Effect of land use on the soil physical properties and water budget in a small water shed in NE Thailand

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Abstract
Land clearing has severely affected the uplands in the Northeast of Thailand, where the original forest has been converted into agricultural land, with most probably important modifications of the soil properties. The aim of this study was to assess the effects of land use changes on both the soil physical properties and on the soil water budget in a small watershed. The experiment was conducted in 2008, in a mini watershed located near the village of Ban Non Tun (16°19'43.90" N, 102° 45'07.91" E), in the Khon Kaen Province, Thailand. The experiment was set up in several plots with different land uses: a young rubber tree (RT) plantation, ruzi grass (RG), and natural forest (F). Under the RT and under the RG the presence of a clayey layer at a depth varying from 90 to 150 cm, with low permeability, hindered the water infiltration and led to the occurrence of a perched water table during rainy season. The drainage was around 40% of the total rainfall in RT and RG respectively. The surface runoff was 10.73, 2.76 and 4.80% of total rainfall and the average evapotranspiration in the dry season was 1.80, 1.57 and 2.04 mm d^{-1} for the RT, RG and F respectivity.

Key Words
Hydraulic property

Introduction
In the northeast of Thailand where undulating topography dominates the landscape, the soil is mainly sandy and of low fertility. During these last decades the original *dipterocarpus* forest located in the uplands of the landscape has been cleared into agricultural land dedicated to cash crops. The conversion from forest to agricultural land had several noticeable impacts especially on the soil and water quality. Some studies (Chen *et al.,* 2009) found that land cover changes affect the distribution of soil moisture and hydraulic properties. However, this process has not been addressed in terms of precise quantification in this area. The temporal change of land use and management can thoroughly affect soil hydraulic properties and the soil water cycle. Therefore the aim of this study is to quantify the consequences of land use changes on the soil physical properties and soil water budget in a small watershed.

Materials and Methods
Experimental sites
The study site has been set up in a mini watershed located near Ban Non Toon, Khon Kaen Province, Thailand (16°19'43.90" N, 102° 45'07.91" E). In this undulating landscape, the higher parts of the mini watershed reach 210 m AMSL and 185 m AMSL in the lower parts, with a general average slope of 3.5%. Most of the area is planted with rubber trees (RT) and ruzi grass (RG) along the slopes and paddy fields in the valley line. Some patches of original forest (F) are still present in the watershed. Previously the land was planted with jute, cassava and ruzi grass. The climate of the site is considered as tropical savanna climate, with an annual rainfall of 1,309 and 1,957 mm in 2007 and 2008 respectively, and an average annual temperature of 29 °C.

Hydraulic properties of soil and water budget
The saturated hydraulic conductivity was measured in situ with a disc infiltrometer (Perroux and White 1988) in three different situations of land use: rubber tree plantation, ruzi grass pasture and forest. The water retention curves were derived from Wind evaporation method (Wind 1968) and with van Genuchten model (van Genuchten 1980).

$$Se = \frac{\theta - \theta r}{\theta s - \theta r} = (1+(-\alpha h_p)^n)^{-m} \qquad (1)$$

where θ_r and θ_s represent the residual and saturated water content, h is the matrix pressure head, α, n and m empirical parameters (m=1-1/n).

In order to monitor the water flux in this experimental watershed and in the different situations, a series of experimental devices was installed in the field namely: (i) a network of piezometers to measure the groundwater flow, (ii) several stations with tensiometers and neutron probes to monitor the water flow in the vadoze zone, (iii) in each situation the surface runoff was measured with a PVC cylinder (diameter 60 cm) slightly driven into the soil with a superficial outlet connected to a plastic tank and (iv) a micro-meteorology station. Considering the different terms of the water budget equation evapotranspiration was calculated as below:

$$P - R - D - \Delta S_{soil} = ET \qquad (2)$$

where P is precipitation was estimated from tipping bucket rain gauge, R is surface runoff, D is deep drainage calculated from tensiometric data and ΔS is change in soil water storage.

Results and Discussion

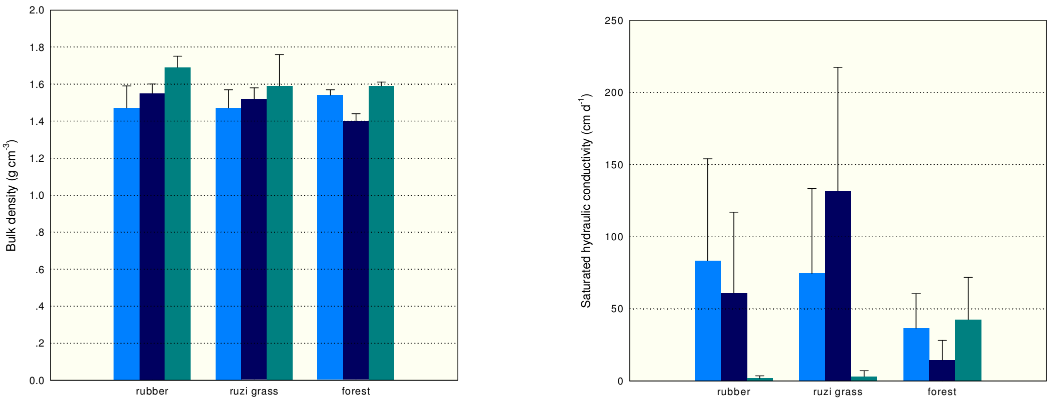
Soil properties

Some physical and chemical properties of soil are shown in Table 1. The texture of RT soil and RG soil is sandy at the top whereas the subsoil is sandy in its upper part, but becomes clay soil in depth. This clayey layer represents the interface between the soil profile and the bed rock composed of sandstone. Under the forest, the soil texture is sandy from the top to the bottom, even if the clay content also increases with depth. The soil pH of RT, RG and F soil is very acidic in the sandy layer but moderately acidic in the clayey layer except at 90 cm depth in forest soil where it is very acidic. The organic matter status is extremely low in all situations, but systematically shows a slight increase in the top soil.

Table 1. Physical and chemical properties of rubber tree (RT), ruzi grass (RG) and forest (F) soil.

Depth (cm)	Sand	Silt (%)	Clay	Texture	pH (1:1) H_2O	OM (%)
RT soil						
10	91.4	5.6	3.0	S	5.1	0.6
50	87.0	8.5	4.5	LS	5.3	0.1
90	57.7	14.3	28.0	SCL	5.5	0.4
RG soil						
10	89.0	7.5	3.5	S	5.4	0.5
40	87.2	10.6	2.2	S	5.4	0.1
90	57.6	12.1	30.3	SCL	5.7	0.2
F soil						
10	84.6	11.1	4.3	LS	5.4	0.5
40	87.8	8.7	3.5	LS	5.2	0.1
90	72.9	10.9	16.2	SL	4.9	0.3

The bulk density of RT and RG soil showed a regular increase with depth (Figure 1a), whereas for F soils it decreased slightly at 40 cm though the general trend from surface to depth is also an increase. Conversely, the value of saturated hydraulic conductivity (K_s) decreased with depth under RT soil (figure 1b). On the RG soil, the value of K_s was noticeably higher at 40 cm than at 10 cm soil depth, but similarly to RT soil the value of Ks is extremely low at 90 cm depth. On the other hand the saturated hydraulic conductivity was much more homogeneous along the soil profile under forest as the clayey layer was not as clearly identified as in the other situations. Saturated hydraulic conductivity shows higher variation on the superficial sandy soil than in the lower clayey soil. The comparison of three land uses showed that the hydraulic conductivity at top soil RT soil and RG soil was significantly higher than in F soil. This may be due to differences in soil compaction, as illustrated by bulk density, but it is mainly the slight difference in clays content that may explain particular properties. Similarly deeper, around 90 cm, the saturated hydraulic conductivity of F soil was much higher than for the soil of the two other situations, due to the difference in clay content.



(a) (b)

Figure 1. Bulk density (a) and saturated hydraulic conductivity (b) of rubber tree, ruzi grass and forest soil (Cyan color is 10 cm depth, Blue color is 40 or 50 cm depth and Dk Cyan color is 90 cm depth).

Water retention parameter was show in Table 2. The value of residual water content θ_r of RT soil and RG soil was higher in the clayey layer than in the sandy layer. Inversely the value of saturated water content θ_s was higher in the sandy layer than in the clayey layer, indicating more available water in the sandy layer than in the clayey layer. In the F soil, the value of θ_r and θ_s slightly decreased with depth. The water retention parameter α in sandy layer is quite similar for most soils but is lower in clay layer. These values tend to decrease slightly from top soil to sub soil with narrow range of variation, accordingly to the clay content. The value of parameter *n* decreased with depth in all situations.

Table 2. soil water retention parameter of rubber tree (RT), ruzi grass (RG) and forest (F) soil.

Depth (cm)	θr ($cm^3\ cm^{-3}$)	θs ($cm^3\ cm^{-3}$)	α (cm^{-1})	n
RT soil				
10	0.07±0.04	0.37±0.009	0.02±0.002	3.09±0.31
50	0.03±0.01	0.36±0.01	0.01±0.0004	2.82±0.25
90	0.12±0.02	0.28±0.01	0.01±0.005	1.92±0.17
RG soil				
10	0.06±0.001	0.39±0.001	0.02±0.002	4.16±0.33
40	0.07±0.02	0.40±0.01	0.02±0.0003	2.57±0.14
90	0.012	0.31±0.018	0.002±0.0001	2.70±0.23
F soil				
10	0.07±0.014	0.32±0.01	0.02±0.0004	2.68±0.45
40	0.06±0.0002	0.32±0.01	0.01±0.001	2.55±0.19
90	0.05±0.07	0.28±0.01	0.02±0.002	1.91±0.72

Soil water budget

The study of the soil water budget under RT and RG was carried out from January to December 2008, except for F, where the tensiometric data was unavailable from January to June 2008. Therefore drainage could only be calculated for half a year in this situation. The annual rainfall in 2008 was exceptionally high with 1,958 mm. In the RT soil, three different topographic situations have been considered: up-, mid-, and downslope. The evolution of surface runoff has been represented in Figure 2. In RT soil, at the beginning of the rainy season upslope and midslope situations have higher runoff than the downslope but at the end of rainy season cumulative runoff becomes higher downslope. Possibly due to lateral perched water flow downslope. In RG and F the surface runoff is noticeably less, and increases mainly at the end of the rainy season when soils are thoroughly saturated.

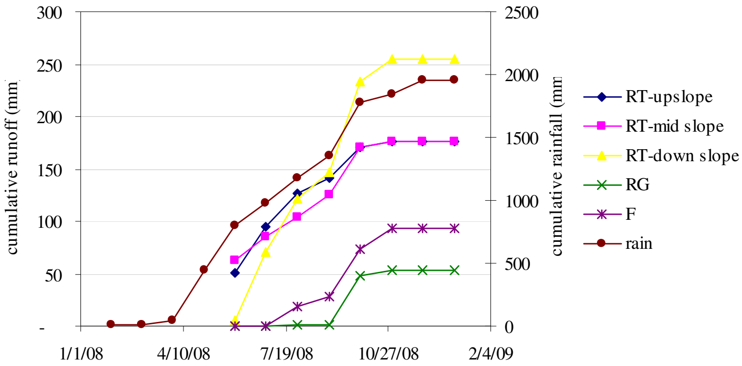


Figure 2. The evolution of surface runoff under three land uses.

In RT and RG, the sandy layer, with its high permeability, had an high drainage capacity, but the low permeability of clay layer limited downward percolation. Consequently a perched water table developed during rainy season. The drainage was higher in RG soil than RT soil (Table 3). From July to December 2008, the drainage in F soil was 459 mm, and in the same period it was 776, 1175 for RT at and RG Evapotranspiration (ET) calculated from the soil water balance equation was similar to Penman's potential evapotranspiration calculated with the meteorological data (1000.13mm). In the RT situation the topography played an important role in the water balance, as shown in Table 3: in mid slope position, drainage was less but ET was highest. The drainage represented around 40% of the total rainfall for RT and RG, whereas it represented only 23% of the total rainfall in the forest. The surface runoff was 10.73, 2.76 and 4.80% of total rainfall and the average ET of RT, RG and F in dry season was 1.80, 1.57 and 2.04 mm d^{-1} respectively.

Table 3. The cumulative drainage water and evapotranspiration in the three land uses

Land use	Drainage	ET
	(mm)	
Rubber soil	776	1012
- upslope	852	1002
- midslope	586	1227
- downslope	890	808
Ruzi grass soil	1175	870
Forest soil	459*	418*

* calculated from July-December 2008

Conclusions

The soil differentiation in the different land use situations, especially the clay distribution, conditioned specific soil hydraulic properties and water balances. The contrasted saturated hydraulic conductivity in RT and RG between sandy layer and clayey layer, contributed to the occurrence of a perched water table during rainy season when rainfall was high and potential evaporation was low. The shallow water table persisted for 2–3 months, with downward and lateral flux causing drainage losses. On the other hand in more the homogeneous soil of the forest, the water storage was higher, the runoff and the drainage less, and finally the ET higher.

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