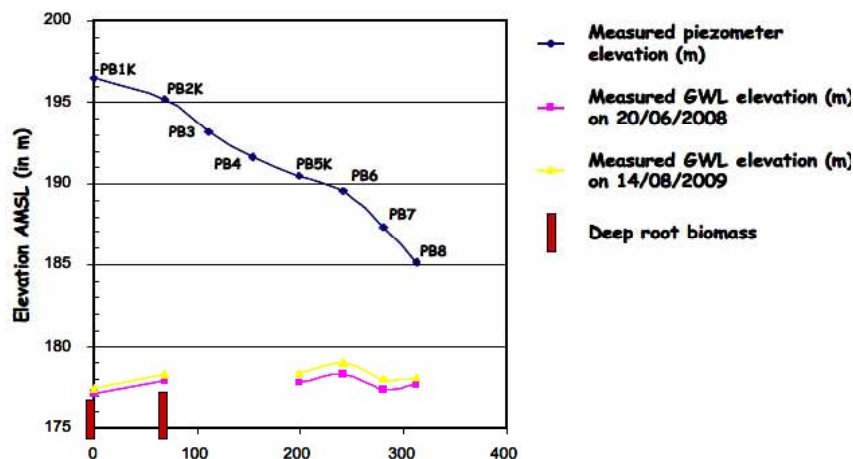

Figure 6. Elevation AMSL of the deep groundwater level (GWL) at two time periods and position of deep root biomass and GWL with respect to the ground surface along the slope

The current presence of a water table suggests that the roots of the past trees had to reach a water-saturated zone, probably deeper, to meet the water and nutrient requirements with minimal energy. Such a possibility is shown in Figure 7 showing the growth of trees in the same watershed in the presence of a water table not far from the surface.

3.4. Deep root origin and age

As a result of the fractionation of stable carbon isotopes during photosynthesis, the $^{13}C/^{12}C$ ratio values of terrestrial plants fall into two discrete ranges, from -23‰ to -34‰ for C3 plants and from -9‰ to -17‰ for C4 plants [12]. The bibliographic references relative to ^{13}C data are numerous for soil organic matter but much less for aerial (trunk, stem, leaf) and underground (shallow root, deep root) parts of plants. Ohashi et al. [13] reported ^{13}C values measured in the wood of dipterocarp species from Northeastern Thailand and ranging from -24‰ and -28‰. The ^{13}C measurements of the PB1K borehole are ranging from -22.6‰ to -26.5‰ (Table 1). They correspond to a C3 plant type, probably a tree species as Dipterocarpus. In contrast, the PB2K data varying from -16.6‰ to -25.3‰ suggest that vegetation changes have occurred by root segregation [14]. Furthermore, for the two boreholes, the carbon content of deep roots is highly variable and ranges from 2.7% to 40.8%.

Figure 7. Some residual trees in the Ban Nong Tun watershed with the presence of an open waterbody near the soil surface; in the background, a recent planting of eucalyptus

Table 1. Carbon content (C), measurement precision (ΔC) and ^{13}C isotope values of selected deep root samples

Sample	Weight (mg)	C (%)	ΔC	δ^{13}C (‰vsPDB)
PB1-K23	0.321	11.72	0.19	-26.49
PB1-K24	0.366	13.24	0.18	-24.14
PB1-K25	0.079	28.94	1.17	-22.67
PB1-K27	0.210	22.61	0.40	-22.76
PB1-K31	0.424	17.45	0.18	-25.22
PB2-K22	0.534	25.27	0.49	-16.67
PB2-K27	0.184	2.77	0.93	-25.30
PB2-K28	0.212	40.80	1.30	-22.06
PB2-K29	0.176	34.94	1.45	-19.60
PB2-K30	0.267	38.58	1.03	-20.49

^{14}C values from Table 2 show that the age of deep roots is after 1950. As the deep roots express the recent plant growth, one can only deduce that the tree cutting did not take place before 1950

Table 2. Carbon content (C), ^{14}C activity (pMC), measurement precision (ΔpMC) and ^{14}C age (age BP) of selected deep root samples

Sample	C (mg)	pMC	ΔpMC	Age BP
PB1-K23	0.667	105.531	0.281	Posterior to 1950
PB1-K24	0.552	104.984	0.277	Posterior to 1950
PB1-K25	0.218	106.193	0.340	Posterior to 1950
PB1-K27	1.272	104.334	0.256	Posterior to 1950
PB1-K31	0.988	105.408	0.271	Posterior to 1950
PB2-K22	0.491	106.975	0.293	Posterior to 1950
PB2-K27	0.748	106.236	0.257	Posterior to 1950
PB2-K28	0.514	105.754	0.278	Posterior to 1950
PB2-K29	1.282	104.867	0.259	Posterior to 1950
PB2-K30	1.028	104.606	0.244	Posterior to 1950

3.5. Biological structure and chemical composition of deep roots
SEM images are very conclusive because they clearly distinguish the structural organization of deep roots showing the well-preserved cell membranes (Figure 8). One can assume that the natural degradation of roots by mineralization due to microbial activity has not occurred. Favourable physicochemical factors, such as renewed underground water, allowed to keep the cell structure of roots in good condition over time.
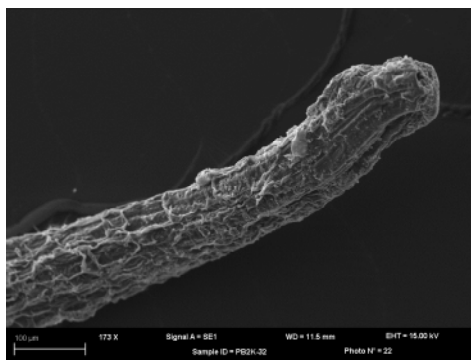

Figure 8. SEM image of a deep root from PB2K borehole at a depth ranging from 31 m to 32 m

Measures to EDX probe show that the organic carbon cell membranes are made in a kind of clay matrix. A 2/1 clay mineral (mainly smectite) is always present in contact with the cell membrane and is in a neoformation phase as if the organic structure is used as crystallization point (Figure 9). One would rather think of clay deposits from soil and bedrock weathering, but the clay membrane contact is so intimate that it is another phenomenon. This would explain probably the very good state of preservation of the roots. For that to occur, a source of dissolved elements (bases, iron, silica) that a supersaturated aqueous medium can bring is needed.
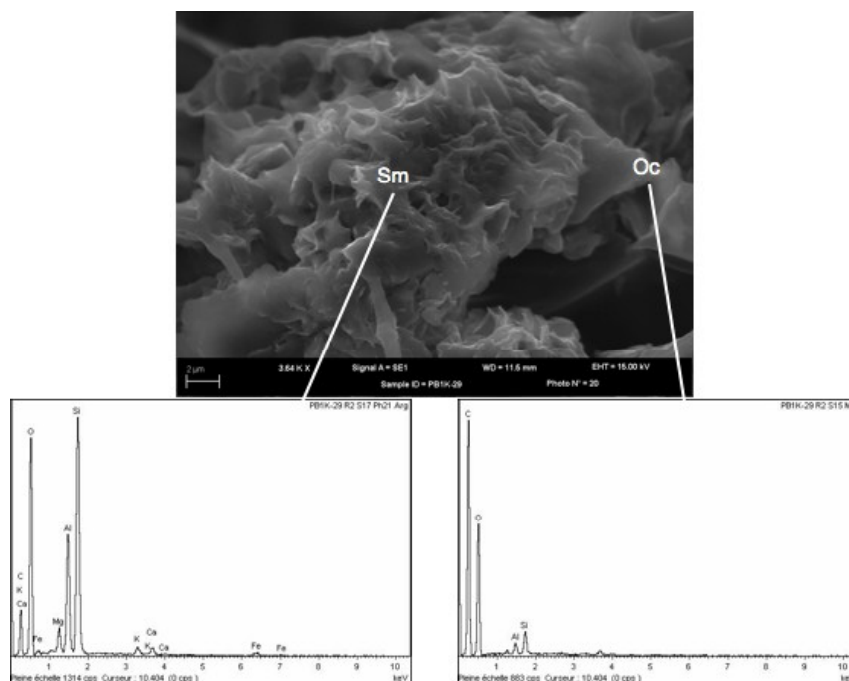

Figure 9. SEM image of a deep root from PB1K borehole at a depth ranging from 28 m to 29 m. Oc: Organic carbon of cell membranes; Sm: Smectite clay mineral

As sandstone-siltstone bedrock is rich in smectite, the source exists and dissolution-precipitation mechanisms are probably active during groundwater recharge by infiltration.

4. Conclusions

For the first time in Northeast Thailand, well-preserved deep roots were collected in a field at several tens of meters in depth, then quantified and observed in laboratory. The proximity of a groundwater body is a favourable environment for the development of a deep root system, which is probably widespread throughout the deforested environment insofar textural discontinuities do not prevent the root progression in depth.

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