ການປະເມີນຄ່າໄລຍະການບວມນ້ຳໃນດິນ ໂດຍນຳໃຊ້ວິທີການຕີລາຄາສີຂອງດິນ ໃນເຂດອ່າງໂຕ່ງ ພາກເໜືອ ຂອງ ສ.ປ.ປ ລາວ

ເອມານູແອນ ບວກດິງ, ດີດີເອ ບລາເວ, ອຸ່ນລາມ ລວງກອງຄຳ, ບຸນສະໄໝ ສຸລິເລີດ,
ອາລຸນສະຫວັດ ຈັນເພັງໄຊ, ອາແລັງ ປີເອເຣ, ໂອລີວີເອ ຣິໂບນຊີ

ບົດຄັດຫຍໍ້

ນ້ຳໃຕ້ດິນ ຈັດເປັນແຫຼ່ງສຳຄັນໃນການຕອບສະໜອງນ້ຳໃຫ້ແກ່ປະຊາກອນ ນອກຈາກນີ້ແລ້ວ ນ້ຳໃຕ້ດິນ ຍັງຊ່ວຍເຮັດໃຫ້ ສາຍນ້ຳຫ້ວຍໄຫຼເປັນປົກກະຕິ ໄດ້ຕະຫຼອດປີ. ຈຸດປະສົງຂອງການຄົ້ນຄວ້າ ແມ່ນເພື່ອປະເມີນຮູບແບບຈຳລອງ 2 ຊະນິດ ເພື່ອຄຳນວນຄ່າໄລຍະເວລາການບວມນ້ຳຂອງດິນຈາກ ນ້ຳໃຕ້ດິນຕື້ນ, ໂດຍອີງໃສ່ການປ່ຽນແປງສີຂອງດິນເປັນຫຼັກ, ວິທີການດັ່ງກ່າວ ໄດ້ພັດທະນາມາຈາກ Blavet (2000) ໃນເຂດອາຟຼິກກາຕາເວັນຕົກ ແລະ ສັງເກດເຫັນວ່າ ວິທີການດັ່ງກ່າວ ແມ່ນເໝາະສົມ ໃນການນຳໃຊ້ ຢູ່ເຂດພູດອຍ ຂອງ ສ.ປ.ປ ລາວ ເຊັ່ນດຽວກັນ. ວິທີການດັ່ງກ່າວ ປະກອບດ້ວຍການ ປຽບທຽບຂໍ້ມູນ (ລະດັບນ້ຳໃຕ້ດິນ, ສີສັນທາງດ້ານກາຍະພາບ, ສີຂອງດິນ) ທີ່ໄດ້ມາຈາກພາກສະໜາມ ແລະ ຈາກຮູບແບບຈຳລອງ. ການທົດລອງໄດ້ເຮັດຢູ່ 2 ຈຸດ ເສັ້ນຜ່າຕັດ ທີ່ມີຄວາມແຕກຕ່າງທາງດ້ານ ພູມສັນຖານ ແລະ ລະບົບນ້ຳໃນດິນ. ຈຸດທີນຶ່ງ ແມ່ນເຂດຮ່ອມພູຕ່ຳ ມີນ້ຳຂັງທັງສອງຂ້າງ ເປັນໂນນພູ ຊັນ ແລະ ຈຸດທີສອງ ແມ່ນເຂດຮ່ອມພູແຄບ ທັງສອງຂ້າງເປັນພູຊັນແບບຫຼຸບໂນນ. ການສຶກສາເບື້ອງ ຕົ້ນ ໄດ້ໄຈ້ແຍກຄວາມສຳພັນລະຫວ່າງສີຂອງດິນ ແລະ ຄ່າສະເລັ່ຍຂອງການບວມນ້ຳໃນດິນ ເພື່ອພັດ ທະນາຮູບແບບທີ່ງ່າຍດາຍ ສຳລັບການຄຳນວນການອີ່ມຕົວຂອງດິນ ໃນເຂດພູດອຍ.

Semi-quantitative evaluation of waterlogging duration using two models based on soil colour in a representative upland catchment of northern Lao PDR

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Abstract

Groundwater is a vital resource for rural populations in tropical areas who depend on seasonal rainfall. Groundwater is often the only source of water feeding streams, allowing them to flow throughout the dry season. The aim of this study was to evaluate two models for estimating the average duration that soil is waterlogged by shallow groundwater table. These models, based on variations in soil colour, were developed by Blavet et al (2000) from observations and measurements made in a semi-arid environment in West Africa. Therefore there is a need to evaluate whether these models are also pertinent in a mountainous context of northern Laos. Our approach consisted in comparing data obtained from field measurements (water table level, morpho-pedological features including soil colour) with predictions made by the models. This study was carried out along two transects with contrasting characteristics in terms of the landscape morphology as well as the soil hydrodynamic: the first was in an open swampy valley with convex hillslopes, the second was in a steep-banked and narrow valley with convexo-concave hillslopes. Preliminary results from our study identified relationships between soil colour and the mean rate of soil waterlogging and are a first step for developing an inexpensive and simple method to predict soil saturation in this environment.

Key words: *Groundwater resources; Waterlogging; Soil colour; Mountainous stream; Lao P.D.R*

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Introduction

Groundwater is a major resource for people living in tropical zones with seasonal rain. In arid and semi-arid environments, it is the only permanent water reserve, whereas in humid mountain climates, it feeds streams resulting in stream flow during the dry season.

Our study is focused on the uplands of northern Laos where groundwater plays a key role in the hydrology of the area. This water resource is used directly in shallow village wells for domestic use or indirectly from the permanent stream for small scale irrigation or to fill ponds for fish farming. Within this context and with the future perspective of predicted global changes in the Southeast Asian region (i.e. global warming, conversion of annual crops to cash crops requiring more water from the underground water table) political decision makers and land managers need to make decisions based on sound scientific data.

A number of morpho-pedological characteristics have been linked with the hydrological functioning of the soil such as the redistribution of carbonate (Bouzigues et al, 1997) or the presence of oxides (Vizier, 1974). The analysis of these indicators often requires expensive and complicated equipment (i.e. scanning electron microscope). A number of studies have shown that the colour of the soil is strongly controlled by the time course of oxidation-reduction cycles linked to the presence of the water table (Schwertmann, 1993; Franzmeier et al., 1983; Veneman et al., 1998; Faulkner and Patrick, 1992). These cycles have an impact on the mobility of elements such as iron, manganese (Fanning and Fanning, 1989) and humic compounds (Duchaufour and Souchier, 1977) which are one the principal factor affecting soil colour in tropical environments (Segalen, 1969). Several authors also described the relationships between oxido-reduction processes and soil colour using different models (Simonson and Boersma, 1972; Megonigal et al, 1993; Genthener et al., 1998; Blavet et al., 2000).

The overall objective of this study was to evaluate soil colour as a simple pedological indicator, which is easy to determine in the field, as a rapid semi-quantitative diagnostic of the water table resources in the mountainous agro-ecosytems in northern Laos. Two models developed by Blavet et al. (2000) predicting soil waterlogging based on soil colour were applied in the Houay Pano catchment.

Materials and methods

This study was carried out in the Houay Pano catchment, the biophysical characteristics of which are described in detail by Valentin et al (this issue). In order to test the models in contrasting situations, two observation and measurement transects were chosen based on of the known hydro-geochemical data of the stream (Ribolzi et al., 2005), morpho-pedological characteristics of the soil (NAFRI, 1999) and existing piezometers (Ribolzi et al., 2008 this issue). The first transect, RIB 48, is characterised by a convex open valley with a swampy area and a stream channel with gentle slope. The second, RIB 33, is in a deep and narrow convexo-concave valley.

Monitoring water table levels

The catchment was progressively equipped with a network of piezometers from 2002 to 2007. The piezometers are made of PVC with a 5.5 cm diameter and are perforated in their base for a distance of 50 cm. The depth at which these were installed depended on the depth of the water table which was determined by auger surveys. These were installed along transects perpendicular to the axis of the river (including RIB33 and RIB48). The depth of water in the piezometers was measured daily during the rainy season and weekly during the dry season. These measurements were made using a probe with an acoustic alarm.

Data collected from 2003 to 2006 were used for a descriptive statistics analysis. The minimums, first quartile maximums, medians, 3rd quartiles and averages were calculated to characterise the water levels measured in the piezometers throughout this period. Furthermore, histograms and cumulated distributions were calculated with a 10cm increment. This analysis was used to determine the time-course of soil saturation. Correlations were sought between these quantitative data and the observed soil colour.

Soil sampling and description

A soil survey with hand augers was carried out during the 2006 dry season. Soil samples were collected every 10 cm along vertical profiles in the vicinity (~1m) of each piezometer in the two selected transects. For each sample the morphology of the material was described in terms of conditions - wet colour, texture, porosity and stoniness. Morphological features associated with hydromorphy were also described (i.e. redoxic coloured spots and lines, pellicular coatings, concretions). These pedological characteristics were used to delimit the volumes of soil along transects which had been affected by the waterlogging (Figure 1).

Soil colour determinations

The soil colour was determined using Munsell colour chart (Munsell, 1976) including Munsell Hue (i.e. shade, noted Hue), Munsell Value (i.e. colour saturation, noted V) and the Munsell chroma (i.e. brightness level, noted C). The Hue is a mixture of one primary colour, white (saturation) and black (brightness). The letters referring to each Hue indicate the following colours: red (R), yellow (Y), green (G), blue (B), purple (P). The colours correspond to alphanumerical values (e.g. 10R 3/6, 10YR 3/4, 2.5Y 4/4) spread around the circle on the Munsell colour cylinder. The shades are converted into an angular coordinate, H^o. By convention the colour Red Purple (10RP) is equal to 360°. The formula used for this conversion is the following:

$$H^o = 36 * \left(I1 + \frac{I2}{10} \right) \qquad (1)$$

where I1 is the numerical coordinate of the hue (i.e. R = 0; YR=1; Y = 2; GY = 3; G = 4; BG = 5; B = 6; PB = 7; P = 8; RP = 9) and I2 is the number associated with the hue (e.g. 10 for 10YR ; 5 for 5YR etc). Table 1 shows the major hue and their corresponding angular notation H^o measured in the field. H^0 of each hue, V and C recorded for the soil are then combined to give the redness rating (RR) proposed by Torrent et al (1983). This ratio describes the forms of iron oxides in the soil and in particular the hematite content (Schwertmann, 1993). It is defined by the following formula:

$$RR = \frac{(360 - 5\,H^o) * C}{18V} \qquad (2)$$

Table 1 shows the correspondence between H^0 and RR. Correlations were then sought between these two variables and the cumulated distributions of the water levels measured in the piezometers to establish the prediction models.

Relationship between soil colour and water table levels

In experiments carried out in the semi arid environment of West Africa on granito-gneissic bedrock, Blavet et al (2000) showed that the cloud of points obtained by comparing the variables H^o and RR with the mean annual rate of soil waterlogging (in %) could be described by a sigmoid type curve using the following equation:

$$\overline{\mathrm{WLG}} = \frac{100}{1+(ae^{bx})} \qquad (3)$$

where x is the value of H° or RR, a and b are the model constants obtained by adjusting the models using the least squares method (Table 2). Confidence intervals associated to the models follow the normal distribution were estimated as follows:

$$E\overline{\mathrm{WLG}}_{0\,95}\left[x\right] = 1,96\, g\left(x\right) \qquad (4)$$

with the hypothesis of a normal distribution of ; g(x) being the function that allowed to calculate the 95% confidence error margin from all the x values observed for H° or RR. Correlation coefficients were obtained by comparing the % values from the models with the measured values.

Results

Water table level behaviour

Figure 1 illustrates the characteristics of the water table depending on the topographic position of the two transects included in the study. On the slope in RIB 48 (Figure 1a, piezometer T3A3), the water table is found at an average depth of 118 cm (median = 110 cm), with an interquartile deviation around the median of 25 cm. The depth of the water table varied from 25.7 and 138.7 cm, thus with a maximum difference of 100 cm. Next to the stream (piezometer T3A2), the average depth of the water table was 12.7 cm (median = 12.4 cm), the interquartile deviation was only 10 cm and the water table level fluctuated between a depth of 24.4 cm and a height of 11 cm above the soil surface, thus a maximum difference between the extremes of 35 cm. On the slope in RIB 33 (Fig.1b, piezometer T1A4), the water table is found at an average depth of 445.4 cm (median = 436 cm), with an interquartile deviation of 20 cm and the difference between the extremes reached 200 cm. Next to the stream (piezometer T1A1), the average depth was 41.8 cm (median = 42.4 cm), the interquartile difference was only 5 cm and the difference between the extremes was only 69 cm (the level of the water table fluctuated between 15 and 54 cm).

Characterisation of the soils near the piezometers

On the slopes (Figure 2a), the soil close to the piezometer T3A3 (transect RIB48) was reddish grey (2.5 YR 3/2, 4/2) to reddish brown (2.5YR 4/4) down to a depth of 70cm while, near piezometer T1A4 (transect RIB33), it was reddish brown (5YR 3/4 to 5YR 4/4) down to a depth of 200 cm. The soil texture at these two piezometers is silty clay. These soils are saturated for 0 to 36 days out of 365 (0 to 10 % of the year).

Deeper into the soil horizon, from 70 cm for piezometer T3A3 and 200 cm for the piezometer T1A4, the particle size distribution of the material was more heterogeneous with a sandy-silt to sandy-clay texture. The processes of oxidation and reduction are more pronounced and are indicated by shades of dark brown (7.5YR 5/6) to greyish brown (10YR 5/2), yellowish brown (10YR 5/8) and/or yellowish olive brown (2.5Y à 5 Y 5/1) associated with reddish brown colours (2.5YR 4/6). These soils are saturated for 169 to 202 days out of 365 (46 to 55% of the year). The reduction processes are indicated by shades of greenish grey to bluish grey (5GY, 5B).

In the proximity of the stream (Figure 2b) at piezometer T3A2 the oxidation and reduction processes appeared from 10 cm in depth and from 20 cm at piezometer T1A1. These processes are highlighted by brown (7.5YR 4/2), reddish grey (2.5 YR 4/2) to dark grey shades (10YR 3/1, 5/1). These soils are saturated for 40 to 193 day in the year (11 to 53 % of the year). The particle size distribution of the material is from a silty-clay to a sandy-clay texture. Below the first 20 cm the two profiles showed morphological characteristics suggesting reduction. The shades are generally greenish grey (5GY 4/1) to bluish grey (5G 4/1).

Correlations between soil colour and water table level variations

Correlations were calculated using the values obtained from field observations for H^o, RR and WLG and those predicted by the models. A first comparison (Table 2) using all the values obtained for H^0 and RR resulted in linear correlations with r2 values of 0.82 and 0.87, respectively. This result was obtained using the coefficients a and b from Blavet et al (2000) and those adjusted using the data from the transects. A second comparison taking into account the topographic position of the piezometers calculated linear correlations near the stream, with correlation coefficient r^2 values of 0.93 for H^0 and 0.98 for RR. On the slopes these cœfficients were 0.57 and 0.54, respectively. By adjusting the a and b constants from the two models with the data from the piezometers located on the slopes the linear correlation coefficient, r^2, increased to 0.78 for H^0 and 0.72 for RR (Table 2).

In Figure 3 the H^0 and RR values which were in agreement with the prediction models are indicated. This was a function of the topographic location and the duration of soil saturation at the piezometers.

Correlation between the measured H^o and the model predictions

Near the stream (Figure 3a), the following H^o values were the same as those proposed by the model: 63° for a saturation period of 11%; 72° for a saturation period between 6% and 53%; 126°, 162° and 234° for a saturation period between 92 and 100%.

On the slopes (Figure 3a), the following Ho values were the same as those proposed by the model: 90° for a measured saturation period of 50 to 60% is close to the model; 72° for a saturation period of 1 to 46%. However, an angular value of 45° does not agree with that proposed by the model for a soil saturated period greater than 20 %. This analysis carried out on the dominant shades of the soil indicated wide ranges of WLG between the angular value 72° and 45°.

Correlation between the measured RR and the model predictions

The piezometric measurements (Figure 1) indicated that in the first case the water table was at an average depth of 445±20 cm with a RR= 0 between 420 and 440 cm for a saturation period of 28 to 46 %. In the second case for RR=0 at 50 cm the water table was at an average depth of 41.8 cm ± 10 cm and a saturation period of 36%.

Near the stream (Figure 3b), the following values agreed with those proposed by the model: RR=0 for a saturation period of 36%; RR=1.3 for a saturation period of 11%; RR=-3.75 and -6.3 for a saturation period from 96 to 100 %. However, the values did not fit closely with those of the model for RR = 0 and a saturation period of less than 6% or equal to 53 %.

On the slopes (Figure 3b), the following values agreed with those proposed by the model: RR=0 for a saturation period between 21 and 46 %; RR=5.0 for a saturation period of 3 to 7%: RR=-1.0 which corresponded to a saturation period of 55%. However, the following values did not agree with those proposed by the model: RR=11.3 for a saturation period of 16 to 39%; RR=0 for a saturation period of less than 21%.

Discussion

On the slopes, our observations of the dominant colours and piezometric measurements agree in part with H^o predicted by the model adjusted with observations from transects. But we could improve the model by taking into account other parameters such as the proportion of the dominant shade compared with and the presence of spots and/or gleyic volumes (Figure 2a). This would complete the correlations between measured values and those predicted by the model.

When we recorded the colour in the field an inaccuracy may have been introduced by the fact that all the soil profiles were not examined in exactly the same sunlight conditions. This bias could be avoided, at least partly, by using a field spectrophotometer.

The model based on the redness rating can be used to specify the degree of colour saturation (Value) and brightness (Chroma) for each soil colour shade, which can have a strict correlation with the period of waterlogging experienced by the soils due to fluctuations in water table level. At RIB 48 (Figures 2b and 3), on the hillslope and near the stream, for a saturation period ranging from 21 to 46%, the angular value and RR are about 72 and 0 respectively. This indicated that for these two situations, the soil colour had the same dominant shade (i.e. 10 YR) but a different hue and chroma: on the slope the soils were a light yellow brown colour (i.e. 10 YR 5/8) whereas near the stream they were greyish brown (i.e. 10 YR 5/1).

In this study, we only took into account the annual average duration of soil saturation. In a study carried out on a toposequence in North Carolina, He et al (2003) showed that soils must be saturated for 21 consecutive days in the year for iron reduction to be seen as lasting morpho-pedological feature.

Conclusion and perspectives

Our study showed that the prediction models developed on data obtained in a semi-arid African environment can be applied to a mountainous tropical region of northern Laos. Significant correlations between soil colour and piezometric measurements have been identified, which allowed us to use existing models of waterlogging prediction based on colour indicators. This work represents a first step towards developing an inexpensive, simple and indirect method for predicting soil waterlogging. Future research should focus on the cycles of reduction or oxidation in the soils throughout the year on the morpho-pedological characteristics in the dry season.

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Table 1 – *Correspondences between the alphanumerical values for the soil colour observed in the field (i.e. Hue, value and chroma), with their angular notation (H°) and red ratio (RR).*

Hue	Value	Chroma	H° (degrees)	RR
10 R	3	6	36	20
2.5 YR	3	2	45	5
	4	2	45	3.75
	4	6	45	11.3
5 YR	4	4	54	5
7.5 YR	4	2	63	1.3
	5	6	63	3
10 YR	4	1	72	0
	3	1	72	0
	5	8	72	0
2.5 Y	5	1	81	-3
5Y	5	1	90	-1
5GY	4	1	126	-3.75
5B	4	1	234	-11.25

Table 2 **–** *Coefficients a and b from the model by Blavet et al (2000) and adjusted values using data from RIB48 and RIB33. Comparison of the correlation coefficients (r2) for the two transects (s & rb), on the hillslope (s) and near the stream (rb). The input value used in the models was either the angular coordinate Ho or the red ratio (RR).*

Variables	***a***	***b***	***n***	***r^2***	**Position**
Coefficients a and b from Blavet et al (2000)					
H^o	382353	- 0.16	40	0.82	s & rb
			29	0.57	s
			11	0.93	rb
RR	2,07	1	40	0.87	s & rb
			29	0.54	s
			11	0.98	rb
Coefficients a and b adjusted					
H^o	382353	- 0,16	40	0.82	s & rb
		- 0,14	29	0.78	s
		- 0,16	11	0.93	rb
RR	2.07	1.2	40	0.87	s & rb
	3.9	1.4	29	0.72	s
	2.07	1	11	0.98	rb

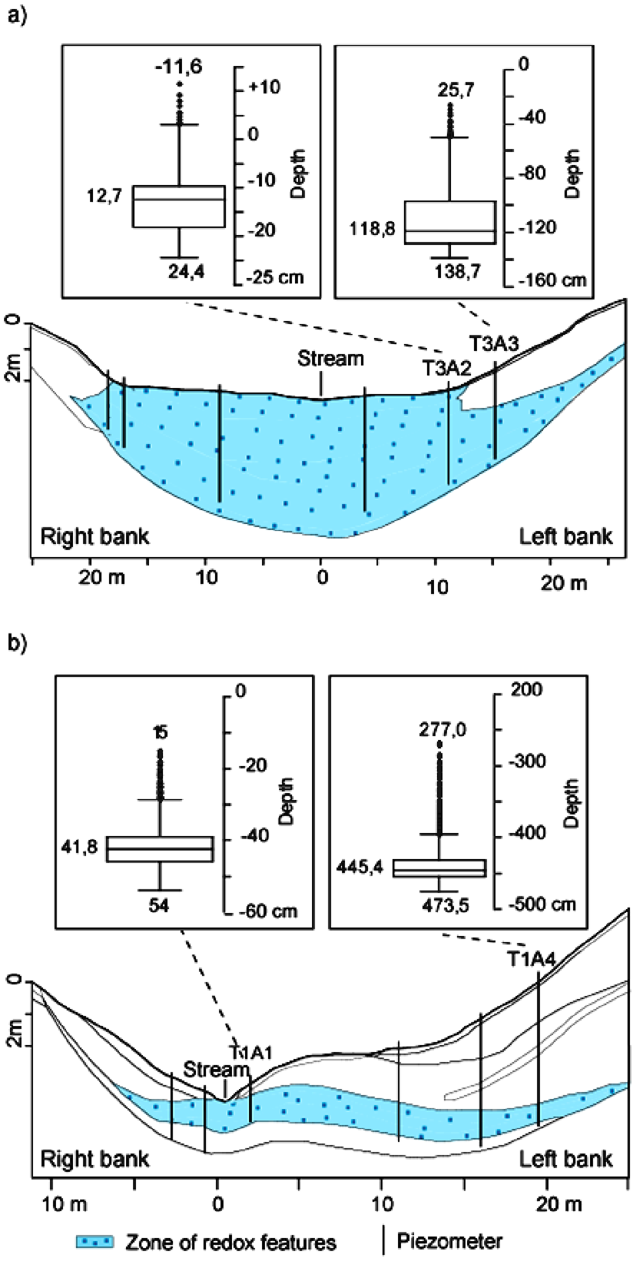

Figure 1 – *Schematic showing a transversal section of the interaction zone between the stream and the water table for the traverses RIB48* ***a)*** *and RIB33* ***b)****; Location of the piezometers (T3A2, T3 A4, T1A1, T1A4) along the transects; Map of the subsurface zones showing redoximorphic features. Whiskers plot (1st quartile, mediane, 3rd quartile, minimum and maximum) of water table levels measured in the two piezometers at each site.*

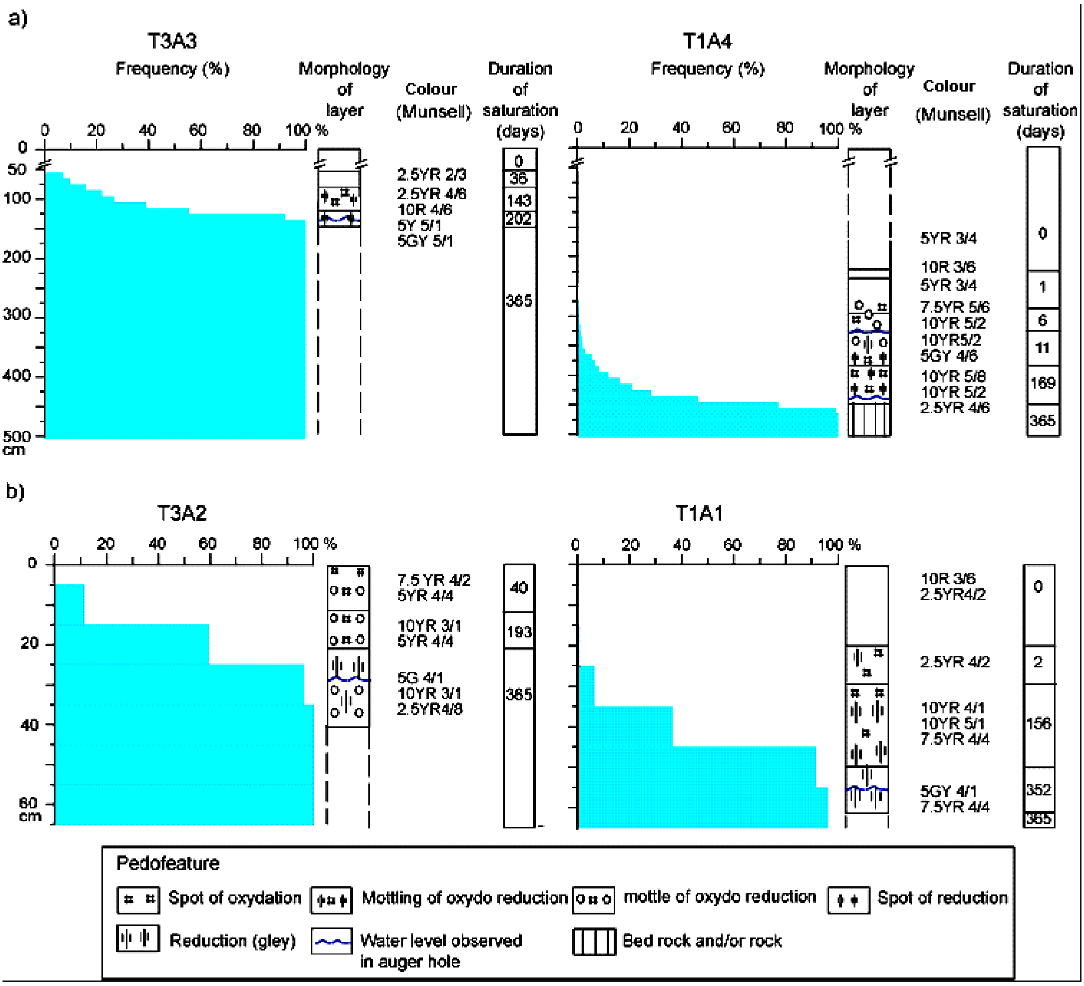

Figure 2 – *Histograms showing the combined frequencies and pedological characteristics linked to the duration of soil saturation* ***a)*** *on the slopes (piezometers T3A3 at transect RIB48 and T1A4 at transect RIB33) and* ***b)*** *on the stream bank (T3A2 piezometers at transect RIB48 and T1A1 at transect RIB33).*

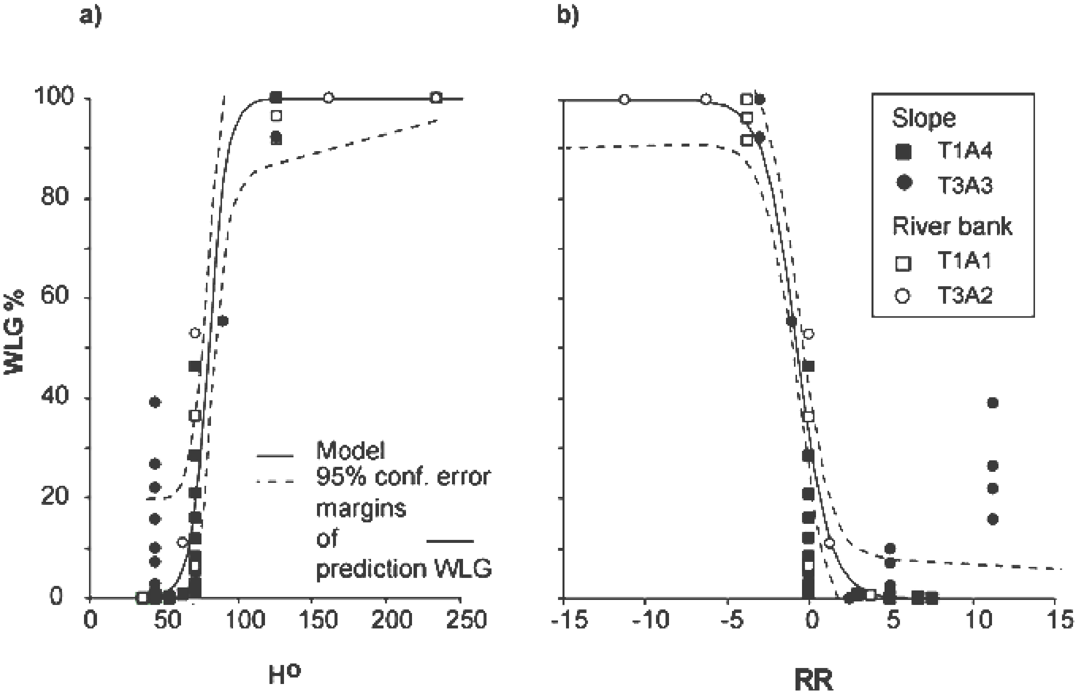

Figure 3 – *Frequency of soil saturation (WLG %) as a function of a) the angular value (Ho) and b) the red ratio (RR).*