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Attempt to understand the relationship between the water of the soil system and the vegetation: the case of the Martinique lower vegetation floor

Philippe JOSEPH
Doctor & Professor of Biogeography, Botany and Ecology
University of the French Antilles, UMR AREA DEV
E.mail : joseph.phil@wanadoo.fr

ABSTRACT

The soil and water dynamics and the dynamics between soil and vegetation are difficult to explore. Yet plant phenology is closely linked to this interdependence whose characteristics vary with the seasons and the climates as well as the stages of floristic succession. In this area, at the interface between botany, ecology and pedology, the references in the scientific literature are few, particularly concerning the Lesser Antilles where the diversity of floristic assemblages cannot be solely explained by the bioclimates and the topography. By using six stations in the dry sub-humid areas of Martinique and conventional pedology methods we were able to characterise the following descriptors: size, total soil moisture from January 1995 to March 1996, humidity of the different layers and their associated matrix potential (pF) for the same period as well as their porosity volumes. The collected data were used to outline the major functional trends between the floors and the phytocenosis in what regards the water element.

KEYWORDS : French Antilles, ecology, bioclimates, plant phenology, floristic succession, pedology, soil and water

Academic Discipline And Sub-Disciplines:

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1. INTRODUCTION

Many works of the specialised literature deal with the functioning of agricultural soils in order to improve agricultural production [1].However, the "soil-vegetation" system approach in the case of environments colonised by the natural flora is sorely needed, especially for the Lesser Antilles [2, 3]. The "soil-vegetation" system is a complexentity in its structure, in its operation and in its evolution, whether progressive or regressive [4]. The soil is a structured and hierarchical ecosystem element having both an abiotic function (mechanical receptacle and root development area) and a biotic function (environment for recycling and the production of absorbable nutrients) [5, 6]. The soil and vegetation are placed in a permanent position of interdependence in which the components mutually structure each other and affect each other's evolution; irrespective of the characteristics of the vegetation cover [7.8].

In this study we mainly focused on the liquid phase of the soil, aqueous medium where metabolic processes and inorganic compound exchanges take place [9]. Water is an important element in the physiology of plants, its limiting factor status in the Martinique lower plant floor allows us to assess the behaviour of vegetation formations under various phases of the floristic succession [10, 11, 12 13]. The data used in this article are for 1995 and 1996, but are nevertheless essential to understand the key functional modalities of this hyper-structure (soil and vegetation) in its main degrees of organisation. At the time the progress of our research did not allow us to describe the various aspects of the relationship existing between the vegetation cover and the soil in relation to water. The results and analyses we will present in this document are, in fact, a first milestone which can be used as a reference for programmes for further studies of the "soil substrate-plant formations" ecosystem. The introduction supplies a few benchmarks to better understand the soil as a physical element, but also as a biologically functional component to further integrate it in the global ecosystem issues.

2. MATERIALS

2.1 Some general features of the soil

Whatever its origin and the processes which generated it, the soil consists of liquid, solid and gaseous elements in varying proportions [14].Inorganic and organic constituents form the solid state [15]. The first gather particles of various size, shape and composition: gravel, sand, very fine particles such as fine silt and clay [15]. The latter correspond to living organisms (fauna, flora and roots) and organic compounds in various stages of degradation (parts of organs and tissues, polymers and simple molecules) [15]. The liquid component is in fact an ionised aqueous medium whose solutes are inorganic ions (cations and anions) and small organic molecules [16]. The solution thus created exhibits some variability in its composition and mobility [17]. There is a complex interaction between the solid and liquid entities through elements which can be exchanged [18]. At all times the soil solution is the result of all the interactions between its components [19, 20, 21, 22]. The gas made up of gaseous state molecules such as oxygen, nitrogen and carbon dioxide is added to the liquid and solid soil elements: in relation to the physiological processes [23, 24, 25.26, 27, 28, 29]. This limited data on soil composition shows the difficulties we may encounter in defining it.

Water is essential for plants. Knowledge of its states and its dynamics in terms of soil distribution and absorption is crucial for understanding the interactive vegetation-soil system [30, 31, 32]. The state of the soil partly determines the flow of water as well as root distribution. In fact, a good soil structure is the guarantee of a normal development with the essential phases of plant growth (morphogenesis) [33, 34]. In particular the germination, because it is important that the seed maintains contact with the ground which in turn ensures it has an adequate water supply [35]. Due to its structural quality the soil induces plant development allowing the future plant to reach a sufficient degree of competitiveness [35]. In reality, a good physical soil condition[1]is necessary in plant growth for the development of an optimal root morphology, ensuring a large future volume [36].

The soil's structural state is an important parameter for the vegetation at the scale of the installation and expansion sites (nanosystems, [37]), but also at station scale in terms of level productivity [37][2]. As mentioned above, a soil volume element has three states (liquid, solid or gaseous). The liquid state of particular interest to us is a very diluted solution of inorganic compounds, ionic compounds and organic substances in very low amounts [38, 39, 40, 41, 42]. This aqueous component provides both the plant water supply and the nutrient availability through transfers which can be active (molecular vectors) or passive (chemical gradients) [43, 44, 45]. Due to all of its properties, mainly its low viscosity, water stands out as the one factor among the essential ones in the soil-plant interaction [46]. Ultimately, the soil and vegetation are two inseparable components which are both structured and structuring [47]. Now we understand the

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[1] Adequate ventilation of the root system, reliability of the transfer of water and nutrients to it.

[2] In the implementation and expansion of the individuals of the plant species.

importance to be attached to the soil-plant system in vegetation studies [48, 49, 50]. In the absence of significant anthropogenic transformations, these two ecosystem components (soil and plant) develop in parallel [51, 52, 53, 54, 55]. Depending on the bioclimate, they select a specific flora and initiate a specific soil formation [56, 57].

Each soil is characterised by a structure in relation to several water states [58, 59, 60]. This structure can be seen in the porosity which amounts to a distribution of pores or families of pore spaces [61]. All studies and concepts on this topic identify several behavioural aspects of water in the soil, which correspond to different degrees of freedom [62].These various energy states of water must be placed in relation to its quantity in the soil [63, 64, 65]. In fact, when the water quantity is important (high humidity), the water completely or partially occupies the pore spaces of the soil. Conversely when it is limited in quantity, water can be found at the surface of the solid mineral particles in the form of a film which is more or less thin. The successive states acquired by water in a saturated soil which gradually dries are:

1. All the pore spaces are filled, the soil is saturated and any excess is removed by gravity,

2. The pore spaces are filled with water after the end of the gravity draining. The amount of water retained by the soil corresponds to a moisture level equivalent to the retention capacity (CR) or the field capacity,

3. The pores belonging to several diameter classes are gradually emptied. The water is now located only around the soil particles, organised as a film. The maximal root suction force (15 atmospheres) is now insufficient to remove the water from the soil. The plant organs wilt due to the water deficit and its associated moisture percentage is the permanent wilting point (Pfl)

4. The water surrounding the soil particles settles in hygroscopic equilibrium with the soil atmosphere, this water cannot be absorbed by the roots.

The various forms of the water element listed above are the result of the distribution of pore space classes or pores [66, 67, 68]. During drying, their load will depend on their size [69]. Thus, the gravity draining is facilitated by the big and average pores, with diameters between 50 and 10microns [70]. The water corresponding to field capacity is retained in fine pores with diameters less than 10 microns. And the bound water (hygroscopic water) which is strongly retained on the surface of the particles and cannot be absorbed by the roots, is located in the very fine pores with diameters less than 0.2 micron. The movement of the water in the soil is due to the existence of a potential gradient, from the high potential points towards the low potential points and is inherent in the soil structure [71]. Through the interface tensions at the level of the contacts between the water and the solid state and due to the water adsorption effect on the surface of solid particles, the latter produces the matrix action which results in the matrix potential defining the water state in the soil (72). Thermodynamically, the energy must be provided to reversibly transform the free water mass unit in a mass unit of water fixed by the soil [73]. From a physical point of view this energy represents an action which is reflected in the lack of capillary pressure or in the vapour pressure deficit of soil water compared to that of free water [74]. Specifically, the matrix or capillary potential is represented by a designated pF parameter which is actually a logarithmic expression of the soil’s suction force. As a result each water state in the soil has a particular pF. In fact, to estimate the Useful reserve (UR) of a soil we should obtain the moisture values associated with the pF(2) and pF(4.2) which respectively represent the field capacity (CR) and the wilting point (Pfl) [75, 76, 77, 78].

2.2 The study sites

In order to decipher the general characteristics of the soil-vegetation relationship as regards water, six reference stations were selected for their ecosystem characteristics. The stations are located in the Martinique lower vegetation floor influenced by the dry bioclimate with an average annual rainfall lower or equal to 1500 mm (Figure 1). They (the stations) are colonised by plant communities belonging to three stages of plant succession therefore they exhibit three levels of complexity or evolution (Figure 2). These correspond to the opening degrees of the vegetation cover associated with specific leaf indices. For each study site, these facts result in certain characteristics of the soil-plant system. In fact, the flora formations, the structures and architectures which they generate vary from one station to another in terms of density, stratification, soil biomass, spatial distribution as well as dominant species of their sociability modes (Figures 3 and 4, Tables 1-6). The main soil parameters associated with these flora formations also show variations in particular regarding their depth:

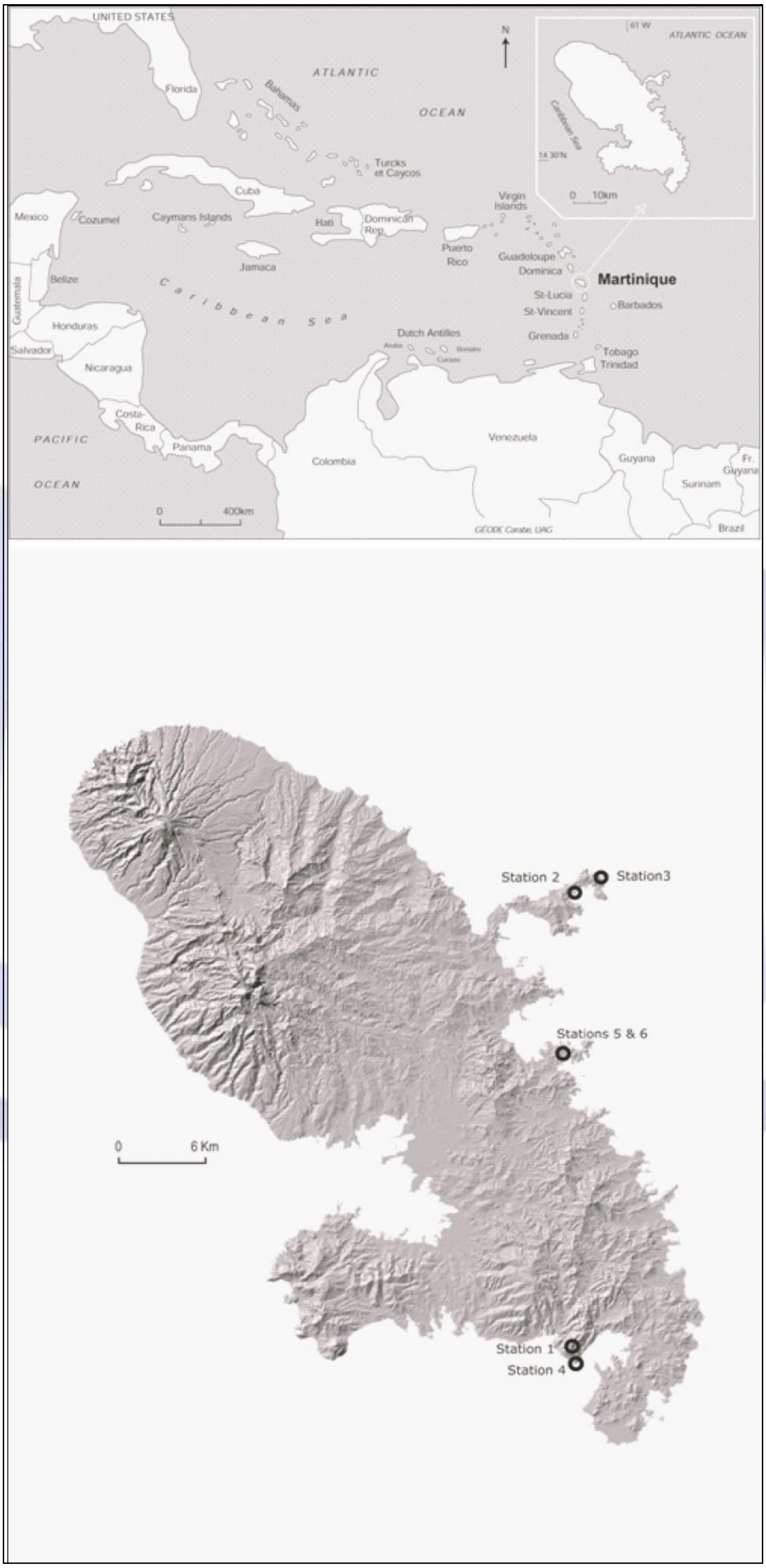


Figure 1. The Martinique in the Caribbean/ the study stations

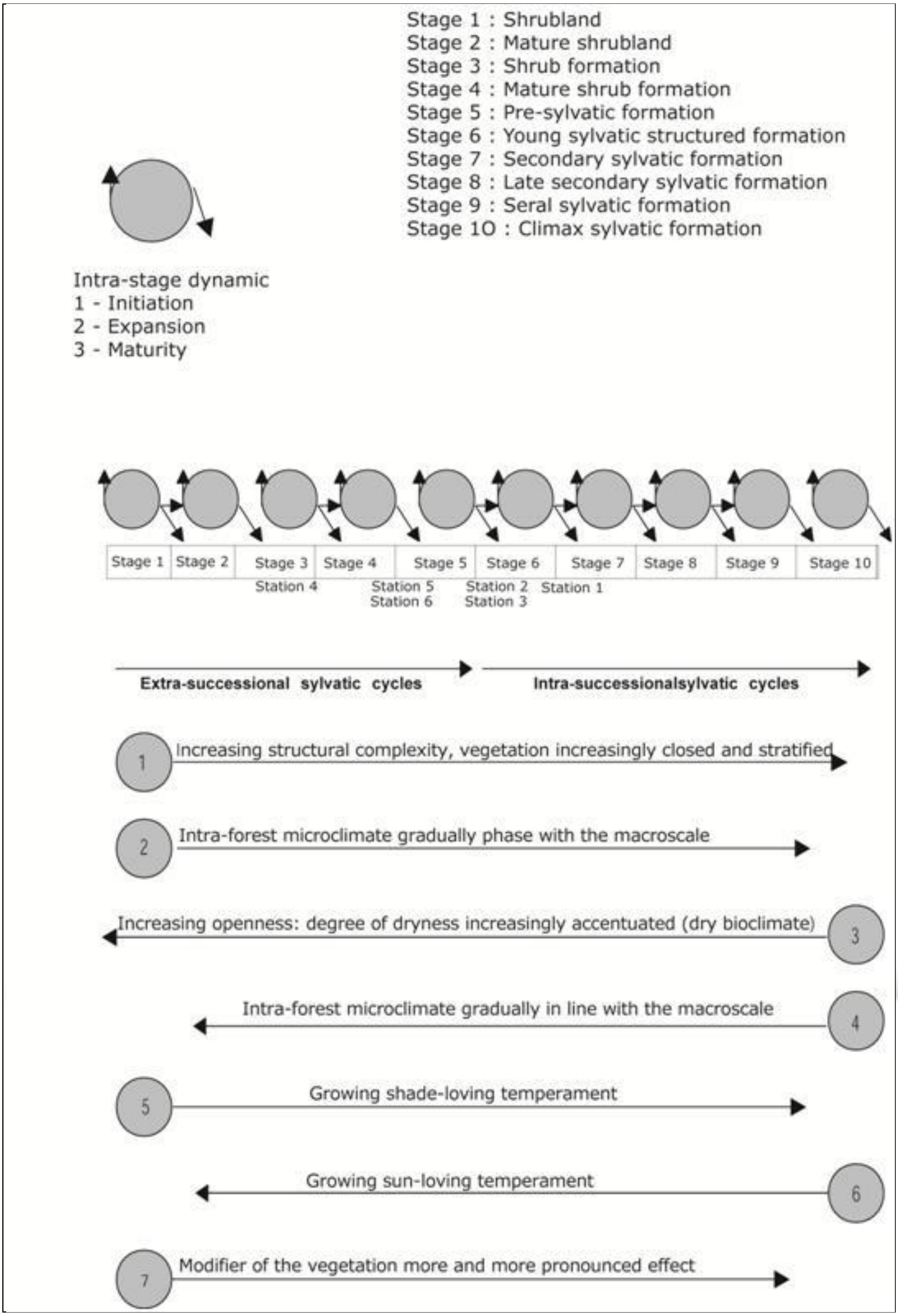


Figure 2. Description model of plant dynamics and station positions

Station 1 - Morne Aca (150 cm soil depth): structured secondary sylvatic formation (two states or exchange surfaces)

Table 1. Biodemographic characteristics of the main species of Station 1

Species	FA	NQ	FR	NI	SR	D	Id	AB	ID
Coccoloba swartzii	15	21	71.43	49	1050	0.047	3.36	0.8	2.7
Myrcia fallax	17	21	80.95	66	1050	0.063	5.1	0.2	1.02
Eugenia pseudopsidium	18	21	85.71	53	1050	0.050	4.3	0.2	0.86
Ocotea patans	17	21	80.95	98	1050	0.093	7.53	0.1	0.75
Inga laurina	16	21	76.19	25	1050	0.024	1.83	0.3	0.55
Bourreria succulenta	10	21	47.62	18	1050	0.017	0.81	0.1	0.08
Coccoloba pubescens	5	21	23.80	16	1050	0.015	0.36	0.2	0.07
Guettarda scabra	7	21	33.33	8	1050	0.0076	0.25	0.2	0.05
Byrsonima spicata	4	21	19.05	5	1050	0.0048	0.091	0.3	0.027
Buchenavia tetraphylla	3	21	14.28	5	1050	0.0048	0.07	0.2	0.014
Bursera simaruba	4	21	19.05	4	1050	0.0038	0.072	0.2	0.014
Ficus nymphaeifolia	2	21	9.52	2	1050	0.0019	0.02	0.1	0.002

FA: Absolute Frequency-NQ: Number of plots of land- FR: Relative Frequency (FR = Fa/NQ) - NI: Number of individuals-SR: Survey surface-D: Density (D = NI/SR) - Id: Index of distribution (Id = D×FR) - AB: Basal area - ID: Index of Dominance (ID = Id×AB).

Station 2 - Caravelle-Alluvial Basin (150 cm soil depth): young and barely structured pre-sylvatic to sylvatic formation (forest eco-units with two layers combined with the other eco-units consisting of trees emerging from a sparse shrub matrix)

Table 2. Biodemographic characteristics of the main species of Station 2

Species	Fa	NQ	FR	NI	SR	d.	Id	AB	ID
Tabernaemontana citrifolia	15	16	93.8	170	800	0.21	19.92	0.5	10.36
Eugenia monticola	16	16	100.0	90	800	0.11	11.25	0.1	1.46
Myrcia fallax	15	16	93.8	78	800	0.10	9.14	0.0	0.41
Ardisia obovata	14	16	87.5	52	800	0.07	5.69	0.1	0.29
Coccoloba pubescens	8	16	50.0	23	800	0.03	1.44	0.1	0.17
Byrsonima spicata	2	16	12.5	2	800	0.00	0.03	0.2	0.01
Coccoloba s swartzii	12	16	75.0	28	800	0.35	2.63	0.4	0.94
Hymenaea courbaril	7	16	43.8	36	800	0.045	1.97	0.4	0.71

FA: Absolute Frequency-NQ: Number of plots of land- FR: Relative Frequency (FR = Fa/NQ) - NI: Number of individuals-SR: Survey surface-D: Density (D = NI/SR) - Id: Index of distribution (Id = D×FR - AB: Basal area) - ID: Index of Dominance (ID = Id×AB).

Station 3 Caravelle: Sapeur-mineur (soil depth 90 cm) young barely structured pre-sylvatic to sylvatic formation (forest eco-units with two combined layers associated to other layers consisting of trees emerging from a dense shrub matrix).

Table 3. Biodemographic characteristics of the main species of Station 3

Species	Fa	NQ	FR	NI	SR	d.	Id	AB	ID
Lonchocarpus punctatus	15	17	88.2	53	850	0.062	5.47	0.8	4.44
Pisonia fragrans	16	17	94.1	57	850	0.067	6.3	0.7	4.29
Ardisia obovata	17	17	100.0	203	850	0.24	23.88	0.2	4.25
Cassine xylocarpa	15	17	88.2	101	850	0.12	10.48	0.2	2.05
sideroxylon foetidissimum	5	17	29.4	11	850	0.013	0.38	1.6	0.59
Bourreria succulenta	10	17	58.8	22	850	0.026	1.52	0.2	0.25
Tabebuia heterophylla	3	17	17.6	10	850	0.012	0.21	0.4	0.09
Garcinia humilis	10	17	58.8	27	850	0.032	1.87	0.04	0.08

FA: Absolute Frequency-NQ: Number of plots of land- FR: Relative Frequency (FR = Fa/NQ) - NI: Number of individuals-SR: Survey surface-D: Density (D = NI/SR) - Id: Index of distribution (Id = D×FR - AB: Basal area) - ID: Index of Dominance (ID = Id×AB).

Station 4 - Point Borgnesse (60 cm soil depth) shrub formations,

Table 4. Biodemographic characteristics of the main species of Station 4

Species	Fa	NQ	FR	NI	SR	D	Id	AB	ID
Calliandra tergemina	16	16	100.0	841	800	1.05	105.13	0.66	69.38
Pisonia fragrans	14	16	87.5	105	800	0.13	11.48	0.15	1.708
Tabebuia heterophylla	8	16	50.0	20	800	0.03	1.25	0.82	1,026
Lonchocarpus punctatus	10	16	62.5	31	800	0.04	2.42	0.24	0.581
Pimenta racemosa	12	16	75.0	88	800	0.11	8.25	0.06	0.485
Guettarda odorata	5	16	31.3	27	800	0.03	1.05	0.18	0.193
Casearia decandra	12	16	75.0	19	800	0.02	1.78	0.07	0.120
Bursera simaruba	4	16	25.0	4	800	0.01	0.13	0.13	0.017
Guazuma ulmifolia	1	16	6.3	4	800	0.01	0.03	0.10	0.003
Inga laurina	3	16	18.8	9	800	0.01	0.21	0.01	0.002

FA: Absolute Frequency-NQ: Number of plots of land- FR: Relative Frequency (FR = Fa/NQ) - NI: Number of individuals-SR: Survey surface-D: Density (D = NI/SR) - Id: Index of distribution (Id = D×FR - AB: Basal area) - ID: Index of Dominance (ID = Id×AB).

Station 5 - Pointe-la-Rose (150 cm soil depth) pre-sylvatic formation (eco-units consisting of trees emerging from a sparse shrub matrix)

Table 5. Biodemographic characteristics of the main species of Station 5

Species	Fa	NQ	FR	NI	SR	d.	Id	AB	ID
Cassine xylocarpa	16	16	100.0	79	800	0.10	9.88	0.3	3.00
Maytenus laevigata	16	16	100.0	264	800	0.33	33.00	0.7	22.00
Lonchocarpus punctatus	13	16	81.3	35	800	0.04	3.55	0.4	1.28
Bourreria succulenta	15	16	93.8	62	800	0.08	7.27	0.1	0.76
Bursera simaruba	8	16	50.0	11	800	0.01	0.69	0.5	0.37
Capparis coccolobifolia	15	16	93.8	52	800	0.07	6.09	0.1	0.34
Ouratea guildingii	4	16	25.0	47	800	0.06	1.47	0.1	0.15
Tabebuia heterophylla	4	16	25.0	6	800	0.01	0.19	0.7	0.14
Calliandra tergemina	6	16	37.5	55	800	0.07	2.58	0.0	0.12

FA: Absolute Frequency-NQ: Number of plots of land- FR: Relative Frequency (FR = Fa/NQ) - NI: Number of individuals-SR: Survey surface-D: Density (D = NI/SR) - Id: Index of distribution (Id = D×FR - AB: Basal area) - ID: Index of Dominance (ID = Id×AB).

Station 6 - Pointe-la-Rose b (80 cm soil depth) pre-sylvatic formation (eco-units consisting of trees emerging from a sparse shrub matrix)

Table 6. Biodemographic characteristics of the main species of Station 6

Species	Fa	NQ	FR	NI	SR	d.	Id	AB	ID
Maytenus laevigata	14	14	100.0	197	700	0.28	28.14	0.2	4.24
Haematoxylon campechianum	9	14	64.3	42	700	0.06	3.86	0.9	3.54
Coccoloba s swartzii	9	14	64.3	39	700	0.06	3.58	0.4	1.51
Pisonia fragrans	11	14	78.6	34	700	0.05	3.82	0.3	1.02
Ardisia obovata	12	14	85.7	64	700	0.09	7.84	0.1	0.48
Bursera simaruba	6	14	42.8	8	700	0.01	0.49	0.2	0.12
Tabebuia heterophylla	3	14	21.4	4	700	0.01	0.12	0.3	0.03
Cassine xylocarpa	14	14	100	106	700	0.15	15.14	0.1	1.93

FA: Absolute Frequency-NQ: Number of plots of land- FR: Relative Frequency (FR = Fa/NQ) - NI: Number of individuals-SR: Survey surface-D: Density (D = NI/SR) - Id: Index of distribution (Id = D×FR - AB: Basal area) - ID: Index of Dominance (ID = Id×AB).

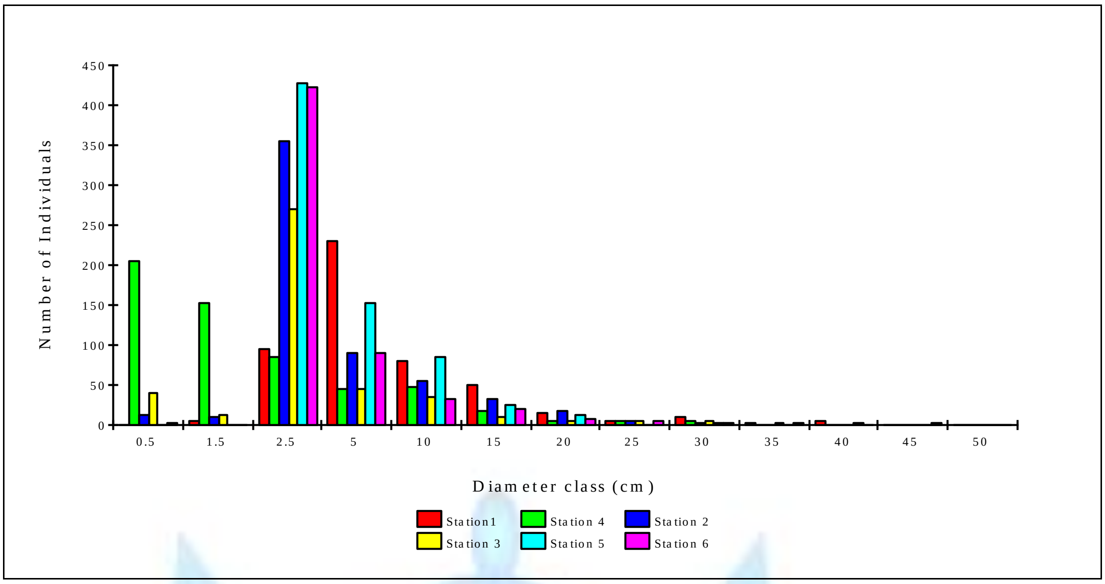


Figure 3. Distribution of the diameter classes

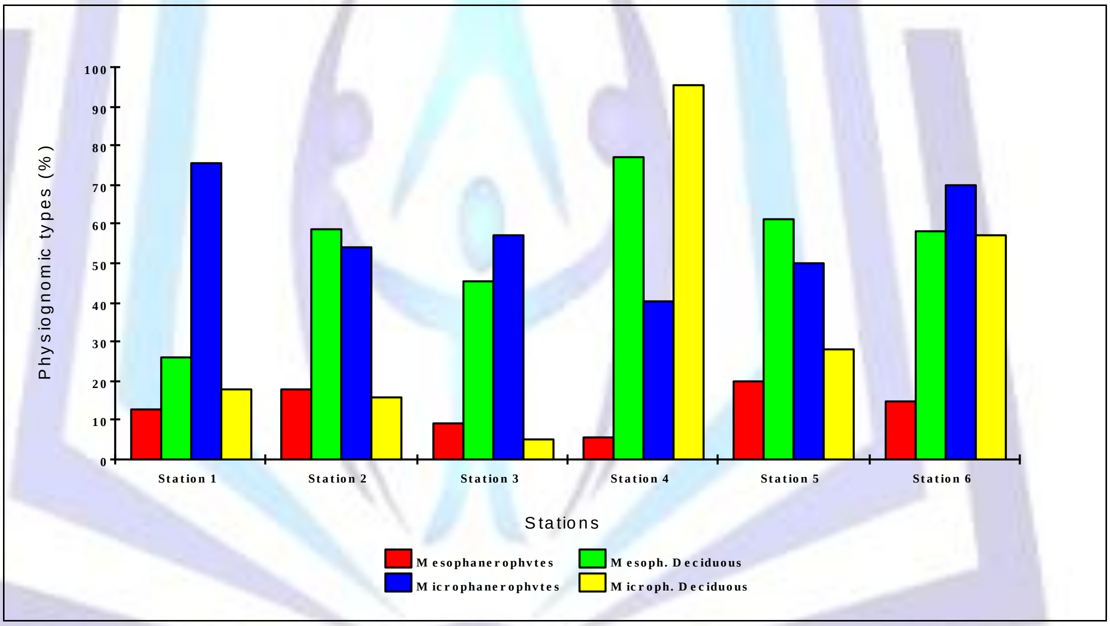


Figure 4. Distribution of the physiognomic types

3. METHOD

In each of the studies stations the soil types and their profiles as well as the water parameters such as soil Moisture (H%), Useful Reserve (UR), the Wilting Point (Pfl) and Matrix Potential (pF) were characterised with the help of researchers, engineers and pedology lab technicians of the French Institute of Research for Development (IRD).To track the monthly average weight changes of the water, the sampling was carried out from January 1995 to August 1996 using an auger for the entire soil depth. It was also important to know the monthly moisture distribution through the soil profiles in different layers. For this purpose we took into account three climatic situations: May, July and August. We did it in order to compare the moisture profiles of the study stations soil between the end of the dry season (between May and the first week of July) and the beginning of the active wet period (the month of August).

The average moisture percentage was estimated based on the dry weight after a double weighing [wet weight (Ph)/Dry weight (Ps)] according to the following formula (Ph-Ps/Ph)×100.The procedure used to determine the matric potential (pF) refers to the behaviour of water linked to the capillary processes. The soil suction pressure can be expressed in pressure units or water height. As a rule soil scientists use a particular unit, the pF, which is the logarithm of the P negative pressure expressed in water centimetres: overall, the experimental protocol consists in extracting water from samples taken at the reference stations after moisturising and according to an artificial pressure gradient corresponding to various pF. The purpose of this gradient is to progressively mobilise the different families of pores or pore spaces, from those with larger diameters responsible for gravity draining to the smaller ones, until reaching the point where theoretically water molecules cannot be used to feed the plant: which corresponds to the wilting point [pF (4.2)]. In a simplified manner, we can say that by increasing the extraction force, the capillaries are progressively emptied from the larger to smaller ones. We can use this procedure because in the soil water has several degrees of freedom, that is, it is bound in different ways. For each pF, intermediate operations allow us to measure the moisture of the treated samples. These special laboratory techniques will not be explained here, as they provide no additional data for the exploration of the complex nature of the soil-plant system as regards the water element.

4.RESULTS

4.1 Soil profiles

The soil profiles were developed by the IRD researchers and technicians according to the international classification, characterise the stations and exhibit significant differences (Boxes 1-5). It includes the following types of soil:

- Ferrisoils: station1 (Morne Aca) station2 (Caravelle-Alluvial Basin) and station3 (Caravelle Sapeur Mineur)

- Inter-grades: station 4 (Pointe-Borgnesse)

- Vertisoils: Stations 5 and 6 (Pointe-la-Rose).

The structural differences observed in the field foreshadow significant textural variations between the stations. Theconstant features seem to concern the high root density in the upper floors (between zero and thirty centimetres) indicating a relatively high biological activity (Boxes 1-5).

Box. 1

Station 1/IRD-BOST description (Appendix 1)

A layer (0-10 cm)

Wet -Colour 10 YR 3/4 (dark yellowish brown)

-many millimetre size roots, sub-horizontal

-larger sub-horizontal roots (1-5 cm)

-little contiguous sub-angular polyhedral (very inconsistent) to sub-angular structures–

-millimetre size with small millimetre rounded aggregates (termites, ants ??)

-we see few centimetre size biological pores (some earthworm activity on the surface)

-1 cm limit with the next layer.

A/B layer (10-25/30 cm)

-lighter colour layer 7.5 YR 4/4 (brown)

-average sub-angular polyhedral (5 cm) consistent (compact) structure

-roots between and some in the aggregates

- rounded circa 1 mm size pores in the aggregates

-1 mm to 1 cm roots with horizontal trend (but zigzag)

-some earthworm activity

-5 cm limit with the next layer.

A/B layer (25/30 to 40/45 cm)

-same layer as above but different structure

-better structured

-centimetre size aggregates, low cohesion

-millimetre sized biological pores

-still few millimetre to centimetre size roots

B layer (to the bottom of the profile)

-7.5 YR 4/6 (strong brown) mottled pink, fairly continuous structure,

- inconsistent millimetre sized polyhedral structure.

Box. 2

Station 2/ IRD-BOST description (Appendix 1)

A layer (0-3/4 cm)

- lumpy structure

-10 YR 3/4 (yellow dark brown) with 10 YR 2/2 areas

-important biological -activity

Al layer (4-30 cm)

-larger lumpy structure

-10YR3/3and4/3

- important root activity up to 2 to 3 cm in diameter

- polyhedral blocks 2 to 5 cm

-few roots in the aggregates

-biological porosity

-transition to 2-3 cm

A/B layer (30-60 cm)

-same structure with the roots in aggregates

-more moist and plastic, hydromorphic patches with iron deposits on the surface of the aggregates

-becomes increasingly sandy to sandy clay

-continuous structure

-roots up to 90 cm

-10YR4/4

Box. 3

Station 3/ IRD-BOST description (Appendix 1)

-0 Cm: 5 YR 3/2 colour juxtaposed at 2.5/2

-20 Cm: 7.5 YR 3/2 colour

-40 Cm: 10 YR 3/4 colour

-the profile is distinguished mainly by its colours

-texture: mostly clay

-gravel from 10 cm

-with depth, the texture seems to become increasingly bimodal: modified clays and gravels

-no preferential localization of the roots in the first layer.

-the roots are located on the entire profile up to the tuff

-the biological pores are 1 to 2 mm, especially in the first 10-15 centimetres and then disappear

- humidity gradient: the drier surface becomes very humid from 30 cm and stays wet to cool down to the bottom.

Box. 4

Station 4/ IRD-BOST Description (Appendix 1)

A level (0-8/11 cm)

-generally average granular structure (2-5 mm) to gravel (5-10 mm)

-dry layer, many rounded gravel particles (2-10 mm), clay texture

- 10 YR 2/2 colour (very dark brown)

-some earthworm activity on the surface

-many roots (millimetre size, some with centimetre size)

-net 1 cm limit with the next layer.

B1 layer (10-30 cm)

- 10 YR 4/3 colour (brown - dark brown)

-moist, higher part up to the plasticity limit

-rather numerous roots in and around the aggregates

-no millimetre size biological porosity

-compact layer polyhedral sub-angular structures of varying sizes (cm to mm)

B2 layer (30-55 cm)

-7.5 YR 4/4 (brown - dark brown)

-sandier texture at depth

-plasticity limit

-compact polyhedral structure (gravel)

-many millimetre sized gravel elements

-less roots and not in the aggregates.

BC layer (55-75 cm) sandier

-10 YR 5/6 wet and 10 YR 6/4 dry or rather dry

-massive structure with specific flow, no roots.

Box. 5

Stations 5 and 6/ IRD-BOST Description (Appendix 1)

A1 layer (0-2/3 cm)

2.5 -5 YR/1 (black)

-many rootlets with lumpy structure

-dry

-consistent aggregates

-earthworm galleries

-millimetre biological porosity

A2 layer (3-25 cm)

-5 YR 3/1 (dark grey)

-cool

-polyhedral angular structure 2-5 cm

-millimetre flow

-roots growing through the aggregates

-many galleries

-low millimetre biological porosity

-millimetre roots

B layer (25 to the bottom)

-10 YR 4/2

-massive structure

-dry

-few millimetre sized roots but some centimetre sized roots

-sand contents increasing with the depth

-no biological porosity

4.2 Monthly changes in average soil moisture

The profiles of soil moisture curves between January 1995 and March 1996 (Figure 5) show two key aspects allowing us to characterise the study sites. First, the stations are distributed along a water resource gradient. From the point of view of a gradual decrease in humidity we see: Pointe-La-Rose (station 5, *soil depth: 150 cm*), Pointe-la-Rose b (station 6, *soil depth: 80 cm*), Morne ACA (station 1, *soil depth: 150 cm*), Caravelle Bassin-Alluvial (station 2, *soil depth: 150 cm*), Pointe-Borgnesse (station 4, *soil depth: 60 cm*), Caravelle-Sapeur Mineur (station 3, *soil depth: 90 cm*).Secondly, the seasonality is well marked for the following stations, with significant gaps between the dry season and the wet season (Figure 5): Pointe-Borgnesse (station4, *shrub formations*), Caravelle-Sapeur Mineur (station 3, *young barely structured pre-sylvatic to sylvatic formations*), Caravelle Bassin-Alluvial (station 2, *young barely structured pre-sylvatic to sylvatic formations*), Pointe-La-Rose (stations 5 and 6 *pre-sylvatic formations*). As for station 1, a structured forest, the differences between the dry period (Lent) and the wet period (wintering) are barely noticeable, the moisture exhibits only very small fluctuations.These soil moisture profiles seem to highlight the functional ecosystem differences between the stations.

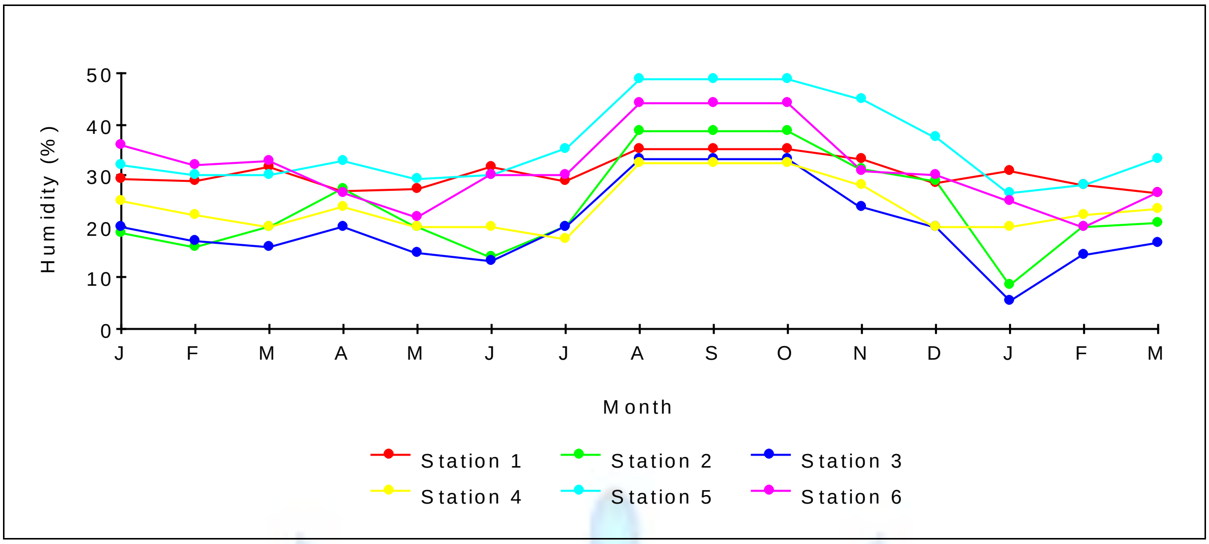


Figure 5. Monthly moisture variation between January 1995 and March 1996

4.3 Water profiles of the stations between the dry period and wet period

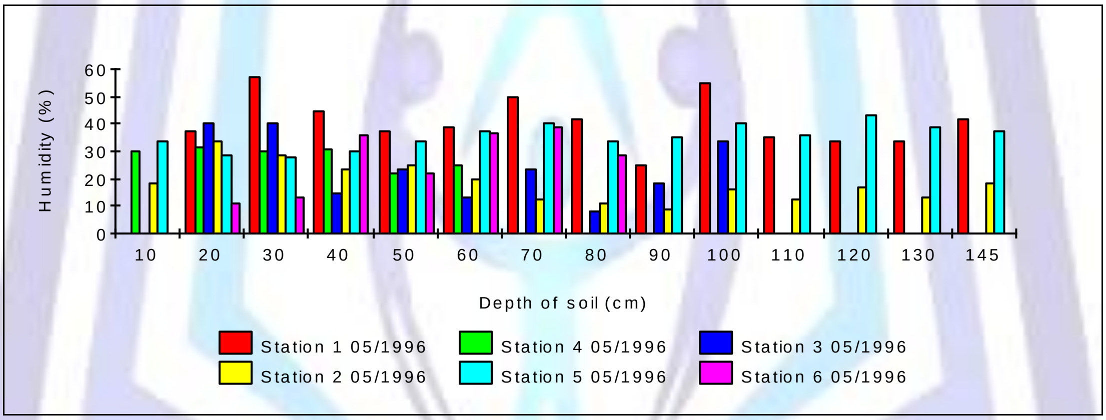


Figure 6. The moisture percentage of the floors (the dry season)

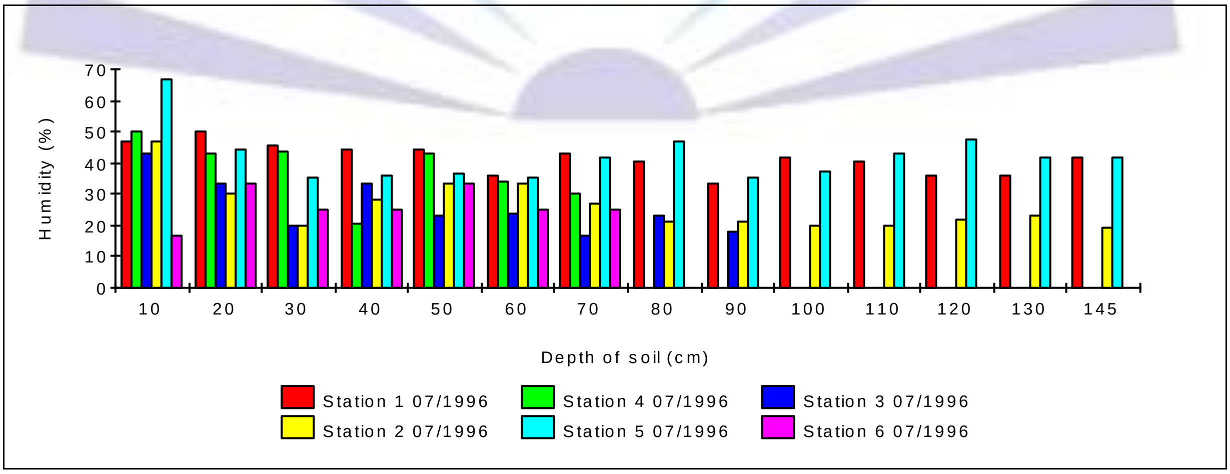


Figure 7. Humidity percentage of the layers (late dry season and early wet season)

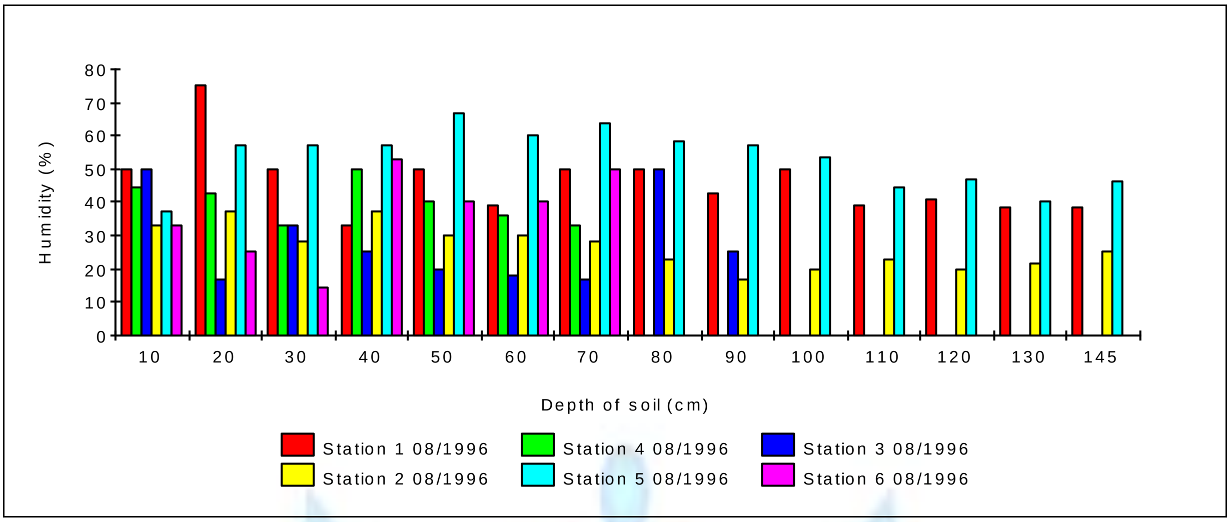


Figure 8. Humidity percentage of the layers (wet season)

Figures 6, 7 and 8 correspond to the distribution of relative humidity every ten centimetres from the surface to the stations soil depth in May, July and August 1996 between the end of the dry season (May to early July) and the start of the wet season (August). Naturally the soils are different, since the stations do not have the same ecosystem characteristics, however the relative humidity at layer level can be compared. The soil water profiles obtained for the three months (May, July and August 1996) (Figures 6, 7 and 8) are different enough to differentiate between stations. Despite the variations recorded for the stations, they fall in the following order of fluid retention importance (Figures 6, 7 and 8): Station 5 (Pointe La Rose) and Station 1 (Morne Aca) have very strong retention power, station 4 (Pointe Borgnesse) and station 6 (Pointe La Rose) have an average retention power, stations 2 and 3 (Caravelle Sapeur Mineur and Caravelle Alluvial Basin) have low retention power. In fact figures 6, 7 and 8 show more or less marked differences of water capacity for the soil layers and the comparison of data from each of the soils studied between May, July and August 1996 suggests a recharging process of some of their layers. Logically, the behaviour of water in the layers must be compared with their structure and texture, but also with the root absorption and exploration means (Figure 9). It is not prudent to exceed this analysis framework without falling into arbitrariness, however for some stations the comparison of the degrees of humidity indicates a trend towards the replenishment of water reserves between May and August 1996 (Figures10 to 15).

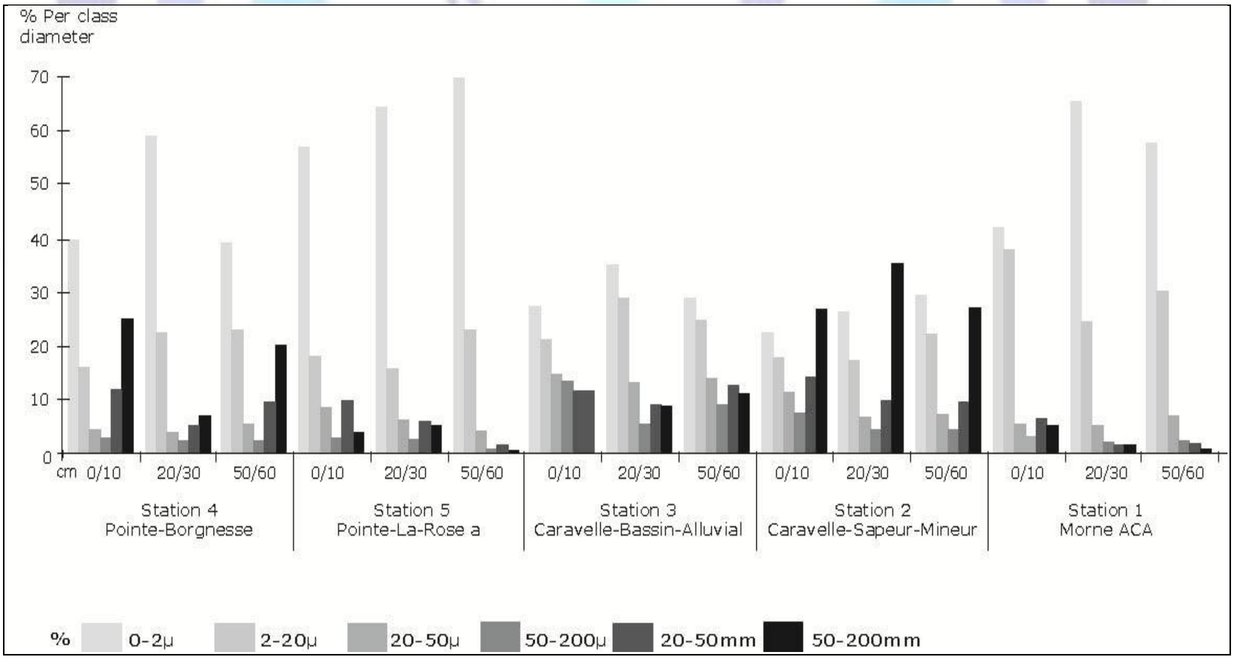


Figure 9 - Particle size

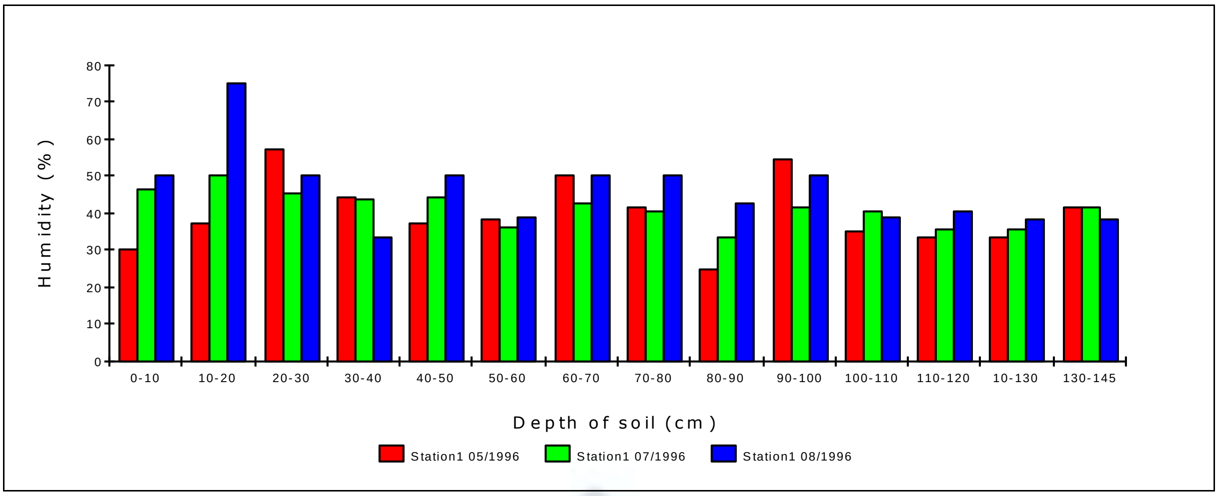


Figure 10. Comparison of moisture levels between the dry season and the wet season

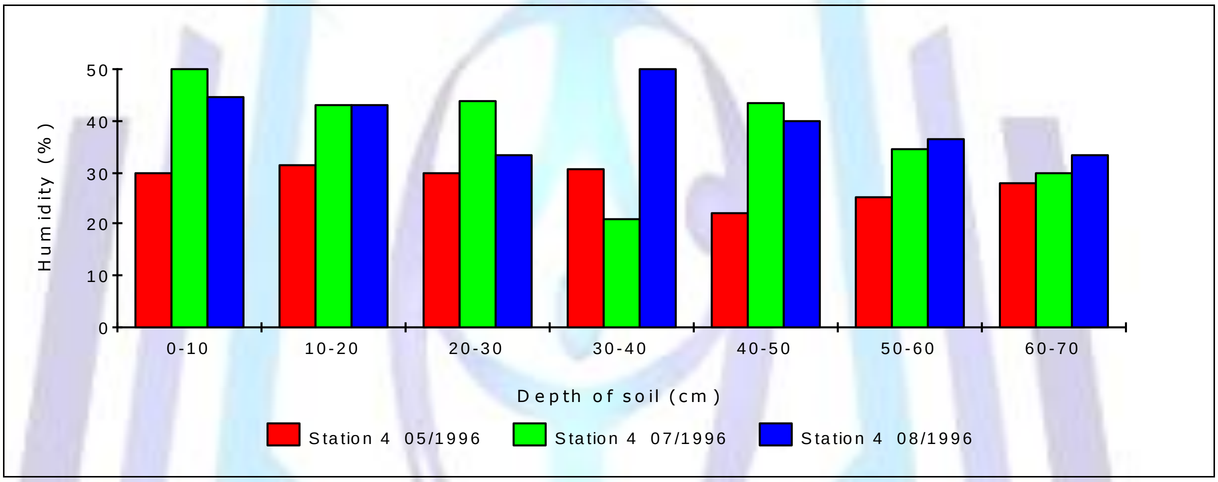


Figure 11. Comparison of moisture levels between the dry season and the wet season

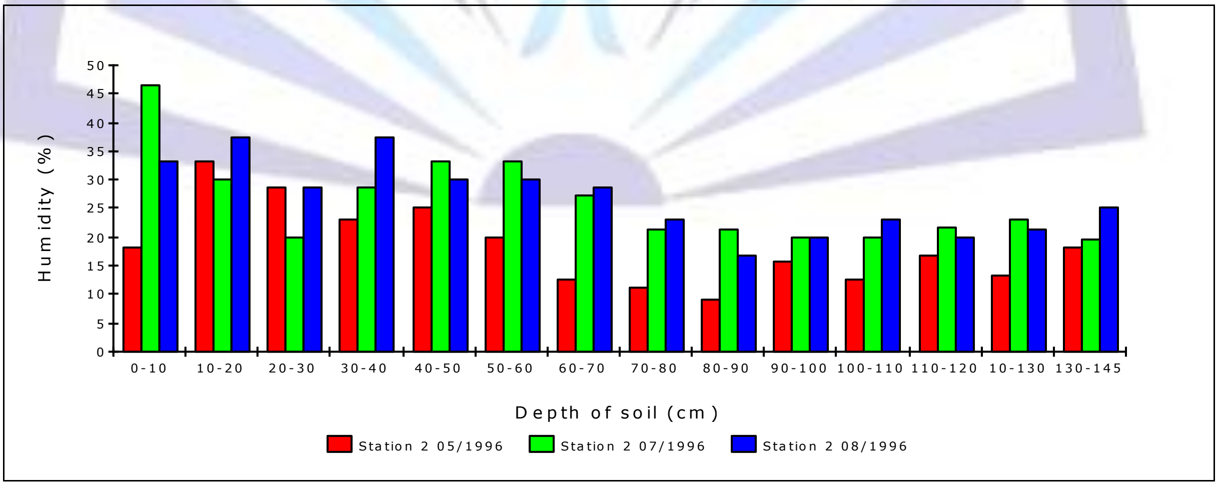


Figure 12. Comparison of moisture levels between the dry season and the wet season

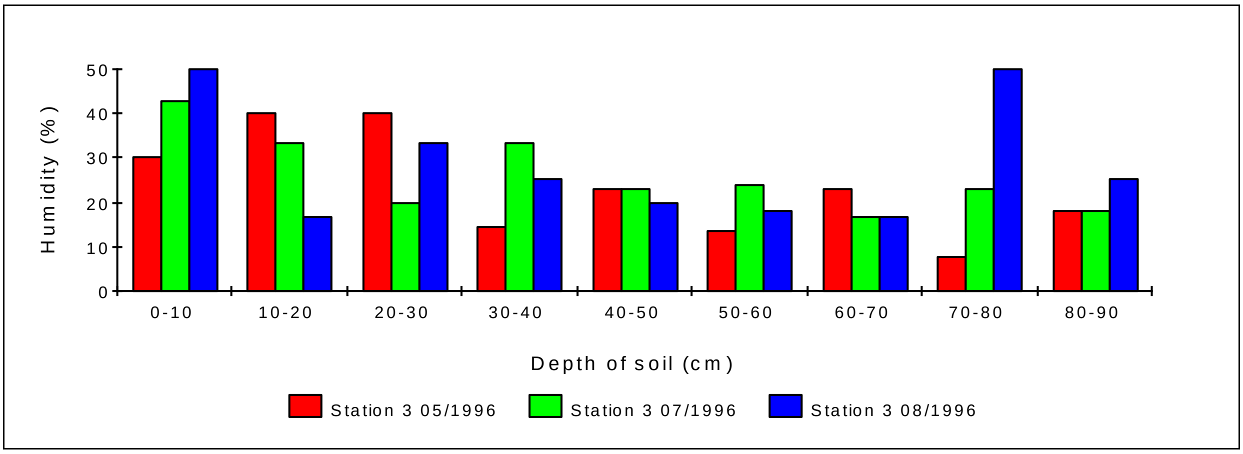


Figure 13. Comparison of moisture levels between the dry season and the wet season

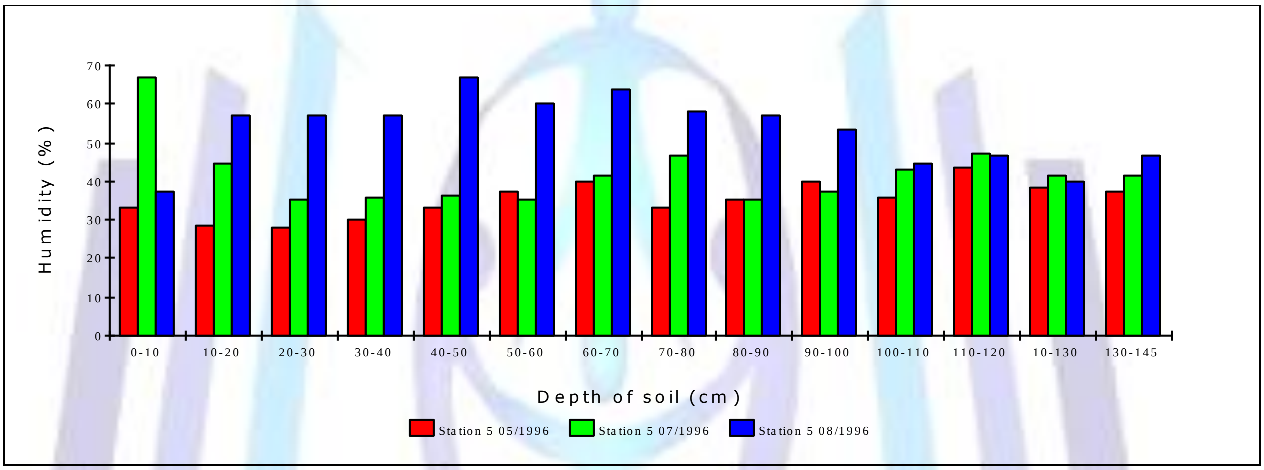


Figure 14. Comparison of moisture levels between the dry season and the wet season

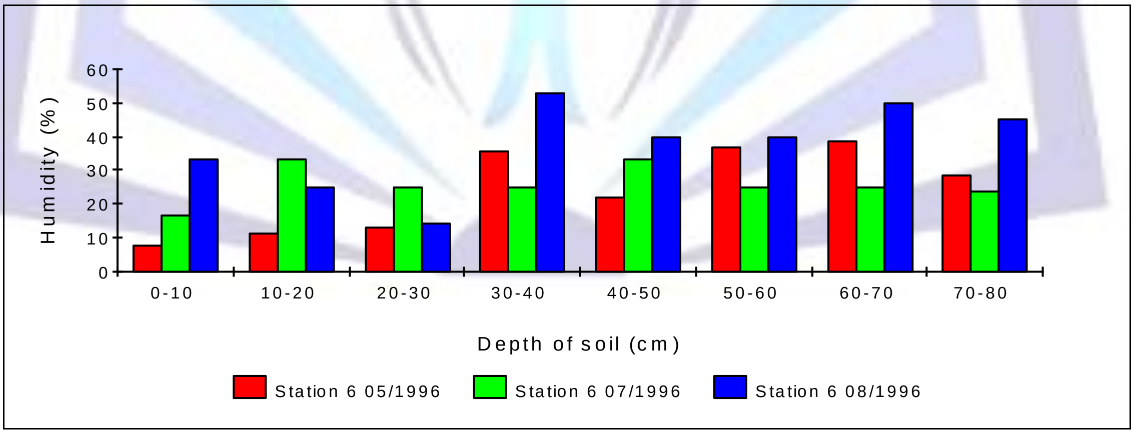
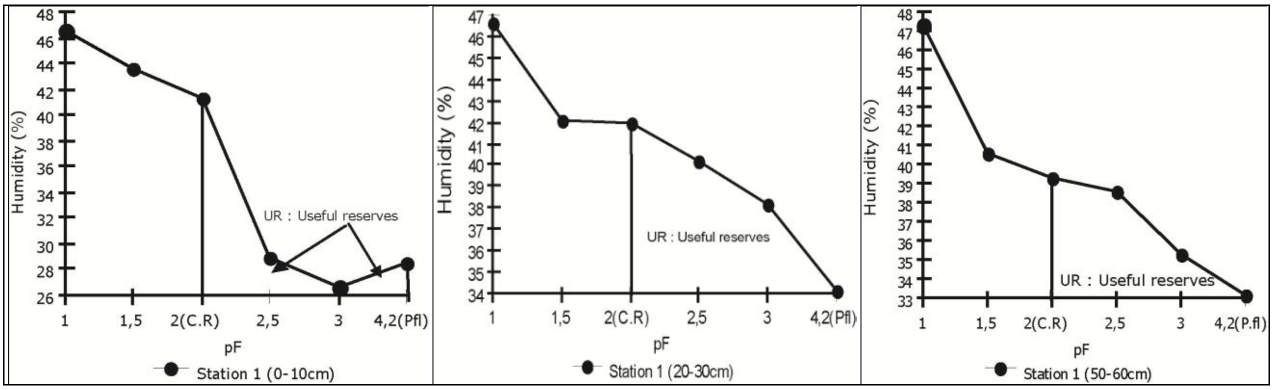


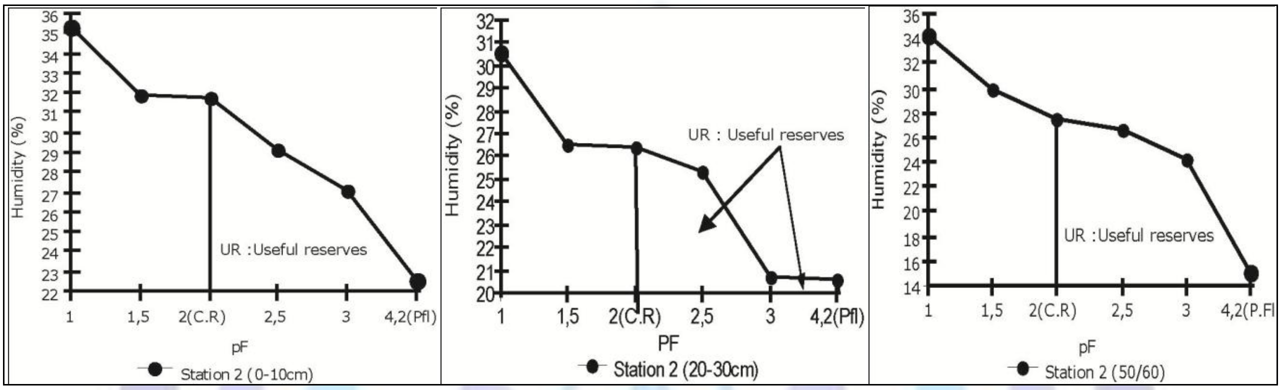
Figure 15. Comparison of moisture levels between the dry season and the wet season

4.4 Matrix potentials, distribution of pore volumes and size

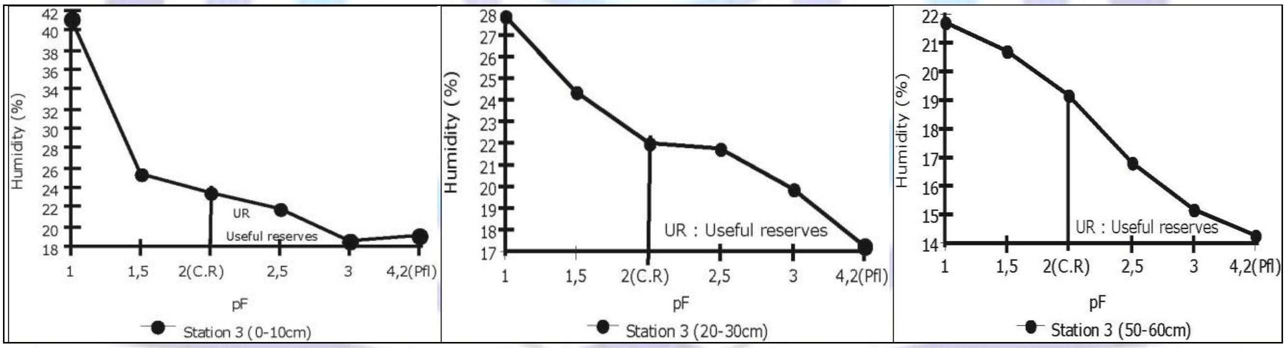
The matrix potentials (pF) or capillary potentials reflect the different aspects of the soil suction force with regard to water and are used to characterise the survey stations soil. The pF curve shapes are linked to the structure and texture of the taken soil samples. Only the 0/10, 20/30 and 50/60 cm layers were taken into account because they represent the support where biological processes seem to be very active (Boxes 1-5). The obtained pF curves appear to range between two diametrically opposed particle size situations (Figure 9): the heavy clay soil substrata [(station 4 (Pointe-Borgnesse) stations 5 and 6 (Pointe-la-Rose)] and those containing a high percentage of gravel (stations 2 and 3: Caravelle).Station 1 ranks between these two groups (Figures 16-30).



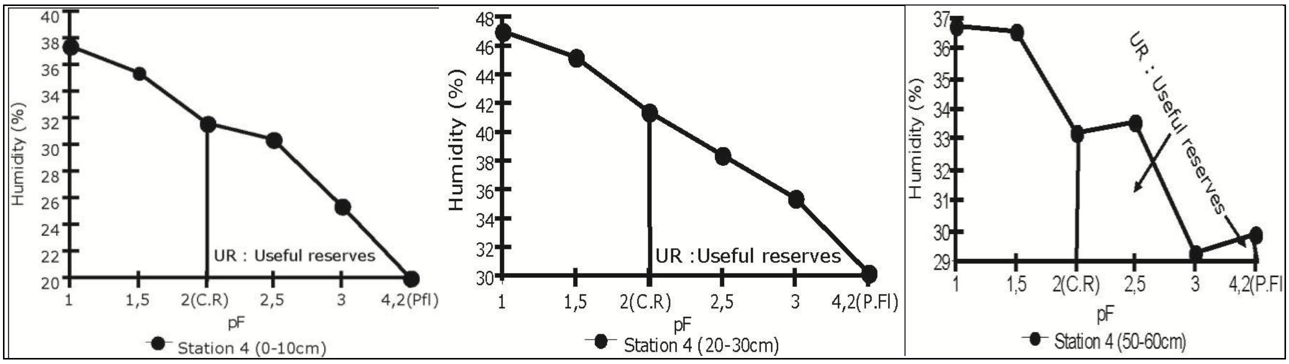
Figures 16, 17 & 18. Humidity and matrix potential



Figures 19, 20 & 21. Humidity and matrix potential



Figures 22, 23 & 24 Humidity and matrix potential



Figures 25, 26 & 27. Humidity and matrix potential

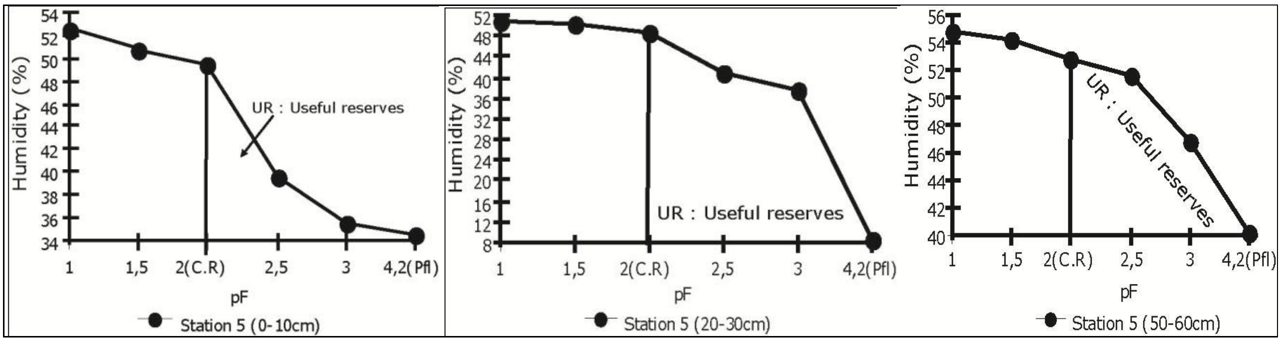


Figure 28, 29 & 30. Humidity and matrix potential

The pF curve results from pore distribution in the three above mentioned layers. Due to their preponderance ratio, the pore classes allow us to understand the water dynamics in soils through their storage or retention capacity (Figures 31-35). The average and large diameter pores ensure the slow and rapid gravity drainage[3] (> 15 µ) which is quantitatively higher than that corresponding to the fine pores[4]and allow the flow of water absorbable by the plants which is also named absorbable capillary water. Logically, between 15 and 0.15 microns in diameter, there is a range of pore classes where the water is absorbable by the roots, but with varying energy expenditure. In fact, water absorption becomes increasingly difficult from 15 micron fine pores (Figures 31-35) to 0.15 micron. There is therefore a storage gradient of the capillary water absorbable by the roots which, for each station, results in the characteristics of the matrix potential (pF) or soil suction force therefore important pore class relations (Figures 16-30).These means of retention of the absorbable capillary water reflect various energy aspects of the bound water and are critical for the vegetation water supply. Especially for those which make up the vegetation growing within the dry bioclimate and particularly during the period with a marked rainfall deficit (the dry period: Lent).

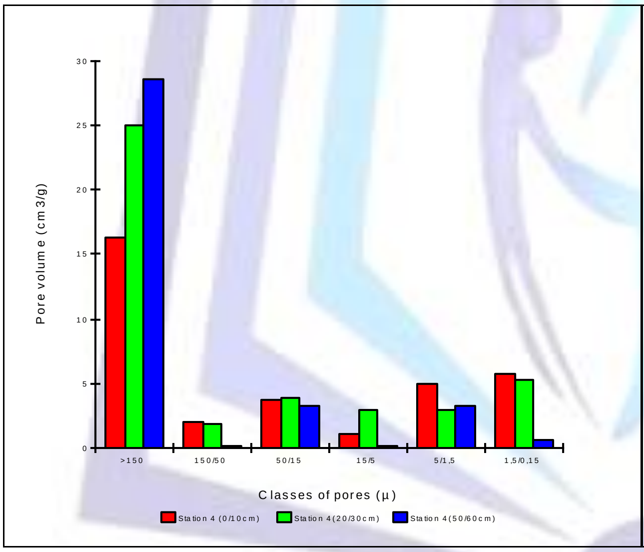


Figure 31 – Pore distribution per layer

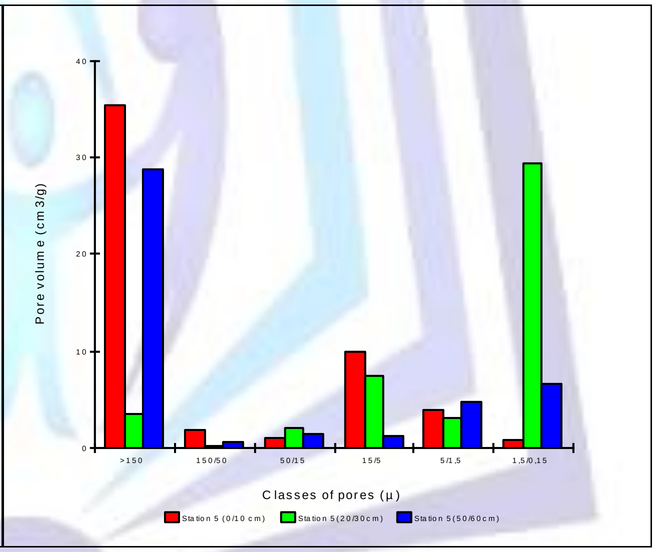


Figure 32. Pore distribution per layer

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[3] Diameters larger than ten or fifteen microns: slow gravity draining (between 10 and 50 microns),fast gravity draining (>50 microns).

[4] Diameters lower than ten or fifteen microns and larger than 0.15 or 0.2 microns: the suction forces oppose gravity, without the water being retained too vigorously.

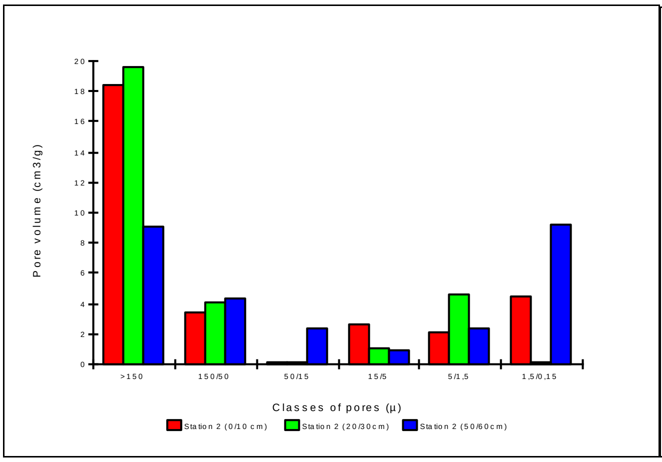

Figure 33 - Pore distribution per layer

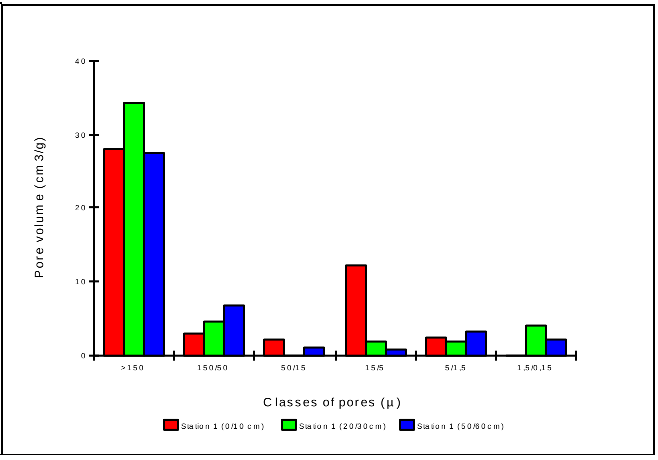

Figure 34-Pore distribution per layer

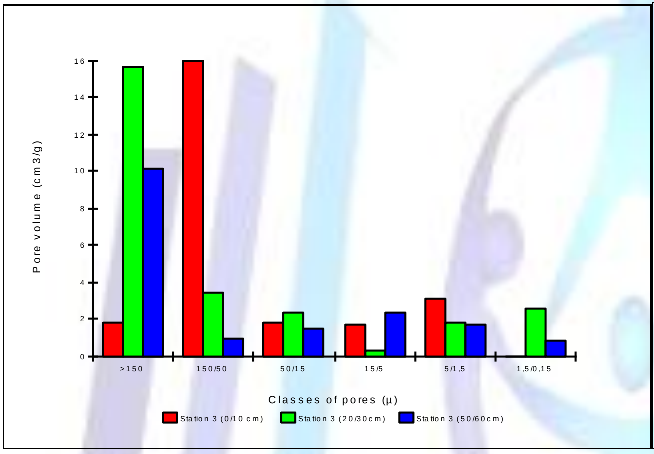

Figure 35. Pore distribution per layer

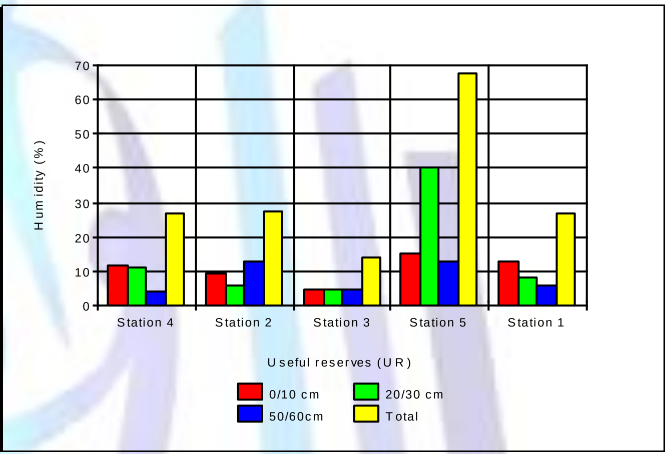

Figure 36. Useful reserves per layer

The fine pores between 15 and 0.15 microns are emptied respectively between pF(2) and pF(4.2), that is to say at humidity equivalent to the field capacity or the storage capacity (VC) and the wilting point (Pfl). The pore volume ranging between these particular limits of capillary potential is assimilated to the water potentially usable by the roots, called Useful Reserve (**UR**)[5]. Each station has a distinct distribution of fine pore classes where the absorbable water flows and their number defines the scope of the useful reserve (Figure 36). The latter (UR) varies from a soil system to another and depends on the relevant soil layer and must be correlated with the particle size (Figure 9). In fact, the results show that as a rule the stations with a high rate of fine particles have a higher Useful reserve (UR). In order of importance for 0/10 cm, 20-30 cm, 50/60 cm depths we find: Pointe-La-Rose (station 5), Pointe-Borgnesse (station 4) and Caravelle Bassin-Alluvial (station 2), Morne Aca (station 1), Caravelle-Sapeur Mineur(station 3) (Figure 9). The texture/structure question is clearly stated in the statements mentioned above. In fact, the water reserve (UR) estimated in this way does not affect the efficiency of the return of potentially absorbable water, especially in the low rainfall season characterised by soil dryness and a significant increase in their suction force. It seems that the importance of different classes of fine pores which defines the useful reserve is essential for the release of water during Lent. With the exception of station 4 (Pointe-Borgnesse), the useful reserves (**UR**), evaluated on the basis of three layers (0/10 cm, 20-30 cm, 50/60 cm) do not correspond to the total soil depths. The fertility represented by the carbon/nitrogen ratio seems constant and rather low for all three layers and stations. Given the importance of the bed layer observed in the latter, we may infer that the recycling of organic matter takes place with a fairly high speed (Figure 37).

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[5] The Useful Reserve is the sum of the pore volumes of the different layers.

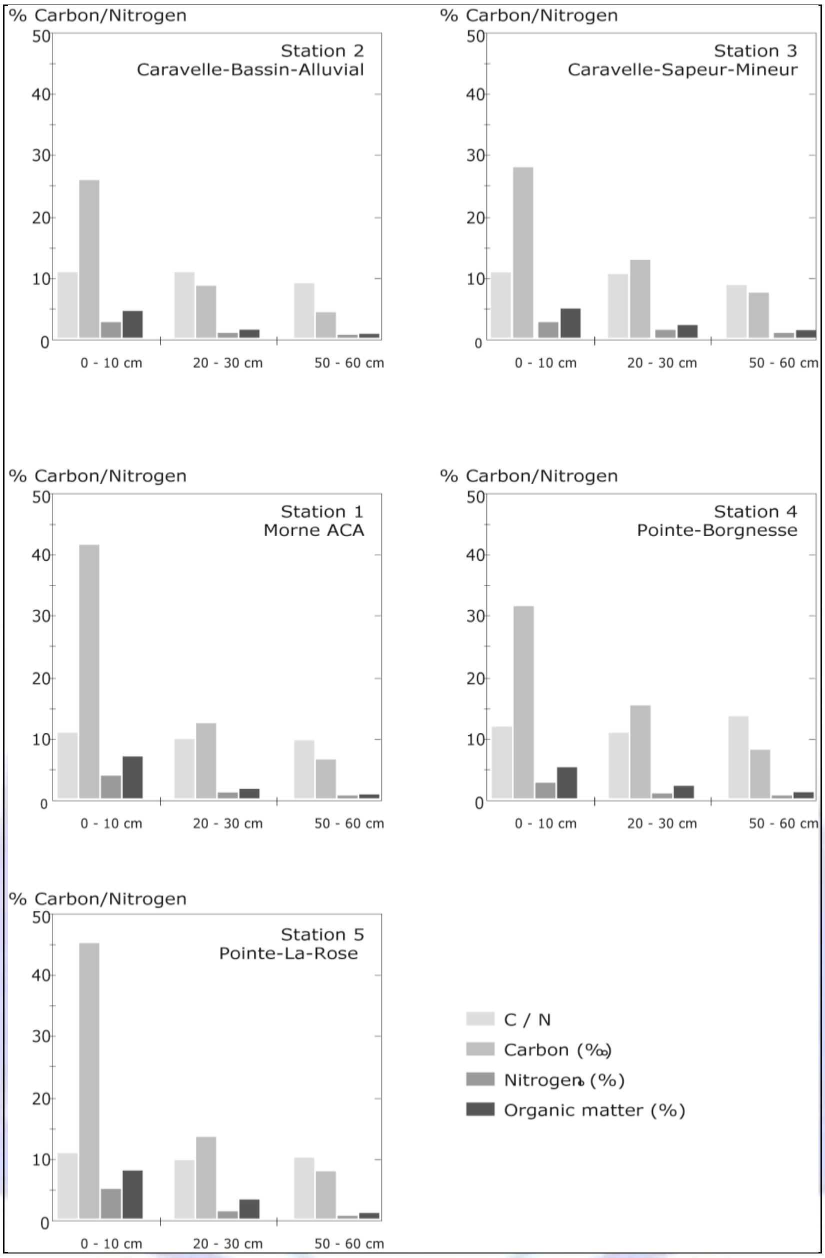

Figure 37-The Carbon (C)/nitrogen (N) and MO (Organic Matter) ratio

5. DISCUSSION

Due to a wide variety of situations, the interpretation of the results presented above is difficult, especially in terms of soil forming processes (textural and structural aspects), pore families distribution in different layers and root biomass distribution. The latter is linked to the development stage of the plant cover. However, we can clearly see the existence of marked differences between the soil systems of the different stations selected for this study. The matric potential diagrams (pF, Figures 16-30), soil moisture [average monthly humidity (Figure 5) and water profiles (Figures 6-15)] the pore volume (Figure 31-35), particle size (Figure 9) and useful reserve (Figure 36), but also the values of the carbon/nitrogen ratio and organic matter (Figure 37), characterise the stations and show their functional features. This diversity of qualitative and quantitative data shows an entire series of factors explaining the overall variability between the different soil substrata. These elements provide information on the physicochemical aspects which define the network of fine pores for the storage of absorbable capillary water. In fact for a given soil, the return of the latter corresponds to varying energy demands depending on the many families of fine pores. These are to be compared with the phenological phases linked to the stages of plant succession (Figure 2).

5.1 Relations between Useful Reserves and the importance of fine pore families

In a simplified manner, the absorption force of the absorbable bound water by plants increases from the field capacity (CR) to the wilting point (Pfl)[6]. Therefore, for an identical useful reserve (UR), the soils with different physical (texture and structure) nature will not exhibit the same restitution dynamics of the bound absorbable water (Figures 16-30). The total usable reserves calculated for the three layers ranging between 0 and 60 cm show a high capillary storage capacity for station 5 (Pointe-La-Rose). While station3 (Caravelle-Sapeur Mineur) seems to have a very low capillary water retention capacity. Between these extremes we find stations 1, 4 (Pointe-Borgnesse) and 2 (Caravelle-Bassin-Alluvial). This hierarchy regarding the Useful Reserve seems to follow the hierarchy of fine particlelevels (Figure 9). There seems to be a particular particle size identity specific to each station resulting in significant differences between the clay percentages (Figure 9). Stations 1 (Morne Aca), 2 (Pointe-La-Rose), 4 (Pointe-Borgnesse) are among the most clay rich with layers ranging between 0 and 60 cm while two stations, Alluvial Basin-Caravelle (station 2) and Sapeur Mineur: Caravelle (station 3) are identified by very high gravel levels (Figure 9).

The total depth of the different soils was not taken into consideration in the study of the matrix potential (pF) for determining the field capacity (CR) and the wilting point (Pfl). Therefore, the results obtained are indications which differentiate the soil systems and specify their functional characteristics revealing their physical and chemical properties. Assuming all soil depths are taken into consideration, we would obtain higher useful reserves than those previously mentioned. Data analysis of the average monthly water potential and water profiles (Figures 6-15), compared with the wilting point (0/10 cm, 20-30 cm, 50/60 cm) provides a glimpse of the importance of the physiological dry season. By inference, the number of months for which the wilting point can be reached during the rainfall deficit period (Lent) varies: two months for the young forest station (station 1), three to six months for the other stations, knowing that those which show a particularly long physiological drought are those whose vegetation falls between the shrub and pre-sylvatic stage (Figure 2).

5.2 Use of the soil water by plant groups

The comparison of three soil stations[7] of identical depth (average 1.50 m) subjected to similar rainfall (between 1500 and 1600 mm/year) highlights the differences in behaviour between the soil substrata but also between the "soil/vegetation"complexes. The curves of average water resources (Figure 5) describe the state of water resources throughout the study campaign and specify the soil storage capacity. Therefore, we showed that the soil associated with station 5 (Pointe-La-Rose) had a much higher retention power compared to stations 1 (Morne Aca) and 2 (Caravelle-Bassin-Alluvial). For each situation, this fact is corroborated by information obtained from the physical analysis (matrix potential: pF) and particle size of soil samples from three layers used in the procedure (Figure 9 & Figures 16-30). A priori the difference in the absorption dynamics of the absorbable capillary water for root feeding does not seem to be the only data which may explain the great variability of the period of physiological drought. The high insolation, the lack of effective rainfall and the high evaporation are characteristic of the dry period (Lent) of the Martinique lower vegetation floor.

The drying of the soil depends on the intensity of the heat energy and the level of phytocenosis physiological activity. The stronger the internal environment of the vegetation is affected by the macroclimate, the larger and faster the water dissipation [79]. Generally when the wilting point is reached in the natural vegetation, multiple adaptive mechanisms take place to allow plants to cope with the difficult period, which is attested by a minimal metabolism and growth stop.

5.3 The role of the soil plant mass

Based on the above presented facts we should expect that the differences in the physiological drought between the above mentioned stations (Stations 1, 2 and 5), are partly due to their degree of floristic structural complexity. The high soil moisture differences between the dry season and the wet season are characteristic of stations located in an extra-sylvatic succession (Figure 2). They simply reflect the opening status of these plant communities whose internal climate is consistent with the macroclimate. In these plant units, their annual marked[8]rainfall asymmetry typical of the dry bioclimate of the Lesser Antilles reflects the asymmetry of the soil water potential. Shortly after the end of the wet season (winter), the soil moisture for the non-sylvatic stations decreases abruptly (mid-January) and the first signs of water deficit appear and are visible through the expression of adaptive phenomena similar to leaf loss. Station1 deviates from this approach, since the

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[6] Correlatively with classes of increasingly smaller fine pores.

[7] Resulting respectively from the vertisoilisation process (Pointe-La-Rose station 5) and ferrallitisation (Aca Morne: Station 1 and Station 2: Caravelle Bassin-Alluvial).

[8] Strong rainfall differences between the wet and dry seasons.

average humidity of the soil remains at a good level at the beginning of the dry season (Lent) and the majority of species are evergreen ones. This characteristic can be noted much later in the dry season even for the small number of deciduous species. Due to their architecture, this behaviour of the station1 forest formations is synonymous with the beginning of autonomy and a more efficient water management in their internal environment or microclimate.

In reality from fruit trees to climacic forest, the leaf area index increases with the number of exchange areas or strata (Figure 2). Stations 5 and 2 (Pointe La Rose and Caravelle Alluvial-Basin) are pre-sylvatic and characterised by high openness. Within these biological communities, unlike forest formations, the intensity of light energy measured with a light metre is high (interception of the light energy ranges between 20 and 30%), but still lower than that of the external environment. In fact in these plant communities (stations 5 and 2: Pointe-La Rose and Caravelle Alluvial-Basin) the sunspots are dense. However, station 1 has entered the processes of intra-sylvatic succession (Figure 2) and exhibits ayoung structured forest community with two layers whose leaf index is definitely higher than that of the other stations: the interception of light energy ranges between 70 and 80% of the incident energy. We are therefore tempted to think that the physical removal of soil water is based on the importance of the exchange surfaces constituting the various strata. In this structured secondary forest station (station 1), the gap between the climate drought and the physiological drought, beginning respectively in January and in June, is due to the significant reduction in the physical removal of the soil water by evaporation [79]. It is the air biovolume[9], high leaf area index in relation to the shrub and pre-sylvatic plant communities, which is responsible for the much slower dissipation of water from useful soil for the metabolism associated with different phenological phases. By postponing the occurrence of the wilting point, in other words by reducing the physical evaporation of water from the various fine pores, the forest and soil plant mass therefore createa longer lasting water supply for the vegetation.

For these deep soils (> 1.50 m), the overall useful reserve is a complex parameter because it is the sum of the partial useful reserves of the different structure and specific texture layers. Logically, during the period of low rainfall, as the soil dries, excluding the functional layers where the roots are located, the stored water is moving from the bottom to the top along a moisture gradient due to capillary action. The kinetics of water loss is an important element in the characterization of the "soil/vegetation" systems and it must be linked both to the edaphic component and to the floristic component in particular its architectural appearance. Therefore the degree of floristic complexity partly determines the onset of the physiological drought. Probably during the gradual succession, a coevolution process takes place between the soil and the vegetation whose internal environment gradually deviates from the macroclimate. During the progressive dynamics, the autonomy of the vegetation internal environment becomes increasingly pronounced. In fact, the "intra-vegetation" climate change is in total covariance with the changes in soil and climate. These ideal conditions are poorly represented today. Often a deep inherited soil is associated with a regressive plant community whose microclimate is somewhat out of step with the macroclimate.

These few data show that the modifying vegetation power plays an important role in the management of the water in the soil /plant community system [79]. Depending on its strength, this modifying power allows the selection of plant species with multiple adaptations. These adaptations may be physiological, anatomical and morphological. They are linked to the extent of physiological drought, the specific characteristics of the kinetics of the removal of the absorbable water and the physical and biological properties of the soil. It is not easy to assess the functioning of the soil system. Nevertheless we list several elements which are essential in characterising the situations we encountered:

-the depth, structure, and texture of the soil, the particle size, the qualitative and quantitative distribution of the pore classes (the pore volume)

-the biotic status in terms of food chains and quality of organic matter which depend on the plant processions and degree of organisation of the plant cover they create.

CONCLUSION

All these developments are attempts to explain the functioning differences observed between the study stations. This first step towards the understanding of the functional states of the edaphic ecosystem component of the dry bioclimate in the Lesser Antilles highlights the extreme difficulty of producing data which can decrypt the key factors. In future, we will have to strongly focus on soil dynamics in natural environments, in all phases of plant succession. Vegetation and soil are two complex components of the same and unique system. Now, in an ecosystem analysis framework, we will have to strengthen the flora aspects with knowledge of soil substrata (functional entities). This will require another investigative logic and will be

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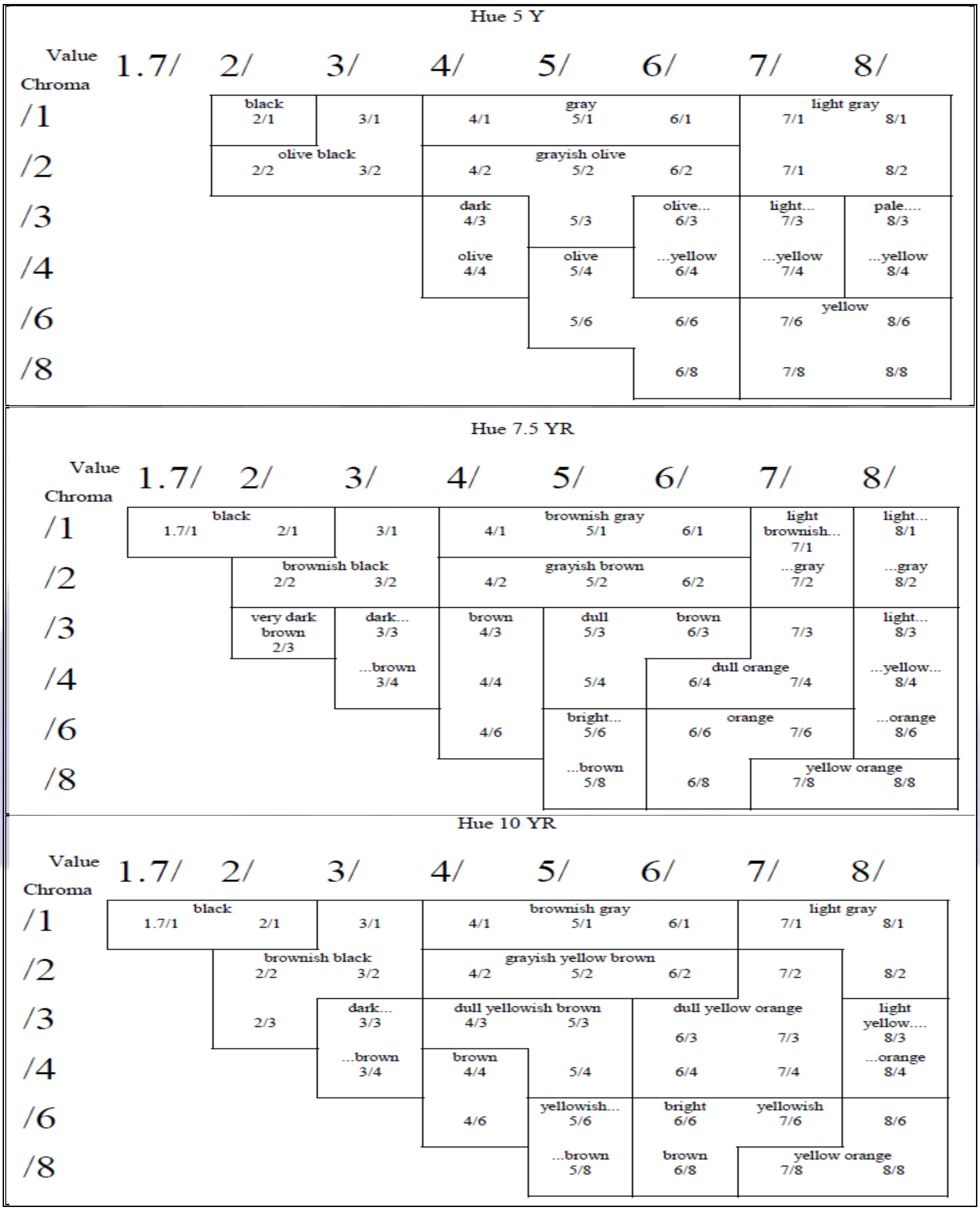
[9] Bio-volume, soil biomass or air plant mass.

characterised by the implementation of much stricter protocols than the one used above, whose only purpose was to identify station variations. Ultimately, what interests the botanist, ecologist and bio-geographer are the specific elements which differentiate the study stations and more broadly the regional vegetation entity which can be built in the ecosystem unit. Among the many parameters, the most relevant are [80, 81, 82, 83]: the field capacity, wilting point, the useful reserve and soil depth. However, these factors do not give us information on the numerous aspects of the dynamics of the "soil-vegetation" system, which is a function of their multiple interactive and prioritised modalities. In an auto-ecological study approach, having clarified the various synecological operations, we must focus on the lower level of integration represented by the installation and expansion site otherwise called the "nano-system" [84]



Hue 5 Y

Value Chroma	1.7/	2/	3/	4/	5/	6/	7/	8/
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/2		olive black 2/2	3/2	4/2	grayish olive 5/2	6/2	7/1	8/2
/3				dark 4/3	5/3	olive... 6/3	light... 7/3	pale.... 8/3
/4				olive 4/4	olive 5/4	...yellow 6/4	...yellow 7/4	...yellow 8/4
/6					5/6	6/6	yellow 7/6	8/6
/8						6/8	7/8	8/8

Hue 7.5 YR

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/2		brownish black 2/2	3/2	4/2	grayish brown 5/2	6/2	...gray 7/2	...gray 8/2
/3		very dark brown 2/3	dark... 3/3	brown 4/3	dull 5/3	brown 6/3	7/3	light... 8/3
/4			...brown 3/4	4/4	5/4	dull orange 6/4	7/4	...yellow... 8/4
/6				4/6	bright... 5/6	orange 6/6	7/6	...orange 8/6
/8					...brown 5/8	6/8	yellow orange 7/8	8/8

Hue 10 YR

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/4			...brown 3/4	brown 4/4	5/4	6/4	7/4	...orange 8/4
/6				4/6	yellowish... 5/6	bright 6/6	yellowish 7/6	8/6
/8					...brown 5/8	brown 6/8	yellow orange 7/8	8/8

Appendix 1. The tint of the soil layers

ACKNOWLEDGMENTS

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