

Soil colour variables as simple indicators of the duration of soil waterlogging in a West African catena

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ABSTRACT

The duration of soil waterlogging by phreatic or perched groundwater is a decisive parameter for agricultural or forestry development on hillsides of the West African granito-gneissic bedrock, as it can vary widely over short distance. However, existing methods (eg. piezometer monitoring or remote microwave sensing) do not give ready access to this parameter, as they involve numerous measurements or remain imprecise. On the assumption that soil colour, which depends on the types of soil constituents, and the waterlogging conditions, could give relatively low cost and low time-consuming indicators of the duration of soil waterlogging on these hillsides, we studied the soil and water table variations on a selected catena in central Togo, during three annual cycles. Data collected allowed to establish statistical relationships between the mean annual rate of soil waterlogging (WLG) and several soil colour variables. The two most significant relations were those between WLG on one hand, and mean angular hue and mean redness rating on the other hand. Within some operational limits, these relationships provided the basis for logistic models predicting the mean annual rate of soil waterlogging.

OBJECTIVES

The final objective of this study was to define easily-obtained soil indicators for the forecasting of the duration of soil waterlogging by phreatic or perched groundwater on hillsides of the West African granito-gneissic bedrock.

MATERIALS AND METHODS

Study site

The study was carried out on a typical hillside of a wide biophysical environment of West Africa (cf. figure 1) whose characteristics are i) tropical climate with sharply dry season, ii) bedrock of granite and gneiss, iii) landform consisting of a succession of hillsides and iv) soil mantle organised in catenas with rhodic Ferralsol upslope (red ferrallitic soils of CPCs, 1967), xanthic Lixisol (ferruginous soils) at midslope, and greenish gleyic Lixisol downslope (hydromorphic soils). Table 1 gives the main features of the site studied and figure 2 shows the soil catena.

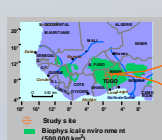


Figure 1. The study site in its biophysical environment

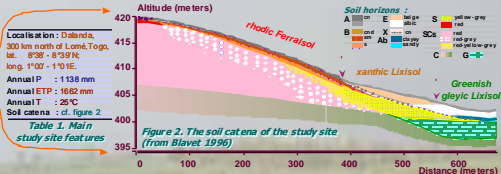


Figure 2. The soil catena of the study site (from Blavet 1996)

Soil and water table study

19 hydrogeological stations were installed on the hillside, along a toposequence of 650 m long (cf. figure 3). The water table monitoring continued daily through 3 full annual cycles (1989-1992). Concurrently, we identified 144 sub-horizontal elementary soil volumes (called SVs) for the 19 stations, and we recorded their vertical boundaries and the proportion of their un cemented phase.

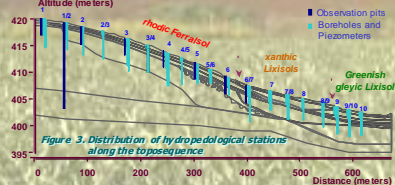


Figure 3. Distribution of hydrogeological stations along the toposequence

Soil samples and data analysis

Obtaining variables derived from soil colour. The Munsell colours (value V, Chroma C and Hue H) of the un cemented phases of each Soil volume (SV) were assessed from air dried samples, under constant light conditions, then introduced in our soil database (cf. picture 1a). Hues were converted into angular hues H° , in degrees, according to their position in the Munsell colour space (cf. figure 4) and equation 1: $H^\circ = 36 + (1 + I_1/10) (1)$ where I_1 is the numerical coding of the Munsell hue segment (eg. 0 for R; 1 for YR; etc.) and I_2 the number associated with the hue (e.g. 2.5 for 2.5 YR; 5 for 5 YR; etc.). Redness ratings RR (Torrent et al., 1980 & 1983) were also calculated following equation 2: $RR = C \cdot [10^{(5 \cdot H^\circ / 18 - 10)}] / N (2)$.

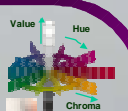


Figure 4. Munsell color space

Finally, four "mean colour" variables were obtained for each SV, from the main un cemented phase (V_{un} , C_{un} , H°_{un} and RR_{un}), and four "mean colour" variables following equation 3: Mean Color variable = $\sum (\alpha_i \cdot ColV_i) (3)$, where $ColV_i$ are the values of a color variable for each un cemented phase, and α_i the weighted proportions of these phases.

Computing mean annual soil waterlogging rate WLG. The mean soil waterlogging rate WLG at given points in the toposequence was computed from our piezometric database (cf. picture 1b), and equation 4: $WLG(x,y,z) = 100 \cdot [N / (n \cdot 365)] (4)$ where x, y, z are the spatial coordinates of the point, N is the number of days during which the water table reached this point, and n is the number of years for which measurements were taken (here $n=3$). WLG was calculated at vertical intervals of 10 cm for each hydrogeological stations, which involved more than 10^6 readings of the water table level by a specific data-processing program.



Figure 5. Screen captures of a) the Soil Database and b) the Piezometric Database

Relating the soil colour variables to WLG. From the Soil Database and a small data processing program, we found the SVs corresponding to the spatial coordinates of each computed WLG points. These connections gave 8 sets of 574 pairs of data relating a colour variable data with a WLG data. We finally analysed these sets in search of possible linear or non linear regression models, and we statistically compared how well the models fitted the data.

RESULTS AND DISCUSSION

1. Soil colour and waterlogging relationships

As shown by Figure 5, the mean annual waterlogging rate (WLG) stayed below 10 % in the rhodic Ferralsol domain. It increased at about 1 m depth in the xanthic Lixisol domain, and reached its highest values downslope in the gleyic Lixisol domain. Concurrently, the mean hue (H°) increased from the rhodic Ferralsol to the xanthic Lixisol domain, while the mean redness rating (RR) decreased. The highest hues and lowest redness ratings appeared downslope in gleyic Lixisol domain.

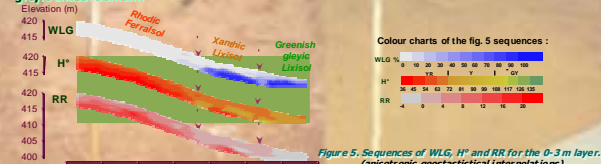


Figure 5. Sequences of WLG, H° and RR for the 0-3 m layer, (anisotropic geostatistical interpolations).

No relationship was found between WLG and the chroma variables (cf. table 2 and figure 6) contrary to the value, hue and redness rating variables. The mean hue H° and the mean redness rating RR, which take account of soil mottling, were the best linked to WLG ($r = 0.72$ for $n = 574$), following logistic regression models.

Colour variables	Regression model	Model parameters	Statistics
Chroma C	Flat (no relationship)	-	0.008 ns
Value V	Exponential	$V_{un} = 0.02 \cdot 1.07 \cdot 0.25^{***}$	0.008 ns
Value V	Logistic	$WLG = 0.07 \cdot 0.87 \cdot 0.35^{***}$	0.008 ns
Hue H°	Logistic	$18551 \cdot 0.11 \cdot 0.57^{***}$	0.008 ns
Hue H°	Logistic	$382353 \cdot 0.16 \cdot 0.72^{***}$	0.008 ns
Redness RR	Logistic	$2.67 \cdot 1 \cdot 0.52^{***}$	0.008 ns
Redness RR	Logistic	$2.07 \cdot 1 \cdot 0.72^{***}$	0.008 ns

Table 2. Relationships between soil colour variables and WLG.

*** = significant at 99.9 %

The $WLG = f(H^\circ)$ and $WLG = f(RR)$ model curves are sigmoidal (cf. figures 7 and 8). WLG remains very low below thresholds of $H^\circ < 75^\circ$ (10 YR-2.5 Y) and $RR < 0$, and is maximum above these thresholds. His maximal uncertainty of prediction is located around these thresholds.

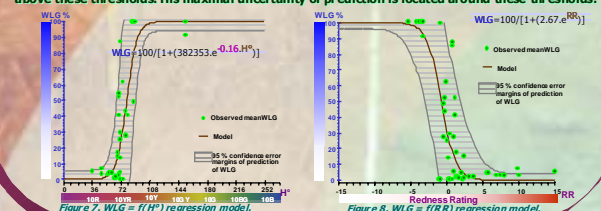


Figure 7. WLG = f(H°) regression model.

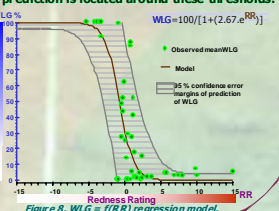


Figure 8. WLG = f(RR) regression model.

2. Example of application to the estimation of soil water logging spatial variability

2a. Acquisition of soil hue spatial variability from soil survey

A systematic soil survey of the hillside included 506 boreholes of 3 meters depth, on a spatial mesh of 30x30m (cf. figure 9). Each core sample was divided in sections of 10 cm thick. These sections were described, by comparison with core samples references.

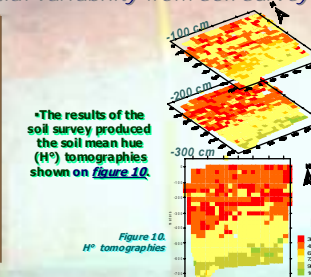
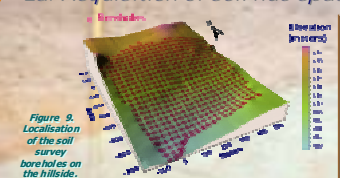


Figure 10. H° tomographies

2b. Application of a Pedotransfer Function $WLG = f(H^\circ)$

The regression model $WLG = f(H^\circ)$ was applied from H° tomographies to WLG estimation ...

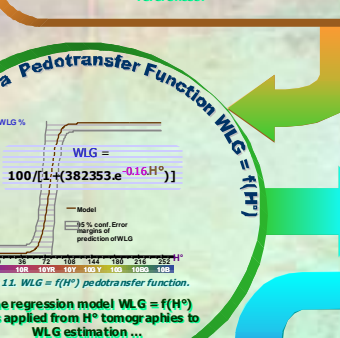


Figure 11. WLG = f(H°) pedotransfer function.

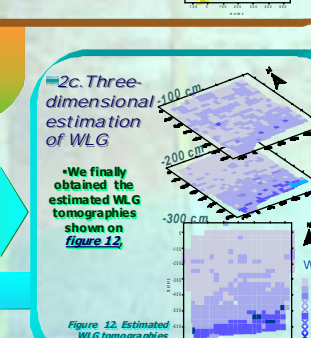


Figure 12. Estimated WLG tomographies

CONCLUSION

Our results show that the mean angular hue (H°) and the mean redness rating (RR) of a soil volume, which depend on its colours and mottling, are two potential indicators of his waterlogging rate in the 500.000 km² biophysical environment of this study. As long as no recent change occurred in groundwater dynamics, these indicators could be useful, in this case, for fast diagnostics on the soils farming aptitudes.

SELECTED REFERENCES

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