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Landgenic interdisciplinarity

Application to soil aluminization

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Foreword

Some of the data published in the literature cited in this book were obtained through Belgian technical cooperation with the Institut des Sciences Agronomiques du Burundi (ISABU). This institute inherited the infrastructure and structures of the "Institut National pour l'Etude Agronomique du Congo Belge (INEAC)" at the time of Burundi's independence in 1962, including the Gisozi (or Kisozi) Experimental Station at an altitude of 2,200 meters. INEAC was responsible for agricultural research in Congo and Rwanda-Urundi.

In the 1980s, the central headquarters of ISABU was located in Bujumbura and included, in addition to administrative offices and logistics stores, the "Agricultural Chemistry Laboratory", which was indispensable for the support of all the researchers of the Institute. The scientific and technical direction of this laboratory was assumed by my colleague Jacques Gourdin. The numerous analytical results of the soils produced in this laboratory date from this period. The latter quickly established a reputation of seriousness and reliability beyond the borders of the country. It should be noted that he had modelled and tested his methods of soil analysis through a sustained relationship with the late Professor Raymond Frankart, in charge of the "Centre for the Study of Tropical Soils" of the "Department of Soil Sciences" of the "Faculty of Agricultural Sciences" of the Catholic University of Louvain in Louvain-la-Neuve (Belgium).

The routine methods adopted included extraction with potassium chloride (KCl 1M) and titration of exchangeable aluminium in the soil as soon as the pH (H2O) of the sample was below 5.8. This is how the aluminization process of soils was quickly diagnosed in Burundi and how it could be the subject of in-depth research in agropedology. It is this work that first inspired the writing of this book.

1. Introduction

1.1. Justification and objectives

For a few decades, we have been witnessing profound changes in scientific research. Several objects are now becoming thermodynamically "open", whereas they were previously "closed" or even "isolated". Faced with the numerous components that animate them, the scientific method is changing and moving from the reductionism of the Enlightenment to a systemic approach.
The notion of holism also becomes essential because the object-system must take into account its multiple associated components. The latter must be studied at several levels of scale according to the environment to which they are subjected. The basic level of holism is the concept of "holon" which designates an unbreakable block, a kind of construction unit of the system.
The notion of equilibrium also loses all its meaning because these systems are endowed with complex dynamics that give them an unpredictable evolution. It is no longer a question of predicting their evolution but of designing an adaptation that is as reliable as possible, based on the systemic knowledge already acquired.
Scientific approach to complex objects, organized on different levels and with many internal and external interactions, is typically multidisciplinary. Ideally, it would even become interdisciplinary or transdisciplinary following a holistic model, where each discipline would expose its own holons to accomplish a fusion and adopt a unified holon of reference.
Some examples of complex dynamic systems can be cited: the global earth climate, biodiversity and of course the ecological ecosystem. This openness is coupled with a growing interest of citizens and the many parties involved. These new objects are thus also socially open to society. This leads to inevitable controversies between the many interested disciplines and between the stakeholders.
The "landscape" is such an object. It concerns several sciences, both natural and human. It even integrates aesthetic or artistic conceptions for the built elements (common sense of the "beautiful", architects, sculptures, etc.) and the picturesque of certain arrangements (vernacular practices, landscape designers, etc.).

In addition to proposing an interdisciplinary model, the objective is also to redefine how territories are distributed. From the forest, livestock or crop plot to the communes, cities, provinces and countries, limits are largely fixed by the administration. These are cadastral parcels, sector plans, feudal inheritances, conflicts and wars, etc. It is typically a top-down approach, from the political power to the citizens. This usually results in spatial divisions that separate the interests and practices of the stakeholders.
There are also bottom-up boundaries at the level of villages, towns, forests and countryside, whose layout is combined with the naturalness of the environment and with the evolution of the habits and customs of the inhabitants. They unite the various categories of occupants in a kind of landscape humanism.
The landscape evolution is thus partially natural by the practice of a secular empiricism as much at the level of the arrangements and techniques of exploitation as of the generated economic and sociological surplus values. But it is also marked by sorts of socio-political cells distributed at several levels of scale, forged according to artificial interests emanating from the classes of the political power.

The local population first, then science, such as physical and human geography, sociology, applied sciences, such as civil and agronomic engineering, but also architects and landscape architects, have invested in the natural and cultural exploitation of territories and in the definition of their borders. Thus we begin to explain and understand their disparity and the mosaics that compose them. We are at the point of foreseeing a real "landgenics" based on characters and traits of the object "landscape", by an extended cluster of disciplines.
This term of landgenics introduces a neologism. It associates at the same time that of "gene" and "genius" which refers to the faculties of the species and the human populations in

technical, scientific and artistic matter. Landgenics becomes a result of a socio-cultural design of the local territory which is shaped according to the complexity and the interaction of its natural and cultural holons.
By associating the landscape and the human genius, the landgenics makes it a complex system always in movement. The transformations are made as much by the natural variations (climatic, geomorphological, ecological) or cultural ones (economic, social, artistic). It thus becomes an evolving system according to the numerous processes that animate it and the various actors and stakeholders that work and interact there. In general terms, landgenic design would be defined as the territorial expression of human genius, relatively to its art of combining local natural resources with its economic and cultural needs.

An application of the interdisciplinary approach is carried out for the aluminization process of soils. The latter addresses their acidification and its phytobiological, ecological and agronomic effects. An important discussion is then proposed. Aluminization is a normal pedogenetic evolution that can be slowed down by mineral amendments or strongly accelerated by drainage operations in potential acid sulfate soils. Naturally, it takes place continuously according to a rather slow dynamic, which can reach thousands of years. It can become a constraint for forestry, cultivation or livestock systems, and thus for the establishment and development of villages and towns. It is thus a highly representative pedogenetic process. It can take place in silence and remains unknown in the spatio-temporal differentiation of landgenics.

1.2. Concept of landscape by other authors

Numerous authors explain or enlighten one or more of the perspectives of the landscape. For BERQUE (1987), the "landscape" is perceived first of all as science of the mediums or mesology, i.e. that of the relation that a society maintains with the space and the nature. It is in fact a conception very close to the landgenics. This author develops a constructivist epistemology of mesology, namely an intimate interaction between the subject and the object, between culture and nature. Landscapes, territories, habitats, monuments, amenities and nuisances, etc., are mesological facts. These facts obey an order, that is to say a motivation, a sequence of spatio-temporal motives. And in this process of motivation, BERQUE (op. cit.) considers that it is very difficult to distinguish what is code or matrix (formative form) from what is practice or imprint (formal form).
Landgenics will propose in this work a model based on processes of differentiation of codes or matrices by opening the door to a whole series of experts, starting with the local actors themselves. Moreover, the model will be inspired by evolutionary biology by comparing the past and the present with new opportunities that may arise or be imposed. In this evolutionary model, the metaphorical concepts of genotype/genome (formative form) and phenotype/phenome (formal form) will be used as in genetics.

For ROGER (1997, p.138 and following), a landscape is never natural but always cultural. He distinguishes the "country" of geographers and naturalists from the "landscape" of painters and landscape artists. He thus confers to this distinction an eminent epistemological status in accordance with CHOUQUER (2002). This last considers that ROGER (op. cit.) puts himself back to back the scientific pragmatism of the mediums and the environments and the aestheticism of the landscape. As for another conception such as the ecology of the landscape, ROGER recalls that it is introduced by the German biogeographer Troll (Landschaftökologie, 1939). A concept which extends then towards the countries of the East then in the Anglo-Saxon thought (landscape ecology). ROGER (op.cit., p.146) recognizes that the geographical or ecological study of a place or country is not superfluous and even that the knowledge of the geosystems and the ecosystems is essential, but that it remains inoperative in the determination of the landscape values which are socio-cultural. The same author (p. 151) also recommends to think the landscape in its evolutionary process and not only as a heritage to be preserved or protected. It would thus also be a question of taking into account the whole of the phenomena which shape a territory as envisaged by the landgenics or the study of the mediums.

CHOUQUER (2003) briefly outlines landscape ecology by proposing a review of the book by Françoise Burel and Jacques Baudry (1999). The principle of this ecology is that human activities are the main factor of landscape evolution at the planetary level, which is also the case of the landgenic model. However, unlike landgenics, it considers the human species as a disrupter of the natural order according to an ecocentric or even biocentric ethic, rather than an anthropocentric one. CHOUQUER (2003, op. cit.) evokes the main theoretical bases of landscape ecology, namely: (1) hierarchical levels of organization in space (ecosystem < landscape < region < continent < planet); (2) the fairly mathematical theory of percolation relating to the flow of genes, individuals and materials; (3) the biogeographical theory of islands, i.e. the gradient of biodiversity as a function of distance from the continent; and (4) the theory of disturbances causing environmental heterogeneity.
At the level of language, landscape ecology uses the terms of fragmented forms, matrices, corridors, patches, mosaics, borders, landscape patterns. For CHOUQUER (2003, op. cit.), it thus intends to participate in the planning and management of spaces, in particular with the question of "green corridors", that of hedges, or by suggesting the respect of connections [between ecosystems] in the layout and the shaping of transport infrastructures. It should be noted, however, that this terminology mainly evokes surfaces, contours and lines and not spatial volumes such as those of the ecosphere in which ecosystems are differentiated.

This landscape ecology focuses on biotic factors and is based on what MOSS (2000) calls a "bioecological" approach. It aims at the spatial dynamics of animal and plant populations and their problems at the community scale. However, MOSS specifies that the landscape context is much broader and also calls upon geography, ecology, soil science, geomophology, etc. The counterpart of the "bioecological" current is then the "geoecological" current, rooted in geography. It aims at the systematic interpretation of land-related components such as landforms, soils, vegetation and the impact of human land use to produce distinct landscape units. The weakness of the "geoecological" current is that the combination of components in a landscape unit is not sufficient to understand its functioning. The latter requires, according to MOSS (op. cit.), the integration of soil, hydrological, geomorphological, etc. processes within the unit. The same author states above all that the fundamental units of the landscape are landscape systems. They are made up of spatially-bounded entities, with both biotic and abiotic vertical components. Finally, MOSS specifies that these units extend from the superficial lithosphere (the soil) to the lower atmosphere. It thus merges the two distinct perspectives of landscape ecology: bioecological and geoecological.

The role that farmers play in landscape design is examined by BENOÎT et al. (2012). These authors propose their model ALaDyn (Agricultural Landscape Dynamics). It focuses on the concept of "cultivated field" (cropping system) as a place of application of agricultural practices, and this as an interface between ecology and other disciplines. For the above-mentioned authors, the spatial configuration of the landscape includes both the topological characteristics of the fields as a whole (shapes, sizes, locations) and their functional relationships with other landscape features (irrigation channels, drainage channels, hedges and parcel borders). Agricultural design is also influenced by natural resources and local topographic conditions. Research in landscape agronomy could integrate both the influence of land characteristics on agricultural practices (technical itinerary) and the influence of farmers in the patterns and processes examined by landscape ecology. Furthermore, RIZZO et al. (2013) focus on the concept of land management units. Agriculture is expected to provide more and more services: besides food and biomass energy production, it should also provide ESS (Ecosystem Services) such as environmental preservation or a pleasant living environment. It is therefore crucial to understand farmers' decisions regarding the spatial organization of their agricultural activities. RIZZO et al. (op. cit) report on how recent agricultural research identifies and models major spatial entities configured by the organization of agricultural activities in the landscape. The aim is to facilitate dialogue between geographers, agronomists and other disciplines.

The landscape scale is also used to ensure agro-ecological transition, as mentioned by BRETAGNOLLE & BAUDRY (2015) and GASCUEL-ODOUX & MAGDA (2015) with arrangements such as NATURA 2000 dedicated to biodiversity conservation. The above-mentioned authors draw attention to the fact that this transition requires a collective approach that includes actors other than farmers, such as local, regional or national NGOs and researchers. For the research, multidisciplinarity is required since the systems are complex and multi-scale. Thus, Workshop Zones (ZA) are implemented as tools for interdisciplinary observations and experiments on biodiversity known as "ordinary", "functional" (pollination, regulation and biological control services) and " patrimony " (birds, plants, insects). Landscape agro-ecology is presented as a top-down approach, as opposed to landgenics which takes a bottom-up approach. However, both approaches share the need for participatory R&D (Research and Development) associating the knowledge of local actors and the knowledge of researchers' disciplines. They also share the concept of "commons" but according to the specific design of each of the two approaches.

As no discipline has yet been able to go beyond the oppositions nature/culture and art/science in the approach to landscape, CHOMARAT-RUIZ (2014) makes an attempt to theorize "landscaping" which would also contain knowledge and methods borrowed or imported from agronomy, geography, sociology, etc. She also develops an in-depth epistemological and ethical reflection.

A similar small essay on general objects, far beyond the landscape, is accomplished by the architect OXMAN (2016). The latter focuses on developing the "anti-disciplinarity meme" for the four fields of art, science, design and engineering. The boundaries between them have become blurred in terms of methods and perhaps even more so in terms of underlying motivations. The distinction between nature and culture is the bread and butter of every anthropologist, says the author. If one describes nature as all life support and that life is unsustainable without culture, both systems of thought merge in the same singularity. It is in this general order of ideas that are presented the first elements of landgenics considering its object as intricate and the exercise of its art as polymathic. An art based on the empiricism of the knowledge and know-how of the stakeholders and the interdisciplinarity or transdisciplinarity of many sciences and applied sciences.

1.3. Book structure

After this introduction, the book focuses on five key points completed at the end with a conclusive synthesis, a glossary and a list of references cited. It is based on my own experience in Burundi and on an extensive literature search. It is therefore based on experimental results obtained in laboratories or sites spread over several continents. It aims at advancing knowledge and know-how in landscape design of territories and focuses in particular on rural areas. It is intended for a specialized public but open to interdisciplinarity. In particular, it requires knowledge of agronomy, pedology, geomorphology, phytobiology and ecology, as well as a sensitivity to socio-economics, urban planning and even genetics. Its audience is therefore primarily geographers and geologists, agricultural- and bioengineers, sociologists, biologists, ecologists, and probably also architects and landscape architects. Researchers and students in these various disciplines could be more specifically interested. Agricultural and forestry cooperatives would also be concerned, both in developed and developing countries. Foresters, farmers and livestock breeders are invited to become acquainted with it, despite its sometimes arduous scientific aspects.

After this introduction, the theoretical elements of territorial landgenics are presented: the general conception of the model, its objects and dimensions, the criteria of identification of the "holons" and of the landgenic "facets" whose denomination is inspired by ancient Roman distinctions. These facets are defined as potential "commons" of "Ager", "Saltus", "Silva", "Urbs", "Hortus", "Aqua", and "Desertum". It is with these elements that empirical landscape design produces instantiations of a landgenic species. A partial application is proposed as an illustration in the natural region of the "Landes de Gascogne" in the southwest of France.

The third point explains the process of soil aluminization: definition of ecoclimatic regimes of acid pedogenesis, soil acidification reactions (root and microbial respiration, ammonium nitritation, iron sulfide oxidation, ferrolysis), subsequent aluminization by acid hydrolysis of primary minerals and weathering products, development of the adsorption or exchange complex, ion exchange of aluminum with basic cations that are then leached.

The "Phytobiology of Aluminization" then focuses on the physiological inductions of aluminization in plant species at the level of the plasma membrane, cell wall, cell cytoskeleton and nuclear DNA. It also reviews mechanisms of resistance and tolerance to aluminium such as root exclusion, increase in rhizosphere pH, accumulation at the root and leaf level or activation of specific metabolic pathways and regulation of gene expression at "quantitative trait loci". A review of the sensitivity of natural and cultivated species to aluminum is also presented based on experimental data obtained with soil samples placed in vegetation vases under cover or with laboratory culture solutions.

Point five makes an important change of scale in space and time. The notions of biodiversity α, β and γ are thus recalled. The ecological concepts of "niche" and "biotope" are distinguished and commented from the literature. Ante-prehistoric temporalities are briefly reviewed such as the geochronology of the 5 great massive extensions or the climatic oscillations and their geomorphological consequences which led for example to the development of lateritic mantles in the Tertiary era. The spatio-temporal scales lead us to reconsider the evolution of species and to reconsider the chances and necessities with new driving patterns. It is also a question of giving the evolution of species a spatial dimension with regard to the environmental changes and stresses induced in particular by the various degrees of soil aluminization. An increase in biodiversity with the age of the holons is reported in relation to their degree of aluminization. Finally, the phenomena of progression and retrogression of ecosystems are discussed.

A final point deals with the landgenics of aluminization as such at the level of territories. The global phenomenon of the anthropization of the ecosphere is first examined since it is with it that the territorial landscape design starts. Since prehistoric times, the main stages and the relative speed of the colonization of the human niche are recalled in various continents and globally through the evolution of the landgenic facets of Ager, Saltus, Silva and Urbs, the latter as a center of development of cities near the non-aluminized Ager. The second part focuses on the interactions of aluminization with the technical itineraries used to shape the landgenic holons in the rural territories. Agro-pedological data are thus gathered and analyzed in Africa, Asia, Amazonia and Europe. These data confirm a decisive relationship between aluminization and the different types of Silva, Ager and Saltus holons, despite their curiously limited number and often fragmentary nature.

A final concluding synthesis points to the organization of knowledge and know-how into disciplinary silos and attributes to it the surprising incompleteness found in the book. Despite these still limited research data, a good cohesion emerges overall, from the cellular level of the plants to the level of the landgenic holons involved.

2. Elements of territorial landgenics

2.1. General conception

Landgenics is conceived as a polymathic art. It is dedicated to the identification and the dynamics of territories, that is to say to their organization, their differentiation and their evolution. Its framework is the territorial development according to a participative and collaborative mode between the actors of ground with specific interests on the one hand and, on the other hand, the researchers-developers of the disciplines and specialities which it calls upon. This art is based on the natural (biophysical) and cultural (socio-anthropological) traits and characters of the territories by a metaphor with genetics, i.e. with the genotypic traits and phenotypic characters of living organisms. Natural traits and characteristics are established without human intervention in the ante-prehistoric period. They are therefore specific to fundamental ecology (see point 5).
Landgenics considers complex evolutionary systems but it includes the cultural traits and characters that have organized the territories. The concept of landscape genome represents the set of traits of a landgenic species (LS) that are shared by its population, that is to say the set of existing landgenic instantiations (LI). By analogy, the landgenic "phenome" refers to the set of characters of a species (LS) and thus to the phase space effectively occupied by all the existing phenotypes of its LI. A LS thus gathers the population of its existing instantiations in the same way as the set of individuals of a species in biology. The landgenic genome can be likened to a kind of " matrix " from which a polymorphism of instantiations is shaped by differentiated ontogeny during a limited period of time. This genomic matrix is not stable. It evolves on the one hand according to the generational temporality specific to the renewal of human populations and on the other hand according to the environmental spatiality.

Landgenics perspective is systemic because many natural and cultural components interact. As a result, several types of knowledge and skills can interact according to disciplines and specialties as fields of knowledge and know-how. The view is also complex because it focuses on several integrated levels of organization similar to AUDOUZE et al.'s (2015) mosaic worlds. It is thus a (self-) organized complexity. But, if a mosaic is in two dimensions, the landgenic model is in three (3D). The landgenic system is thus divided in its epigeal part as well as in its hypogeal part in the same way as the terrestrial ecosphere which contains the atmosphere, the hydrosphere, the lithosphere and the biosphere.

The self-organization of a LI is based on a multi-agent system (MAS) characterized by an awareness of collective interests and issues that shape the potential "commons" at the local scale. These "commons" are spatially distributed in sub-phenotypes or facets of the LI. The agents, which can also be called actors, are made up of direct and indirect indigenous users. These actors are generally in relation with indirect and distant non-indigenous partners. The latter can influence them or weigh in on the decisions they must make.

The concept of "holon" is borrowed from KOESTLER (1969) to designate, according to LE MOIGNE (2006), "*unbreakable aggregates*", "*irreducible and polyfunctional processors such that if they are made to operate in order to ensure one function, they ipso facto lead to the potential activation of all their other functions*". Concretely, the "landgenic holon" (LH) is constituted by a type of anthropized biotope or anthrobiota, as an elementary, fundamental and functional volumetric unit of landgenics. It is therefore a vertically multi-compartmentalized object as illustrated in figure 2.4. In a multidisciplinary hoolistic approach, the different parties each have a specific conception of the holon. To adopt interdisciplinarity, the ideal would be to obtain a unified holon that should be discussed and approved. This could be, for example, the smallest common holon volume between the convoked disciplines.

The term "landgenic facet" (LF) is derived from BLANC-PAMARD (1986). However, it designates here a larger entity and most often fragmented. The LF is a more or less vast assembly of one or more LH distributed in a non-random way in space. The LF is in fact based on the characteristics of a potential common. Actors are likely to develop this common and mutate it to improve their welfare.

The territorial LI is composed of several LF arranged in space according to their epigenetic characters. The photographic illustration of a LI and its FP is shown in figure 2.1.

Figure 2.1. Photographic illustration of a landgenic instantiation and the four potential landgenic facets or commons (LF1 to LF4) that shape it. Village of Makabana in Congo (Photo: Fotolia).

The LF is the visual (epigeal) perception of a common expressed by the underlying and invisible interaction of the traits specific to the landgenic holons (LH) that compose it and provide its functions. Landgenic traits interactions extend laterally not only between holons within the same LF but also within the same LI or even a neighboring LI. The holon concept, however, is based on the higher intensity of trait interactions within the holon compared to the lower intensity of trait interactions between adjacent LH within the same LF, and even more between LH of adjacent LF or even of another LI.
Figure 2.2 illustrates schematically a LF with three PH.

While a character of an LF can be generally felt or observed by an actor of that LF or even of the entire LI that encompasses it, the identification of a trait requires closer observation or examination. The identification of LH is the domain of the researcher-developers who must establish their diagnostic traits. A landgenic trait is a specific characteristic or property of all or part of an LF in a particular LI. Identification of traits related to landgenic characteristics may thus require studies on samples or field measurements using adapted methods, tools and devices. This identification also requires establishing the functional process of expression of the traits considered in the modeling of the trait(s) under consideration. Traits are therefore classified into several "branches" and each is equivalent to a discipline or specialty specific to the classical distinctions of knowledge and skills of researcher-developers. Figure 2.3 shows the interaction of several traits into a network in a five-branch LH of a landgenic facet.

The dogma of one gene for one trait having been shattered, as considered in particular by SUING (2016) in his critical analysis of neo-Darwinism, we can in parallel postulate that a landgenic trait participates in several phenotypic expression networks of landgenic traits. Concretely, this means, for example, that the diagnostic soil trait of more than 50% aluminization of the soil over a thickness of more than 50 cm (see point 3) can be shared by several LH of the same LF or several LI of the same LS. But this can also mean that several landgenic traits belonging to different branches can control the same character in a LH. Thus, in addition to the trait of an aluminization rate higher than 50%, the (agro-)technical itinerary practiced, the meteorological and climatic conditions and the seasonal pest pressure can all play a role in the level of agricultural production achieved in the same LH.

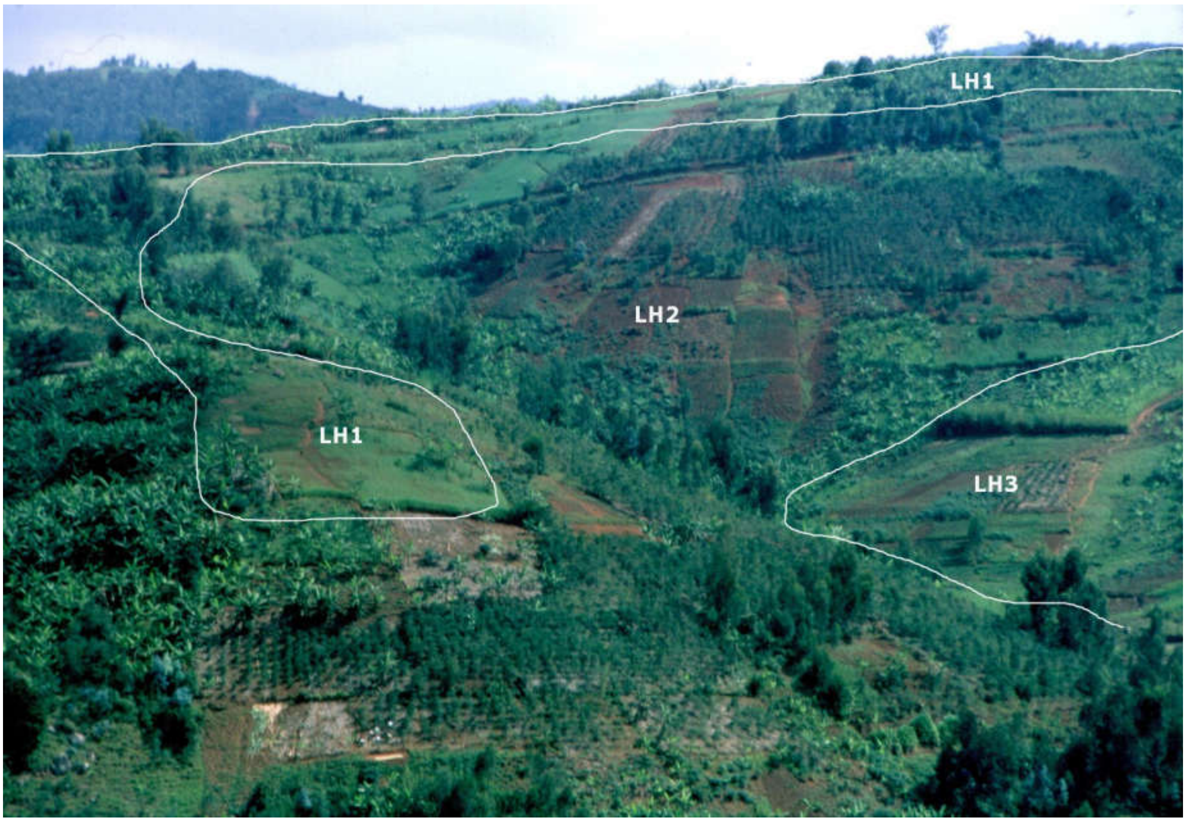


Figure 2.2. *Diagram of a landgenic facet with three holons of topographic position: LH1 for the summit, LH2 for the slope, LH3 for the valley floor (Photo: Luc Opdecamp)*

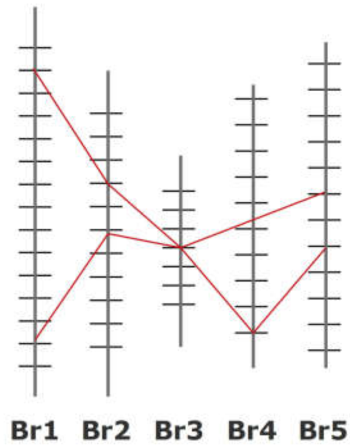


Figure 2.3. *Scheme of an active network of five-branch features (Br1 to Br5) in one of the holons of a landgenic facet*

For landgenic branches, they cover practically all the fields and sub-fields of human knowledge and know-how directly or indirectly "related" to territories, among which box 1 gathers a non-exhaustive list. Landgenics is open to any disciplinary contribution within the framework of the development of its model of self-organized and evolving complex system. It goes without saying that not all of these disciplines must be used in all analyses and projects. However, it is necessary to choose the most appropriate ones according to cases and to ensure their intention to work according to an interdisciplinary approach.

All the disciplines convoked for an interdisciplinary approach of landgenics are requested to adopt the general conception developed here, namely a three-dimensional structure starting from the landgenic species (LS). The latter then groups all its contiguous instantiations (LI) within it. And each LI contains its own landgenic facets (LF). Finally, it is at the level of landgenic holons (LH) that the specific traits of each discipline are identified.

Box 1. Non-exhaustive list of identification branches of landgenics traits

anthropology, agronomy, archaeology, architecture, biology, biogeography, climatology, ecology, economics, epidemiology, aesthetics, ethnography, human and physical geography, civil and rural engineering, geology and geomorphology, history, hydrography and hydrology, horticulture, medicine, paleontology, palynology, landscaping, pedology, philosophy, plant and animal physiology, politics, sociology, urban planning, etc.

2.2. Objects and dimensions

Landgenic objects have spatial dimensions defined by their whole and parts at each level of scale or organization. These dimensions are delimited by boundaries that are neither hermetic nor stable. Organization and internal structure of objects are also variable because they can evolve over time. Therefore they have a history during which the "habits and customs" of the actors have been modified or have been mutated outright. They may thus have undergone ruptures to adapt to political or environmental changes. In addition to the three dimensions of space, there is also time dimension.

The elementary objects at a time "t" are genotypic LH (landgenic holons) and phenotypic LF (landgenic facets) inscribed in the three dimensions (x,y,z) of space of a landgenic instantiation (LI) belonging to a landscape species (LS). If the lateral dimensions are limited by latitude and longitude coordinates (x,y), the vertical dimension (z) is established along an axis with positive dimensions for the epigeal part and with negative dimensions for the hypogeal part. The latter extends for the holons (LH) through the thickness of the soil to the geological or pedological parent material and may include if there is an open water table as illustrated in figure 2.4. It may also include a captive water table if an impermeable layer overlies it. If an open water table emerges or outcrops on the surface, we are dealing with a watercourse, a marsh, a pond, a littoral lagoon, etc. The landgenic objects are thus layered like the atmosphere, biosphere, hydrosphere and lithosphere which compartmentalize the ecosphere. The traits of the landgenic objects are "coded" in the vertical dimension, which is illustrated in the conceptual diagram in figure 2.4. It is therefore understandable that disciplinary branches can be focused directly on all or part of one or more compartments of the ecosphere.

2.3. Identification of commons or landgenic facets

The concept of "common" is not new as explained by LE ROY (2016). Thus, Roman law could not apply to land and its resources insofar as they were essential to the reproduction of groups. It was only in the middle of the 18th century with the first agricultural revolution and the Enclosure Acts movement in Great Britain that the private appropriation and exploitation of land became a matter of course by force of law. This is reflected in the landscape by a retreat of the open field in favor of the bocage. For LE ROY (op. cit.), Western society was then undergoing the revolution of commodification and the addiction to "proprietarism". Local customary rights were transformed into private or state property rights. The colonial regime rediscovered the commons in sub-Saharan Africa but did not care about them and extended the State's land monopoly over all territories not yet privately appropriated. As with the etatization of the sheep pasture commons in the "Landes de Gascogne" by Napoleon III's law of 19 June 1857, as mentioned by Pappy (1977). LE ROY (op. cit.) equates the landlords' seizure of common lands with the appropriation of Indian lands by American pioneers. Recent land grabbing movements in Africa, Latin America and Asia also follow a similar logic. The pre-colonial referent as well as communal land tenure prior to the first agricultural revolution are considered by LE ROY (op. cit.) as "primo-commons". These are sets consisting of a community, resources and governance protocols. However, "neocommons" are reappearing, such as neighbourhood associations, fablabs, participatory housing, cooperatives, etc. These neocommons attempt a mutual adjustment between the commons and private property. The contemporary complex society could not do without either.

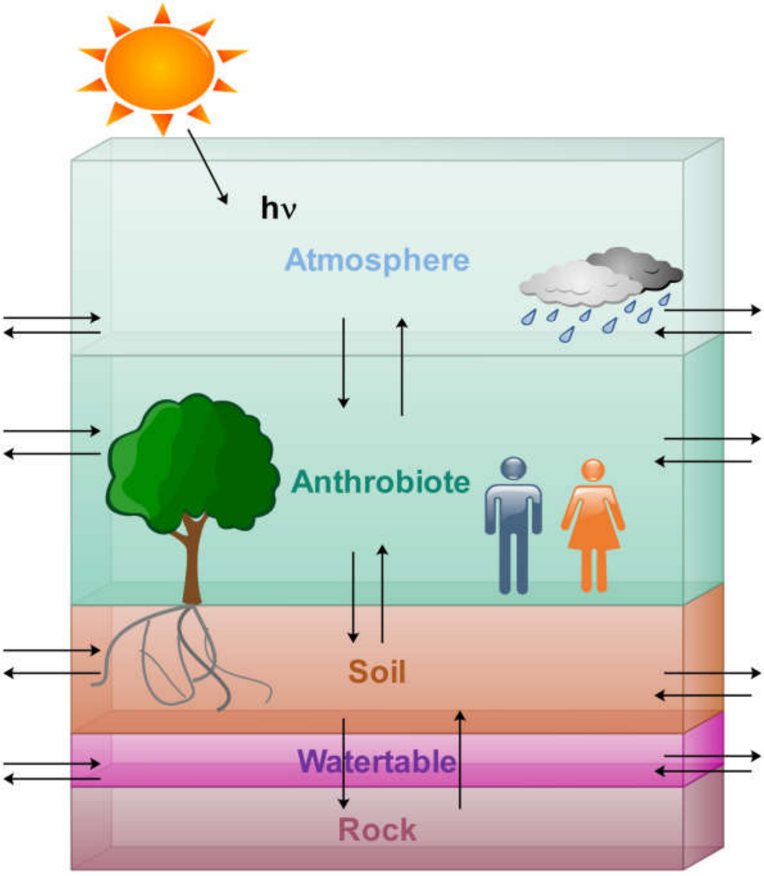


Figure 2.4. Vertical compartments of landgenic holons

BOLLIER (2014) provides a definition of the commons that is particularly consistent with the conception of landgenic objects as illustrated in figure 2.4: "*They are resources plus a defined community and protocols, values, and norms invented by that community to manage certain resources [...] as commons.*"
Elinor Ostrom, 2009 Nobel Prize winner in Economics, also gives a definition of the commons. Here it is, as reported in the BOTTOLIER-DEPOIS (2012) reading note: "*The term common resource refers to a resource system that is sufficiently large that it is costly (but not impossible) to exclude its potential beneficiaries from access to the benefits associated with its use.*"
Based on her experience of field realities, Ostrom induces a set of eight principles or modalities of self-organization of the commons that correspond in some way to the protocols, values and norms mentioned in BOLLIER's definition (op. cit.). These principles are listed in box 2.
The identification of landgenic commons does not de facto lead to their institution. The knowledge of Ostrom's system of eight modalities for the effective and sustainable self-organization of commons is not sufficient for its effective implementation by the actors. But as BOTTOLLIER-DEPOIS (op. cit.) reports, Ostrom considers the implementation of the system as a "sequential and incremental" phenomenon. The self-organization of a community is thus a process. Its landscape identification could then participate in initiating such a process by collecting and making available to the actors the information necessary and sufficient for its configuration. The existence of traits of relative felicity or adversity are indeed shared at the level of the holons that make up the identified potential commons.

2.4. *Levels of landgenic organization*

The term "anthrobiotes" reported in figure 2.4 refers conceptually to phenomenic commons (LF, landgenic facets). They are defined both by a broad type of land use and by a specific category of direct or indirect indigenous actors who enjoy and participate in shaping them. Examples of LF shaping processes are soil and biodiversity evolution processes, gravitational, hydric or wind erosion and sedimentation processes, climatic variations and pulsations, demographic, cultural and political evolution, changes in economic conjectures or structures, development of product and service chains, etc.

<u>Box 2</u>. Elinor Ostrom's eight principles for designing the self-organization of the "Commons", according to BOLLIER (2014) and BOTTOLIER-DEPOIS (2012)

1. Definition of clear boundaries for the commons and for the actors who have access to it
2. Adoption of rules for the use of the commons adapted to local conditions and needs
3. Establishment of collective choice mechanisms that include most of the actors concerned
4. Implementation of a behavioral monitoring system by the stakeholders themselves
5. Adoption of gradual sanctions for non-compliance with the rules
6. Recognition of the self-organization of the common good by external authorities
7. Designing quick and inexpensive mechanisms for conflict resolution
8. Polycentric and multi-scalar organization of governance responsibilities

Anthrobiotes, common or LF, are phenotypes with relatively homogeneous characters. As already mentioned, these characters are expressed by the interaction of variable traits that operate in networks. According to the landgenic model, territories are differentiated by the actions, practices and decisions of six categories of intelligent actors that give rise to six categories of phenomenic commons, each in several dispersed formations or in a single formation in each landscape instantiation (IP). Each formation of a phenomenic common category is shaped by one or more types of "genomic holons" according to processes already discussed. The six categories of phenomenal commons in landgenics are inspired by the ancient Roman categories as revisited by VIDAL (2011) and complemented by the category of continental surface waters: the Ager, Saltus, Silva, Urbs, Hortus and Aqua. A seventh category is added which can be considered as a pseudo-anthrobiote, namely the Desertum where life is strongly constrained by an unavailability of liquid water.
The basic phenomenic categories of agrarian space are taken up by JOUVE (2016) namely "Ager", "Saltus", "Silva" and "Hortus". Their spatial distribution also presides by this author to identify rural landscapes while "Urbs" is evoked by the city-countryside relations. POUX et al (2009a, 2009b) also explain the famous agrarian trilogy of the Ager, Saltus and Silva.

The identification of a landgenic species (LS) corresponds to a population of similar LI, i.e. a group of LI with similar characters and traits. A LI is thus the local expression of a LS but is based on social links constituting the social framework of this LI. The LS is equivalent to the landscape unit (LU) used as a basic concept in landscape atlases in France. Identification of a landgenic LS or a LU landscape atlas requires, at a minimum, stereoscopic examination of aerial photographs or cross-referenced examination of topographic and land use maps. The LU or LS must also be recognized in the field through its LI by a walker in exploratory observation of the area. In addition, the local actors of an LI must be individually identifiable and easily grouped.
Within the framework of landscape atlases elaboration at the departmental or regional scale in France, RAYMOND et al. (2015) recall the initial definition of 1994 for landscape units (LU) namely "*landscapes carried by spatial entities whose set of characters of relief, hydrography, land use, forms of habitat and vegetation present a homogeneity of aspect. They are distinguished from neighboring units by a difference in the presence, organization or form of these characteristics.*" It is a definition which has the merit to evoke characters gathered in some kind of networks, which is close to the concept of LS proposed in landgenics as a set of LI of the same "genome". For the landscape atlases of Wallonia in Belgium, DROEVEN et al. (2004) give a more restricted definition to the LU: "*portion of territory embraced by the human view on the ground and delimited by visual horizons (heights or edges)*". On the other hand these same authors use the concept of "*landscape territory*" as an aggregation of such units with similar characteristics. We can deduce a certain equivalence between the Walloon "landscape territory", the French landscape unit and the LI in the conception of the landgenics. The LU of Wallonia would then be equivalent to the LI which would have no equivalent in France. The LI would thus be a basic motive that would be repeated in a LS.

DAVODEAU (2009) reports that below an area of 100 km2 we are at scales too high compared to the framework of French departmental atlases, namely that of "landscape plans". Moreover, this author underlines the ambivalence of the notion of landscape which is "at the same time material and immaterial", reasoned and felt, according to whether this notion is used respectively by geographers or ecologists on the one hand and by landscape designers on the other hand. However, DAVODEAU (op. cit.) considers that the two types of approach are complementary and that landscapes are "material objects certainly, but always perceived and lived by populations". To integrate the point of view of the inhabitants is however difficult on territories as vast as the departments. The landgenic model adopts however this integrated criterion. It is fundamental and linked with the concept of potential common as the "social structure" of a LI. In this sense, landgenics is quite well linked, via its concept of instantiation (LI), to this other used notion of "living environment". This one is the expression of both the natural and the cultural heritage which found the identity of the populations, in accordance with the article 5 of the European Convention of the landscape (CoE, 2000). The framework of life is also that of social links and the landscape in everyday life. It means in sum the "surroundings" or "environs" at the individual level.

What is unique to the landgenic model is the genotypic role of landgenic holons (LH) in phenotypic shaping of LF. The LH thus act as interactive traits processors. All analogous LH of the same LF constitute a subgenotype of an LI. The various LF are thus also subgenotypes of a LI. A population of LI that share the same "landgenic genome" finally produces a LS. It is the latter that is assimilated to the *landscape unit* of the French atlases and to the *landscape territory* of the Belgian atlases in Wallonia. The landgenic model, however, requires collaboration between the actors of the potential LF commons and the researcher-developers of the engaged disciplinary branches. A strong cohesion of the latter is also required at the level of LH identification. A general synthetic diagram of the organizational structure of landgenics is proposed in figure 2.5. Beyond the LS is the natural region. The latter is thus composed of at least one LS. The natural region, however, is located at an organizational level where the social ties of the commons become much more distant and therefore also much looser.

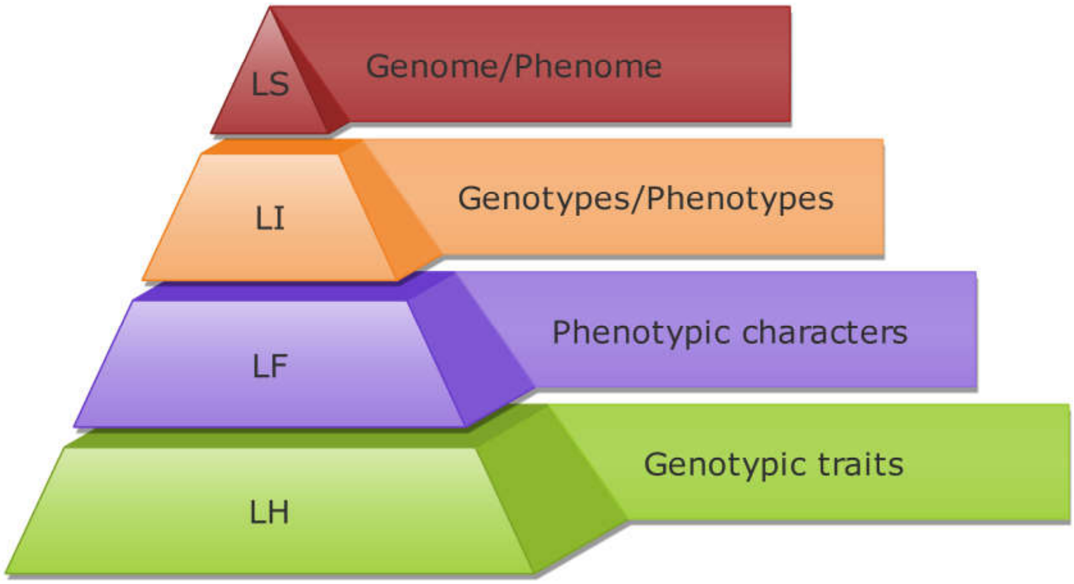


Figure 2.5: Hierarchical structure of a landgenics species (LS)

As for the structure, it is always possible to object that it is more adapted to a rational landscaping than to a sensitive one. However, BERQUE (op.cit.) refers to the existence of rules in the sequence of the spatio-temporal motives of the landscapes as well as to a code or a matrix which would preside over such a process. In relation to the art of gardens in Japan, he evokes the great features of "famous" landscapes that he considers as features of representation in aesthetics and ethics. It is very tempting to make a parallelism between the phenomenic characters and genomic traits of the landgenic species (LS) on the one hand, and the patterns of the Japanese gardens on the other hand, *which play trajectively as imprints and as matrices*. In the same way a parallelism is imposed between the process of evolution of the landgenic model and that of BERQUE's landscape "motivation". And the "medium" that constitutes the (local) society in BERQUE, considered as a mesological relation or mediation, also corresponds well to the landscape instantiation (LI) in a LS.

2.4.1. Commons and holons of Ager

Ager is the LF constituted by the subphenome of the domain that is quasi-permanently cultivated, planted or sown and originally tilled as so-called arable land. It includes all cropping systems practiced in the considered LS and its various LI. Many fields and plots of annual or biennial species can be cultivated in the Ager depending on the climatic zones: food or fodder maize, rainfed and irrigated rice, wheat, barley, sorghum, millet, sugar cane and sugar and fodder beet, potatoes, sweet potatoes, cassava, soybeans, peas and beans, pineapple, etc. We could also mention many spice and perfume plants. Temporary grasslands are also part of the Ager. They are sown with herbaceous species, mowed or grazed for a maximum of 5 consecutive years. After 5 years, they become permanent and are assimilated to Saltus (without mowing).
Temporary grasslands in rotation with annual crops constitute a grassland Ager. Also considered as Ager are vineyards and intensive orchards that are not grazed, as well as more generally plantations of perennial agricultural species such as olive trees, palm trees, banana trees, cocoa trees, coffee trees, tea trees, etc., with the exception of trees intended for the intensive production of wood or logs, which are part of Silva. In Ager, mineral and/or organic fertilization of plots is practiced more or less regularly depending on availability.
Figure 2.6 shows some examples of annual or perennial LF from several regions of the world and therefore from several EP.

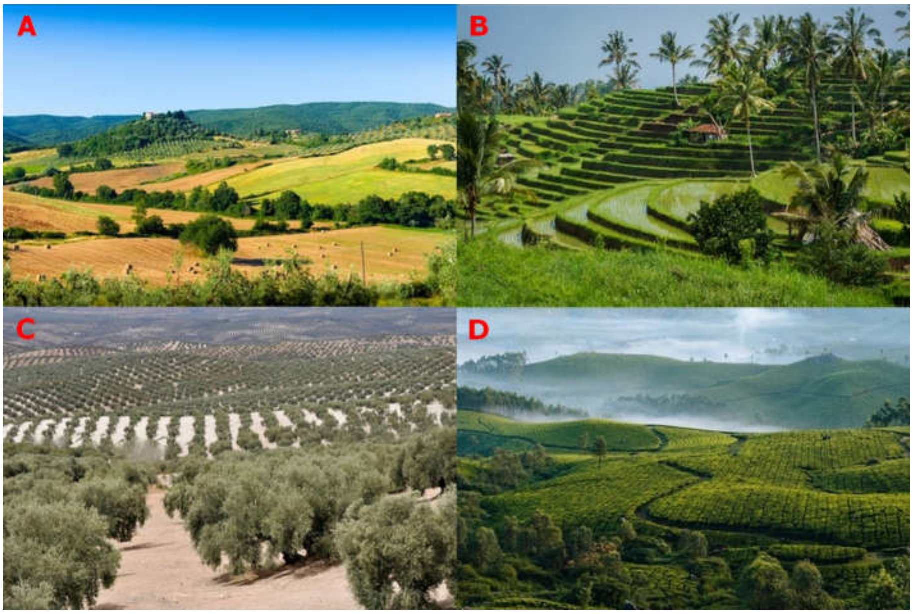


Figure 2.6. Illustrations of 4 LF of Ager (Photos: Fotolia): Bocage Ager in Tuscany (A, foreground), Rice Ager in Bali (B), Olive Ager in Andalusia (C) and Tea Ager in Kerala (D)

The collective of actors in the Ager directly includes sedentary farmers as well as, where applicable, the landowners of the plots. This collective extends to other indigenous people residing in the LI, because they share with the above mentioned actors the environmental issues of the Ager, such as water availability, local transportation routes, air quality, semi-natural flora and fauna, local customs and practices, landscape aesthetics, etc. Finally, in a much more indirect way, the non-native and distant partners in the processing and distribution chains of Ager products are partners in this potential common cause because of the traceable qualities of the products and their outlets.
The phenotypic characters of Ager in an LI are the result of several interacting genotypic traits, in a manner comparable to the way in which the genes of a living organism participate in the expression of its phenotypic characters. The identification of traits that participate in the expression of the phenotype of an Ager results from a diagnosis made by several researchers-

developers according to the branches mobilized. This diagnosis is genotypic in the metaphorical sense and is based on the identification of one or more landgenic holons (LH), each characterized by a specific network of interacting traits for the LF of the Ager.
Each LH of an Ager LF can be symbolized by a general formulation of the type "iAg,abcde...". iAg designates an LF or an Ager common, the prefix "i" reminding that it is an intelligent entity since it also includes the actors who shape it. The letters abcde... are a juxtaposition of diagnostic features identified by the various disciplinary branches involved. For example, for a given LH, each of the letters of the iteration "abcde..." can be the symbol of a trait characterizing the cropping system and its technical itinerary, that of the type of marketing channel for the production(s), that of the major textural class of the soil and that of its degree of hydromorphy, that of the class of topographic inclination, that of the appreciation of its aesthetic or ecological value, etc., according to a detailed legend. Such a formulation would then favor the cartographic representation of LH. The problem with a classical map is however that it does not allow easy updating. However in landgenic dynamics it can be rapid, especially at the level of holons. The technical itinerary of a cropping system can change in a few seasons for example. It can also be rapid at the LF level, for example following deforestation to install Saltus pastures. Therefore, the use of a GIS (Geographic Information System) to represent the different components of self-organization of territories would become almost indispensable.

2.4.2. Commons and holons of Saltus

Saltus is a semi-natural domain. It is a potential common that is already implemented. It bears the mark of human management in an extensive version by the grazing of herds of domestic animals and often by the practice of periodic fires to limit or destroy the brushwood. Saltus is a type of anthrobiota developed in all open spaces not cultivated most of the time. It is generally exploited for pastoral livestock and gathering. The reproduction of soil fertility is natural, ensured by the looping of nutrient cycles without exogenous fertilizer inputs, and can be accelerated by the practice of burning for a short period of temporary cultivation. Different types of herds and herbaceous formations with more or less trees can be part of this type of facet, including grazed meadows. The actors of Saltus are essentially herders and pastoralists, nomadic or sedentary. VANDERPOOTEN (2012) reminds us that the physiocrats of the 18th century opposed the system of "small-scale farming" to that of "large-scale farming". The former is characterized by vast areas of "Saltus", uncultivated (permanent pastures), and only a small part of cultivated land subject to a crop rotation. While in the system of "great culture" a vast "Ager" dominates the landscape, characterized by a regular alternation of crops and temporary meadows. Ager territory is regularly shared by agriculture and livestock on the same plots. Figure 2.7 illustrates some classic Saltus commons.

Symbolism for representing the various Saltus holons of a LI, preferably in a GIS, is similar to that proposed for Ager: "iSa,abcde...". The letters of the abcde iteration can indicate whether the livestock is sedentary or itinerant, the species of the grazing herds, whether or not fires are practiced, the phytosociological composition of the grassy formation, the relative depth of the soil, the species reserved for gathering (gum arabic for example), the possible tourist interest, etc.

2.4.3. Commons and holons of Silva

Silva is the closed wooded area, encompassing vegetation formations perceived as primary and qualified as "wild" by VIDAL (op. cit.). However, it is a common practice implemented by many "tribes" or indigenous peoples for many centuries. The so-called virgin rainforests have in fact been reworked for a long time by the activity of the essarteurs and the itinerant practice of slash and burn. These are also Silva as very slow rotation agroforests, i.e., with long forest fallow, where man has thus inserted himself (ROSSI, 2000). In addition, Silva should be extended to silvicultural anthrobiotes planted or seeded for timber or energy production and whose use is oriented in parallel to hunting and fishing activities. State-owned woods and forests are neo-commons managed by the state. The "Silva" agents are owners, operators and forest workers, among whom may be slash-and-burn farmers, hunters and gatherers. Figure 2.8 shows some classic Silva LF around the world.

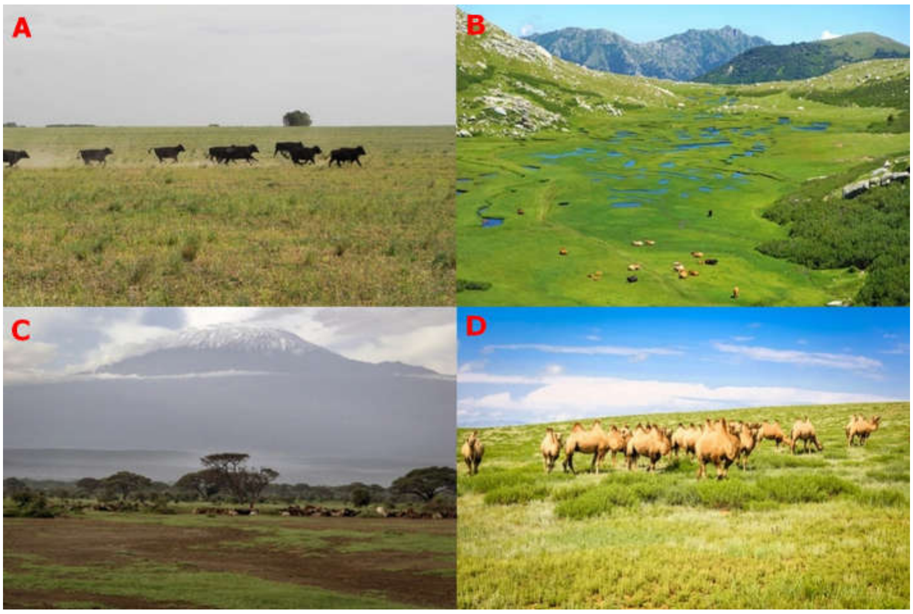


Figure 2.7. Illustrations of 4 Saltus LF (Photos: Fotolia): Saltus of the Argentinean Pampa (A), Saltus of pozzine in Corsica - typical peaty holon surrounded by a rocky holon - (B), Saltus of savannah in Kenya under the background of Kilimanjaro (C) and steppic Saltus of the Gobi grazed by camels(D)

Silva's holons "iSi, abcde..." are based on the traits of stands and forest sites specific to the agrosystemic approach of forest engineers, on the anthropological traits of the actors, on the traits of gathering, hunting and fishing, on the degree of agroforestry anthropization such as the shifting cultivation system, the localized establishment of perennial species (cocoa, rubber, coffee, palm, etc.), the naturalistic interest of fauna and flora, etc.

Figure 2.8. Illustrations of 4 LF of Silva (Photos: Fotolia): Lapponian Taiga in Finland (A), Silva in the volcanic zone of Bali (B), Silva in the Amazon in Brazil (C) and the Vosges coniferous massif (D)

2.4.4. Commons and holons of Urbs

"Urbs" is an LF marked by a built-up area greater than 50% in a minimum area set according to local socio-economic conditions, for example 50 ares in a village hamlet or 1 km² in a small town. This LF is reserved for a concentration of human activities of residence, crafts and

industry, commerce, transport and services. Conventionally, a density of actors of 1,000/km² can also be set to distinguish an urban Urbs LF from a village or rural Urbs LF. An urban Urbs LF is often a hub of economic development.
COLLINS et al. (2000) consider this type of community as a heterotrophic ecosystem, with an "industrial" metabolism because of its high energy and material consumption. These authors also identify sites that partially correspond to urban LH as sub-anthrobiotes, sometimes consisting of a core of concrete and glass, sometimes of industrial parks, as well as LH that are intertwined with "Hortus" such as public parks and private gardens, golf courses, tree-lined streets, etc. Urbs develops according to a dynamic driven by economic and demographic growth as well as by institutional decisions. It is also a common of very variable size, ranging from the simple village hamlet of a few dozen inhabitants to the city of several thousand, tens or hundreds of thousands of inhabitants or to the megalopolis with a population of over ten million. As a community, Urbs can be presented in several subgroups of varied interests distributed throughout the set of urban actors: residents, workers and employees, merchants, artisans, industrialists, service providers, etc. Figure 2.9 provides some diverse illustrations of Urbs.

Figure 2.9. Illustrations of 4 LF from Urbs (Photos: Fotolia): City of Manaus, state of Amazonas in Brazil (A), Village of Montovun in Croatia (B), Cité du Soleil in Haiti (C) and Shanghai Megapolis (D)

The "iUr, abcde..." holons of Urbs can be composed of various residential neighborhoods with sometimes very contrasting architectural, urbanistic and population density features, as well as various industrial or commercial activity zones, with particular topographic and hydrographic traits, with more or less polluted environments, with more or less high road or rail traffic densities, etc.

2.4.5. Commons and holons of Hortus

Hortus was originally a horticultural belt of Urbs that was necessary for the cities for the rapid delivery of perishable goods. This belt still persists sometimes in bits and pieces, especially in developing countries. Currently, the phenomenon of urbanization has increased and concentrates more than half of the world population. This concentration even reaches more than 80% in a country like France according to JANIN (2015), where the phenomenon would gobble more than 200 ha per day. At the same time, VIDAL (op. cit.) observes that green spaces of Hortus type are returning to the city, as well as above-ground horticulture or horticulture in urban wastelands, sometimes for recreational purposes in developed countries and sometimes for functional and food purposes in developing countries. As for the actors of Hortus common, they refer to urban and peri-urban horticulturists and gardeners practicing on a professional or private basis. Figure 2.10 shows some photographic illustrations of Hortus.

Figure 2.10. Illustrations of 4 LF from Hortus (Photos: Fotolia): tulip fields in the Netherlands (A), urban vegetable garden in Brussels (B), Central park in New-York (C) and market garden near Hamburg (D)

The holons of Hortus "iHo,abcde..." can be distinguished, for example, according to the traits of texture or degree of soil pollution, the traits of the services provided (parks and gardens, promenades, golf courses, other sports grounds, etc.) or those of the production flow channels according to their nature (ornamental plants, flowers, market gardening products, etc.), the traits of geographical location in relation to Urbs, the traits of equipment (greenhouses, nurseries, etc.) and the intensity of labor, the organic and mineral fertilization practiced, etc.

2.4.6. Commons and holons of Aqua

Aqua refers to navigable and non-navigable surface waters and outcropping groundwater, excluding seas and oceans. Aqua includes flooded areas such as mangroves, bayou, salt flats and all amphibious ecosystems. Figure 2.11 illustrates four facets of Aqua around the world. River system of Aqua is truncated into LF and LH in each LI and LS because most major rivers extend over great distances. Large rivers therefore cross the boundaries of other potential commons.
Holon "iAq,abcde..." represents a volume of surface water such as a portion of a river or a part of a pond. This volume is shared collectively by a group of known and defined actors. The material content of the volume is relatively homogeneous in its features (abcde) and characters depending on the degree of precision or resolution adopted. One could cite features such as: a given interval between low water and high water flows, a sediment bed of the same type, a similar aquatic biodiversity in number and types of species, the same fishing practices, aquatic leisure activities, navigation, etc.

2.4.7. Commons and holons of Desertum

LF of Desertum applies to spaces of rocky, stony, sandy or ice deserts and pseudo-deserts. The Desertum commons are very sparsely populated or even simple transit places for nomads. They can extend over very large areas relatively uniform and little anthropized as the Antarctic or the Sahara. But, they can also be integrated into temperate, subtropical and tropical LI in the form of rocky outcrops or lateritic cuirassments. Similarly they can be associated with areas of settlement of Ager and Aqua as in the oasis.

Four Desertum LF are shown in figure 2.12. The "iDe,abcd..." holons can be distinguished by the mineral nature of the soils, the relative scarcity and type of vegetation, the closer or lesser access to a water point, the economic activity that takes place there (nomadic transport, ice fishing), etc.

Figure 2.11. Illustrations of 4 Aqua LF of 4 LI also belonging to 4 different LS (Photos: Fotolia): Li river in China, Cormorant fishing (A), Scleusen Canal in Lower Saxony, barge loaded with coal (B), Nile in Aswan, cruise ships (C) and Mekong Delta, mangrove swamp (D)

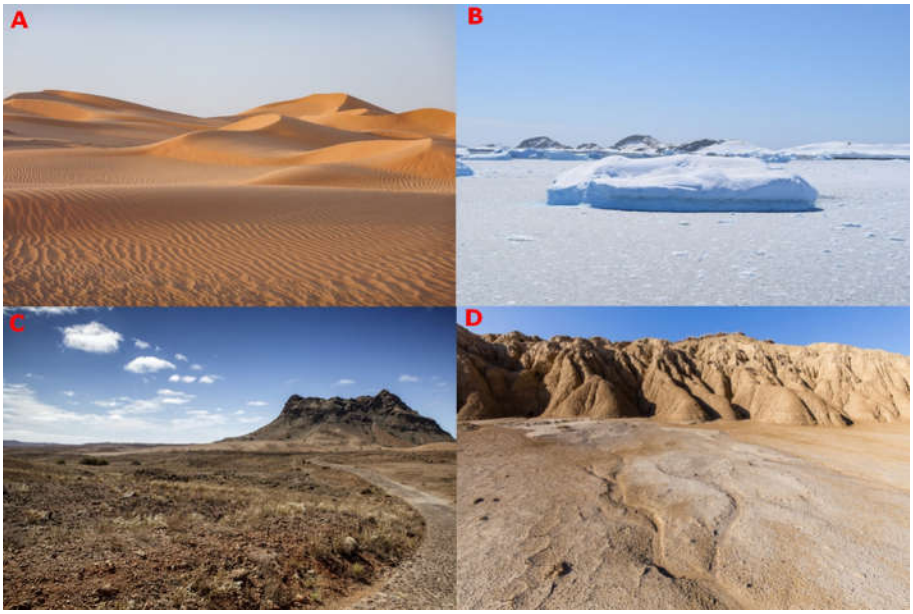


Figure 2.12: Illustrations of 4 Desertum LF (Photos: Fotolia): Sand dunes of Oman (A), Ice and Rocks of Antarctica (B), Rocks of Cape Verde (C), Marls of the Bardenas Reales of Navarra in Spain (D)

2.5. Illustration: traits and characters of the Moors of Gascogne

2.5.1. Traits and characters of the natural environment

Geographic and geological data

The moors (Landes) of Gascogne represent what Pappy (op. cit.) calls a "*large geographical ensemble*" (natural region). They extend on a triangle of more than 1 Mha (1 million hectares) in the South-West of France. Their topography is flat, a sort of vast plateau with an average slope of 1.25% according to JOLIVET et al. (2007).

They are roughly delineated in figure 2.13 on the Atlantic coastline between the mouths of the Adour and Garonne rivers and are spread out between the valleys of these two rivers. Their territory is divided administratively into three departments, mainly Gironde and Landes, but also much more modestly in Lot-et-Garonne.
DUBREUILH et al. (1995) situate the moors within the large geological domain of the Aquitaine Basin, bordered to the north by the Armorican Massif, to the east by the Massif Central and to the south by the Pyrenees. The western part of this basin was filled with alluvial deposits from the Neogene (Miocene and then Pliocene of the former Tertiary Era) and Pleistocene periods, coming alternately from the Massif Central and the Pyrenees. The local presence of lignite accumulations at the end of the sedimentary sequences testifies to plant colonization and therefore also to an aggrading effect on the land. A chronological gradient from south-east to west can be observed for this continental aggradation on the section of figure 2 of DUBREUILH et al. (op. cit.). Alluvial deposits dated to the Pleistocene constitute the formation known as "Castets", an integral part of the "Sable des Landes lato sensu". They are covered by light yellow sands deposited following their eolian reworking by the strong west winds during the Pleistocene glaciations. DUBREUILH et al. (op. cit.) consider that it is mainly the material of the Castets sands taken up by the wind during the Würm glaciations that covered the moors on the surface. These aeolian cover deposits form the "Sable des landes stricto sensu". For JOLIVET et al. (op. cit.), the "Sable des landes" represents an identity character and is thus diagnostic as such of a true natural region. It is also necessary to include there the littoral dune bodies, of sedimentary and eolian maritime origin during the current Holocene period.

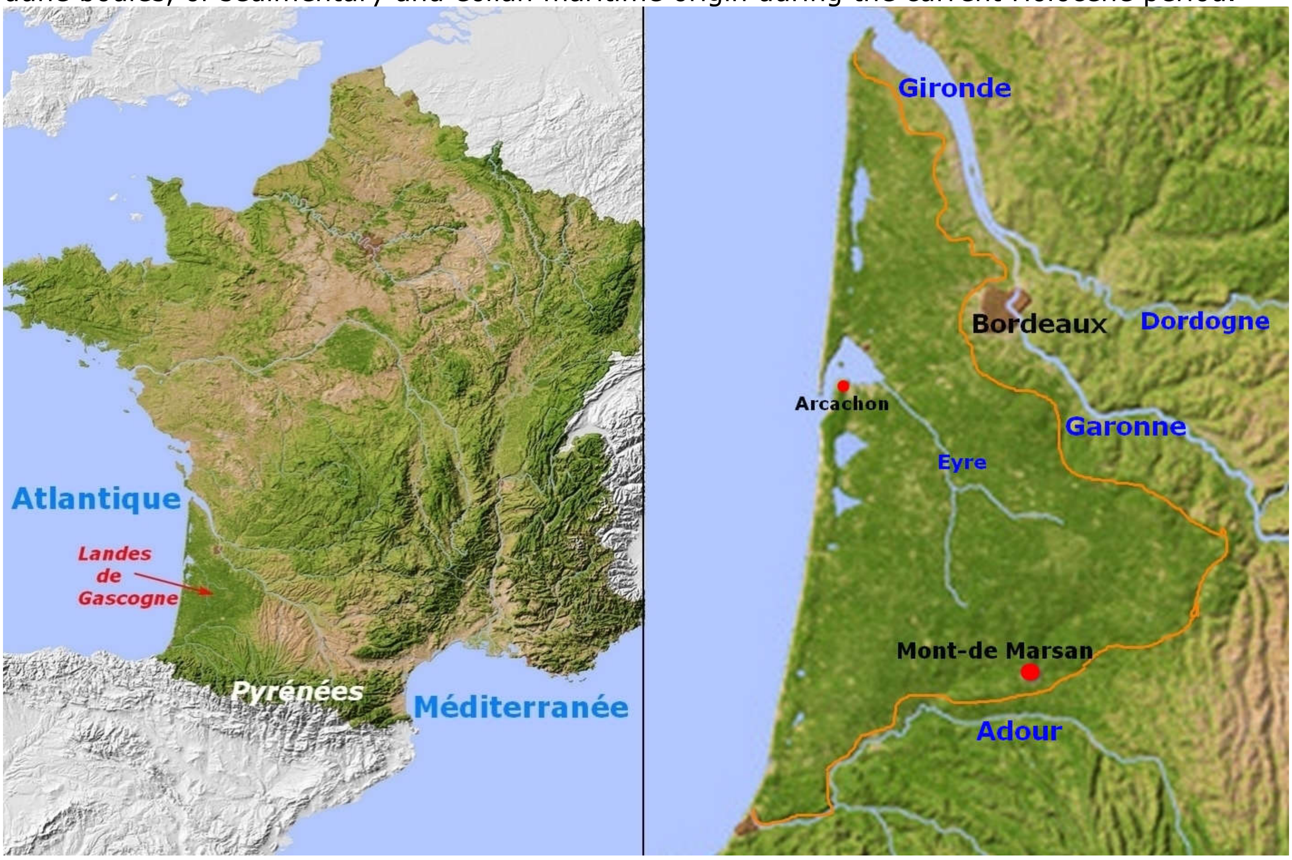


Figure 2.13: Geographical situation of the moors of Gascogne on the left. And on the right, an enlargement (Source of the oro-hydrographic and land use background: Fotolia)

Pappy (op. cit.) identifies three drainage regimes within the moors to establish three distinct areas. First, the wet moorland covers an area of about 500 kha (500,000 ha) naturally flooded for long months. It largely forms the retro-littoral interfluves and the pre-littoral gutter behind the dune formations. Its altitude varies from 30 m in the West to 150 m in the East. Then the semi-humid or mesophilic moorland borders it in the upper parts of the gently sloping valleys. Finally, the dry moorland is limited to the low and often steep part of the slopes of valleys dug by the watercourses like the Eyre or the small coastal rivers (Landes currents) which drain the

retro-littoral plateau. In the humid moorland, Pappy (op. cit.) locates a vast water table of free water close to the surface in all seasons, rarely more than 1 or 2 m deep. It undergoes seasonal oscillations of 0.5 to 2 m in amplitude according to the balances between rainfall recharge, of the order of 1,000 mm/year, and drainage by the rivers as well as evapotranspiration, the amount of which is between 650 and 750 mm/year. This water table is also continuous in the soil and subsoil over a variable thickness of 10 to 130 m throughout the natural region as considered by JOLIVET et al. (op. cit.). Despite the absence of explicit mention by the various authors mentioned above, the presence of this water table should be attributed to less permeable intercalary clays in the various Neogene and Pleistocene fluvial alluvial sequences, as well as to the slow natural drainage of the watercourses due to the low topographic gradient.
For the vegetation, the conclusions of the palynological study by FAURE and GALOP (2011) refers to a mixed, ancient and natural pine forest with birch and oak. It dominates the territory during the first half of the Holocene, until about 6 Ky BCE (6,000 years before the Current Era, i.e., BC). A mixed oak forest with pine trees, but also with a variety of deciduous species (hazel, birch, elm, lime, willow, etc.) followed. This mixed oak forest will be only slightly anthropized, in the form of an agro-forestry system until 3.5 Ky BCE, beginning of the Neolithic.

Geomorphological and soil data

On the coastal fringe in a littoral strip that can reach several km wide is inscribed a dune relief composed of the current barrier beach and ancient dunes in retreat whose appearance is like a crescent moon, sometimes parabolic, with a convex face in the leeward, sometimes barkhanoid, with a convex face exposed to the wind. MUGICA et al. (2008) present the following succession according to a decreasing age gradient from the inland to the coast:
- parabolic dunes from 3 to 1 ky BCE;
- barkhanes from 1 ka BCE until the 13th century, responsible for the formation of coastal ponds and lakes;
- parabolic dunes again from the 13th to the 17th century;
- dunes with barkhanoid crest from the 17th to the 19th century, up to 80 m high;
- current dune cordon with a height of 10 to 25 m.

A cross-section shows these major elements of Moors geomorphology in figure 2.14. Pappy (op.cit.) also specifies that the wet moorland of the interfluves is not strictly flat and presents several local formations in depression or in relief with a relatively low difference in level, such as basins constituting peaty swamps, lagoons and scattered dunes barely exceeding 2 m in height. The "lagoons" are described as round or oval pools of 10 to 80 m in diameter and about 2 m deep where carp and pike could be caught. They could be the trace of ancient ice pans formed under periglacial conditions. The modest scattered dunes are also called "rounds of fern" by the farmers of the Médoc.

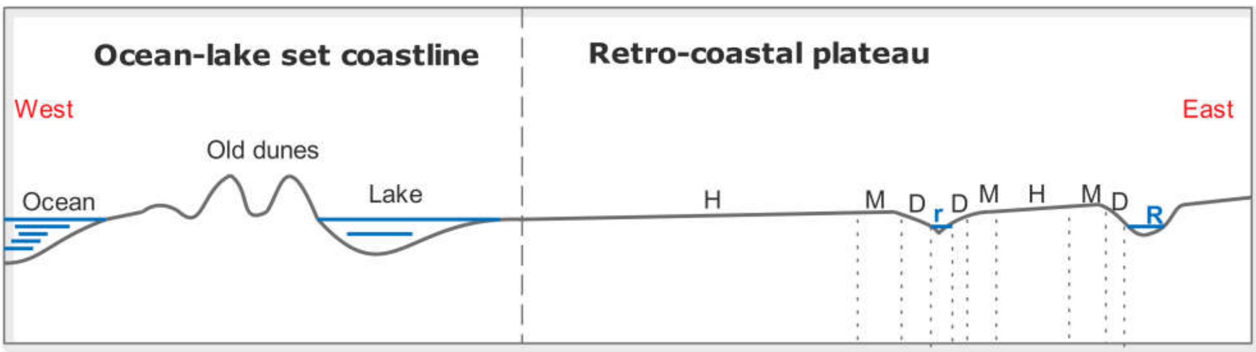


Figure 2.14: Geomorphological cross-section West-East of the moors according to two distinct sets. Legend for the retro-littoral plateau: H=wet moor, M=semi-wet moor, D= dry moor, r=stream, R=river

JOLIVET et al. (op.cit.) locate these continental micro-dunes mainly along rivers. They would be formed by aeolian contributions from the material used to dig the valleys. The same authors

also indicate the presence of a micro-relief characteristic of the moors, made up of transverse ripples of a few decimetres in height, discontinuous and forming parallel undulations largely masked by the vegetation.
Both Pappy and Jolivet et al. provide data on the natural characteristics of the soils. In the retro-littoral plateau, the soils are marked by podzolization. It consists in a migration of humic alumino-ferrous complexes under acidic conditions (acido-complexolysis). These complexes are immobilized in depth by insolubilization. The zone of accumulation of iron and aluminium as well as humic matter above is called "spodic horizon". This is favored by a temporary hydromorphy which allows the precipitation of iron in ferric form during aerobic periods. The cementing of the sand grains by the alumino-ferric constituents can then lead to an induration of the spodic horizon in the form of an "alios". The latter has a lower permeability but is not so impermeable as to cause a superficial suspension of the water table during the winter. The alios is distinguished from the "garluche" which is a hard ferruginous cuirass induced by a brutal oxidation of the water table along the most important water courses. The garluche is thus locally present only in the dry moor. When the hydromorphic conditions become longer, as in the mesophilic moorland, the ferrous-aluminous spodic horizon becomes increasingly loose and less differentiated, until it becomes completely absent in the humid moorland. The soil particle size reveals an average sand content (50 to 2000 µm) of 95%, which makes this material very filtering. The pH (H_2O) often remains below 5.0 in the first 50 cm, indicating a high proportion of aluminum on the clay-humus adsorbent complex. Areenosols (type of soil not very evolved) are representative of coastal dune sands. They are composed of more than 98% of sand and their characteristics at the level of ancient and current dunes do not consist of waterlogging, significant acidity, or differentiation of a spodic horizon. A waterlogging, however, marks the depressions between the dunes which are called "lettes". The salinity decreases as one moves away from the ocean (beach, lette, wetlands along the lakes). The water of ponds and lakes is soft.

2.5.2. Landgenic traits and characters

Historical evolution

Landgenic traits are partly inherited from the natural environment. But, they are also acquired under human influence by organization and management of the territory. The latter gives its essential phenomenic characteristics. The anthropic factor can cause more or less spectacular mutations. FAURE & GALOP (op. cit.) situate the beginning of human colonization of the moors during antiquity, around 2,500 BCE, between the end of the Neolithic and the Bronze Age. Anthropization became then permanent. The human settlement marks the beginning of a forest coexistence with agro-pastoral moors whose extension accelerates in the Middle Ages, period of strong deforestation in Europe. The deciduous forest will persist until this period. It was at this time that the agro-pastoral system was established, which preceded the current pine forest. Until the middle of the 19th century, Pappy (op. cit.) states that while the humid moorland was used for sheep grazing (Saltus), the mesophilic or semi-humid moorland and the dry moorland were used for fields (Ager, Hortus) and the "pignada" (Silva). The manure produced during the winter stabulations of the sheep was used for the fertilization of the crops. The ecomuseum of Marquèze in Sabres has reconstituted the main characters of the agro-pastoral colonization of the moors with a rural habitat organized in "airiaux". These groups were made up of several families and trades. Since the Gallo-Roman era, the pine forest has been exploited for gemmage, i.e. the harvesting of resin by bleeding the trunks. Figure 2.15 illustrates the agro-pastoral and gemmage activities as reconstructed at the above-mentioned ecomuseum. The " quarters " were groups of airiaux and the " boroughs " were real villages. It was an economy centered rather on self-subsistence with the sharing of trades in the airiaux. The lands of Saltus constituted real "commons" where the shepherds moved on stilts to watch over their flocks and keep their feet dry. The gemmage workers were first called "résiniers" then "gemmeurs" when they were unionized after the industrial revolution of the 19th century. The harvested resin was distilled to produce turpentine and rosin. However, it was used as early as the Gallo-Roman period for caulking ships.

In the agro-pastoral system, the drainage of the soil through semi-circular ditches called "crastes" and extended to the river in the flooded areas of the wet moor was practiced according to Pappy (op. cit.). It was thus a question of conquering new spaces in favor of agriculture and pine forest. JOLIVET et al. (op.cit.) also recall the history of the moorlands and its past as both agro-pastoral and agro-forestry. The clearing of the primitive mixed forest was carried out on the heads of well-drained valleys for the installation of airiaux and quarters in the mesophilic moorland as well as on the old wooded dunes of the coast.
With the proto-industrialization centered on coal and the steam engine at the end of the 18th century, the economy began a major transformation. The emergence of a working class, the intensification of trade and the development of markets initiated the enclosure movement in England, a complete privatization of land through the disappearance of grazing rights. At the end of the 19th century, this change was reinforced by a new technological revolution based on electricity, gas and oil as well as the internal combustion engine. Gemmage continued until the middle of the 20th century, when petrochemicals made it obsolete.
Saltus of the wet moorland then became archaic in the eyes of the political leaders and Napoleon III. The latter promulgated the law of June 19, 1857, known as the law of reorganization and cultivation of the "Landes de Gascogne", in order to bring the moorlands into the economic and industrial development underway. This law establishes the obligation for the communes to valorize and wood their lands or to sell them if they do not have the means.

Figure 2.15: Reconstitutions at the Marquèze Ecomuseum (Photos: Luc OPDECAMP): Saltus sheep in the airial (A), Gemmage bleeding on a pine tree (B), Ager rye field and Hortus vegetable garden (C), Millers house and bread oven in the "airial" (D)

For POTTIER (2010), this resulted in a massive acquisition of land by the girondins and moorland notables as well as massive plantations with an existing species, the maritime pine (*Pinus pinaster*). At the beginning of the 20th century, the forest massif increased from 130 to 843 Kha, of which 780 were maritime pines. Little by little, the airiaux and quarters are deserted in favor of the villages (towns) and cities.
Pappy (op. cit.) reports on the various technical difficulties and natural obstacles to drainage. These indirectly caused dramatic fires to ravage the new pine forest until a comprehensive drainage plan perpendicular to the contour lines could be effectively implemented. This plan is based on the inherited "crastes" system, completed and modified.
PAPY also recalls that the monoculture of pine trees in the wet heath has been denounced. Large agricultural areas were then established where the moor is drained and is most suitable. In case of drought, it is also possible to irrigate. Corn and fodder were used because this type of species withstands the winter rise in water. The great agriculture of Ager in the humid

moorland can be summarized for PAPY in 3 stages:
- after 1949, in Solférino and Labouheyre vast estates were created for the cultivation of corn and cattle livestock, but the latter proved unprofitable;
- from 1958 to 1968, the semi-public company for the development of the "Landes de Gascogne" cleared and rehabilitated 8,000 ha, installed infrastructures and family farming units of 70 ha, which were mostly occupied by French people returning from North Africa;
- from 1966 onwards, farmers acquired large plots of land and created estates of several hundred hectares, while traditional dry moorland agriculture was dying out. The new moorland agriculture is supported by powerful financial means. It is based on mechanization and irrigation as well as on a labor force. It covered 45,000 ha of wet moorland at the date of publication of PAPY's article, essentially devoted to the cultivation of corn. Many family farms promoted by the Moorland Management Company could not cope with the high costs of intensive exploitation. But huge corn fields still break the monotony of the pine forest today.

Agropedological data

Agropedological data are those that can be used by agronomic engineering on a territorial scale. This is a scale that exceeds both that of a parcel and most often that of a set of parcels specific to an agricultural or forestry exploitation. The scales of agropedology are typically those of landgenics (LH, LF, LI, and LS in figure 2.5) and relate in some ways to those of pedagogic "pedoscapes" or even more broadly to the concept of agropedosystems introduced by OPDECAMP (2015). Soils are no longer considered as separate natural objects, studied only for themselves. On the contrary, it is their attributes or traits that are important for agronomic purposes that are essentially studied. These traits are therefore classified technically rather than naturally.
SANCHEZ et al. (2003) have updated the latest technical soil classification, but it is already dated and has not been widely applied, probably because of the lack of a suitable scale and of communication between agronomists and soil scientists. Contrary to what the title of this technical classification would imply, it is not limited to tropical regions. In agropedology, soil characteristics are examined in their association with the general technical itineraries implemented by farmers. These itineraries are also strongly conditioned by the development of economic chains. If there are incompatibilities or prerequisites, the number of possible combinations remains potentially high enough to open up numerous "fields" of innovation.
Interactions between anthrobiotes and soils take place in the unit of vertical compartments illustrated in figure 2.4. The following traits, symbolized by the concatenation "Sage" according to the classification proposed by SANCHEZ et al. (2003, op. cit.) can be retained for most of the LH of the moorland retro-littoral plateau, whether or not there is a well-marked spodic horizon. The symbols mean in order:
- "S": sandy material to a depth of more than 50 cm;
- "a": aluminium toxicity for sensitive species but a favourable trait for tolerant species due to a probable better availability or potential assimilation of phosphorus in the presence of cationic aluminium (formation of Al-P complex ion pairs, see point 3);
- "g": waterlogging due to imperfect or inadequate drainage, but which may be advantageous for irrigated rice cultivation, for example, if the water table can be controlled and well adjusted;
- "e": a highly leachable material for ionized mineral nutrients and soluble organic compounds.
As already mentioned, the natural drainage of the plateau is insufficient and is provided naturally by rivers and streams. This natural drainage is distinguished as the crow flies by winding paths and deciduous galleries. It is enhanced by an artificial network of "crastes" connected to the natural drainage system. The four photographs in figure 2.16 illustrate the natural and artificial drainage of the moors.
JOLIVET et al. (op.cit.) specify the current silviculture technical itinerary based on improved pine varieties, systematic drainage, phosphate fertilization, thinning to a final density of 400 pines/ha and clear cutting after 35 to 50 years of growth. Productivity is estimated at 12 m^3/ha/year, but it ranges from 7 to more than 16 m^3/ha/year according to LOUSTAU et al. (1999) cited by these authors. New varieties are being considered for shorter rotations of 20-25 years and more oriented towards crushing. The production has several channels such as firewood, timber, pulp milling or even carbonization to obtain activated carbon (filtration-

purification agent).

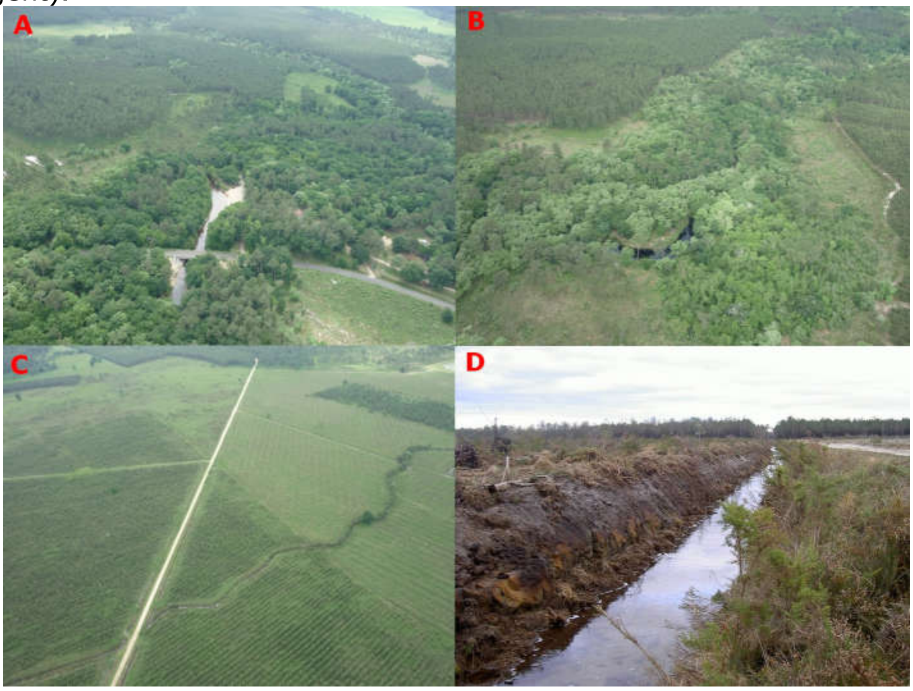


Figure 2.16: Natural drainage by streams and artificial drainage by "crastes" (Photos A, B and C by Luc OPDECAMP and photo D, copyright free, by the Lycée Louis de Foix, Bayonne): tributary of the Eyre near Pissos (A), gallery of deciduous trees along the hydrographic network (B), network of "crastes" emptying into a stream (C), "craste" ditch where an ochre spodic horizon can be seen in the vertical wall (D)

It is necessary to know that Silva of the moorland plateau is more than 90% privatized according to POTTIER (op. cit.) and that its primary function is production. It is divided into multiple parcels of land, according to the cadastral subdivisions. The age of the pine forest can vary greatly and practices can also vary, as illustrated by the photos in figure 2.17. Currently, diversification trials with Eucalyptus are also being attempted (oral communication of June 30, 2018 by Pierre COUDER, autogyro pilot and trainer at the "Le vol des aigles" flying school in Biscarosse).
As for the LF of the littoral Silva, POTTIER (op. cit.) points out that it differs from that of the plateau from the geomorphological point of view because it occupies the old dunes. It is also different from an economic and environmental point of view, since its purpose is to provide protection against the invasion of sand.
Littoral Silva also ensures a social function of reception of the public from which derives a "brand" image. Finally, it is also specific from the point of view of land ownership because it is mostly public, made up of state forests at 52%.
As a reminder, the "soil" compartment of this landscape facet is also quite distinct from that of the retro-littoral Silva of the plateau. Technically, this compartment can be symbolized by "Se" i.e. highly leachable sands according to the conventions of SANCHEZ et al. (2003, op. cit.). Several photos of the dune Silva are collected in figure 2.18.

Ager of Moorlands is oriented towards intensive corn cultivation under sprinkler irrigation with giant turnstiles of 500 to 800 m in diameter on farms of 100 to 150 ha, as illustrated in figure 2.19. This is mainly grain maize (> 90%) produced for the poultry and pig industries. The DRAAF of Aquitaine (2013) reports its increase as well as the appearance of field vegetables (sweet corn, green beans, carrots). Sprinkler irrigation has been maintained and developed because corn is sensitive to summer drought. The yields of irrigated corn (grain) reach 10 t/ha.
The cumulative areas in 2010 for the two main departments of the natural region, namely "Gironde" and "Landes", are close to 100,000 ha for corn and 20,000 ha for vegetables.

Figure 2.17: Plot diversity in the Silva of the Mooland plateau (Photos: Luc OPDECAMP): plots of very variable age (A), pine forest with an understory of young broadleaf trees (B), clear-cut plots (C), variable geometry and size of plots (D)

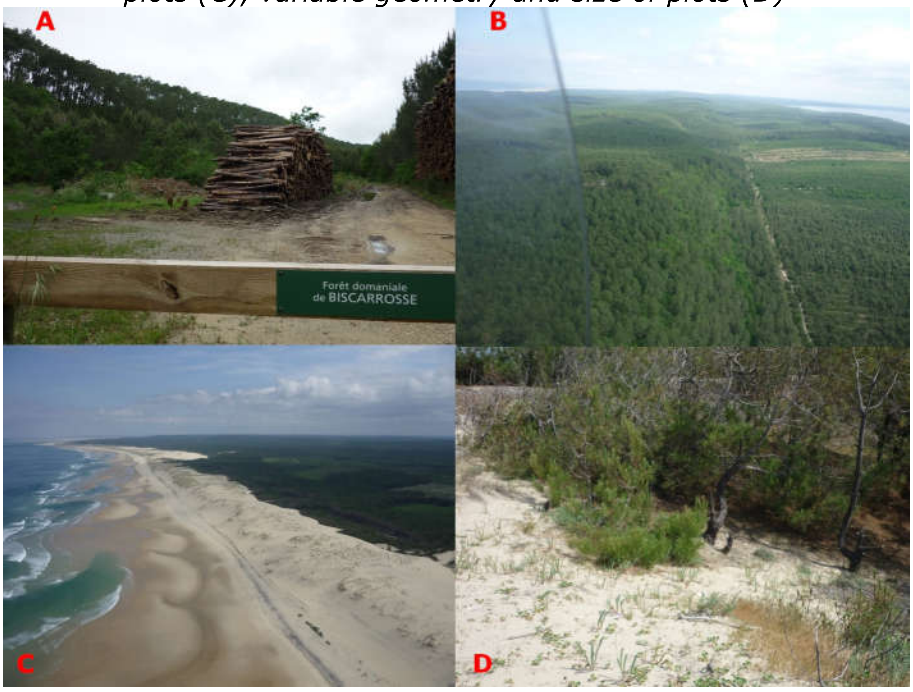


Figure 2.18: Aerial and ground views of the dunar Silva (Photos: Luc OPDECAMP): state-owned forest in the ancient dunes (A), undulations of the dune relief of the littoral Silva between ocean and lakes (B), contacts between the dunar Silva and the current dunes (C), invasion and burial tongues of the littoral pine forest in Lacanau by the sand of the current living dunes (D)

Ager in the Moors thus represents globally approximately 10% of the natural region. It is of course located in the whole of the retro-littoral plateau drained by "crastes" and not in the ocean-lake area represented in the diagram in figure 2.14. Its soil compartment is therefore represented by the same concatenation of letters "Sage" as the retro-littoral Silva, in reference to the technical classification of SANCHEZ et al. (op. cit., 2003). Concerning the easily leachable character of the sands of the moors, JUSTE et al. (1982) measured the leaching of nitrogen (nitric), phosphorus (P), potassium (K+) under fertilizer applications, as well as calcium and magnesium brought by amendment. The measurements were carried out from 1972 to 1979 in field lysimetric boxes on a 1 m thick humic hydromorphic podzol cultivated with corn. First, they observe an average drainage coefficient of 55% [mm drained/(mm precipitation + mm irrigation)], which is almost double the 20 to 30% usual in Western Europe. They also observed that the pH (H2O) of the drained water is 6.4 while the pH (H2O) of the soil varies between 5.3 and 5.0 over its 100 cm thickness, indicating exceptional deep leaching of calcium-magnesium amendments. The average percentages of leached mineral elements compared to their fertilizer or amendment inputs are 24% for nitrogen, 0.2% for phosphorus, 31% for potassium, 102% for calcium and 194% for magnesium. The LH of Ager is therefore depleted in calcium and especially in magnesium. These LH seem to be enriched in nitrogen and potassium essentially exported by the corn, as well as very clearly in phosphorus probably "fixed" in the soil compartment and partly exported at harvest.

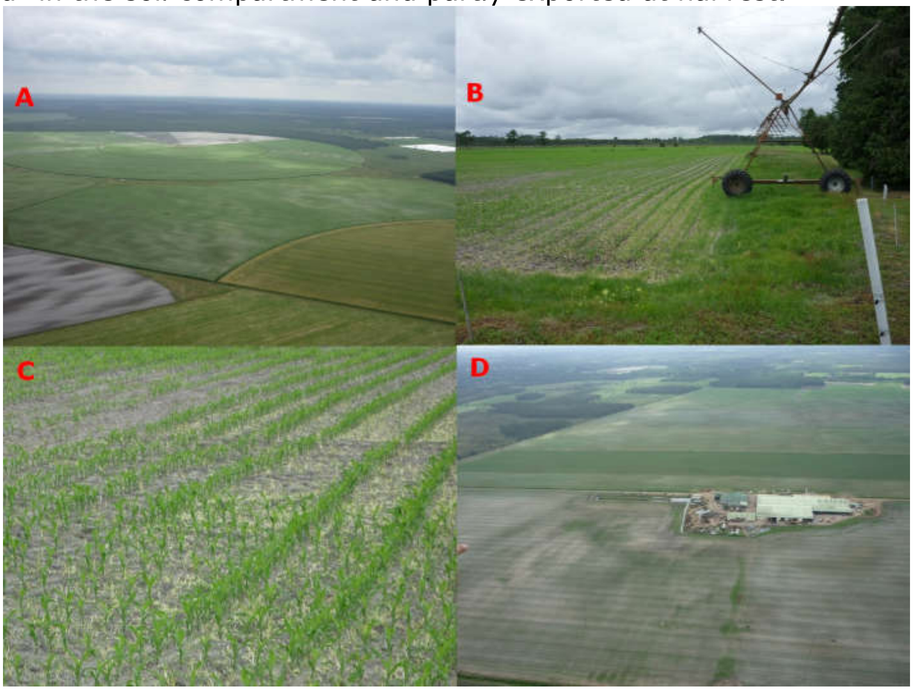


Figure 2.19: Intensive farm focused on irrigated grain corn on the moors (Photos: Luc OPDECAMP): sprinkler irrigation in rotating ramps (A), irrigation ramp at rest in young corn field (B), detail of young corn plants (C), agro-industrial buildings (D)

The present dune system of the Atlantic coast has the characters of a Desertum LF composed of several LH. MUGICA et al. (op. cit.) in their "illustration 3" distinguish the beach, the foredune, the dune cordon composed of the white dune where the oyat (Ammophila arenaria) can be fixed and the semi-fixed or "grey" dune, then the non-wooded back dune with anterior "grey" dune and lette, finally a transition with the wooded ancient dunes. It is in these LH that one can identify possible salinity traits due to contributions by sea spray and sea water bringing the electrical conductivity of the soil water in the lette above 0.4 S/m for example. In the grey lette the dune immortelle (*Helichrysum stoechas*) is resistant to this salinity.

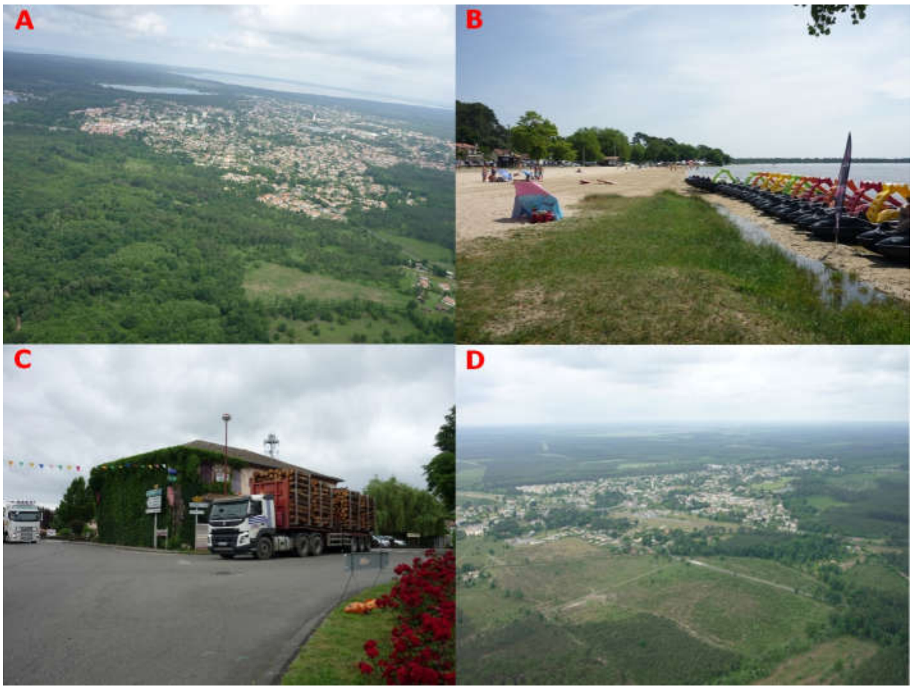
Sociological and urban data

Identification of actors and stakeholders is essential in landgenics. DEUFFIC et al. (2010) provide a partition of private forest owners according to the following three classes of relative importance:
- groups and large families hold 25% of the wooded area. They are less than 200 and own large estates of more than 500 ha according to the 2003 cadastre. Among them, less than 50 have estates of more than 1,000 ha.
- Medium-sized family properties hold 35% of the wooded area. These areas of 100 to 500 ha are held by 1,600 owners, but the forestry income they provide is generally not sufficient to make a living, a minimum of 300 to 500 ha being necessary.

- small individual or collective properties occupy 30% of the wooded area. These properties of 4 to 100 ha are about 16,500 in number. The economic interest is weak to very weak and the value is mainly symbolic. The motivations of these owners are of the order of family atavism, social mimicry (integration) and alternative savings.
The same authors also divide the owners into three groups in the face of the greening of society since the beginning of the 21st century, notably through the classification of NATURA 2000 protection zones:
- skeptics are questioning the functional and economic interest of biodiversity. For them, biodiversity is adjusted to silviculture and these owners are hostile to the idea of establishing the forest as a natural heritage;
- the supporters of ordinary biodiversity, i.e. species that are part of daily forestry practice, as opposed to extraordinary biodiversity, which concerns protected species. For example at the faunal level, they perceive certain species as harmful or destructive: deer, wild boar, insects, etc. Considering that the latter and their biotopes are already invested by naturalists, these owners are primarily interested in the biodiversity of production species in terms of landscape mosaic, age classes also at the scale of the massif. They maintain the riparian forests and the oak trees at the edge of the plots. They share with the previous group the idea that the low level of biodiversity is linked to poor soil conditions and believe that high biodiversity is associated with richer soils. Their practices are justified in the name of economic rationality. They are against regulatory frameworks for the management of natural objects.
- the promoters of integrated biodiversity believe that the work of the forester should take biodiversity into account. They advocate practices such as diversifying production species, maintaining an undergrowth, installing hardwood edges, retaining senescent trees and dead wood, etc. They hope to gain various benefits such as resistance to hazards, stand resilience and even gains in productivity. They hope to gain various benefits such as hazard resistance, stand resilience and even productivity gains.

Other important actors of the landscape of the moorlands are found grouped at the local level in villages or towns (Urbs) whose characters and urbanistic traits are associated with the LF of Aqua that are the Atlantic Ocean and the coastal lakes. We can define them as LH of ocean and lake resort such as Soulac-sur-Mer, Montalivet, Lacanau & Lacanau-Océan, Cap Ferret & Arcachon, Sanguinet, Biscarosse & Biscarosse-Plage, Parentis-en-Born, Mimizan & Mimizan-Plage, Léon, Soustons, Hossegor, Capbreton, etc. The campings often occupy important but discrete spaces. Other LH of Urbs constitute rather crossroads of road or rail communication such as Sainte-Hélène, Le Barp, Belin-Béliet, Pissos, Sabres, Labouheyre, Castets, Magesq, Roquefort, etc. Finally, we must mention the LH of cities such as Mont-de Marsan, Dax or even Saint-Médard-en-Jalles, Martignas-sur-Jalles on the periphery of Bordeaux. The local actors are shopkeepers, forestry and agricultural workers, employees and civil servants, etc. Figure 2.20 shows some illustrations of the LH of Urbs.

MORA et al. (2012, p. 113) refer also to the fundamental emergence of intercommunality, of which the "Parc Naturel Régional (PNR) des Landes de Gasogne" is an example and is indeed a territory project but of public initiative, namely the Regional Executive. This "PNR" groups together 40 communes spread over the departments of Gironde and Landes. It must contribute to policies of environmental protection, regional planning, economic and social development, training and public education. In addition, the same authors mention another type of territorial project, namely the "country" which is an emergence of participatory democracy. The "country" federates private and public actors around a development project on the scale of a living or employment area (p.114). Although the country no longer has administrative legitimacy in France following the law no. 2010-1563 of 16 December 2010 on the reform of territorial authorities, which prohibits the creation of new countries, this law does not specify the future of those that already exist. Moreover, the "countries" can be represented and managed under different legal forms: mixed syndicate of countries, association, public interest grouping, etc. (Source: Wikipedia).



<u>Figure 2.20</u>: Some types of LH of Urbs in the moors (Photos: Luc Opdecamp): Biscarosse and its coastal lakes (A), Lacanau at the edge of its lake (B), the crossroads of Pissos (C), Ychoux in the moorland plateau (D)

2.5.3. Synthesis

The delimitation of the Moors of Gascogne is based on two main natural characteristics: sandy soils from the Atlantic coast to the heads of the Garonne and Adour valleys and a flat relief broken only by the coastal dunes and the valleys of the Eyre basin. The large and fairly homogeneous area so delimited exceeds well over a million hectares, which allows it to be identified as a natural region. The sand is quickly saturated with water by rainfall or irrigation and also dries out quickly by drainage and evapotranspiration. It is easily leached of mineral elements and soluble organic compounds. The name "moorland (landes)" is inherited from the agro-pastoral and forestry history. Poorly drained " moors" dominated the region since the Middle Ages and were exploited as "common" sheep pastures, which is typical of a Saltus LF. It coexisted with a LF of Silva exploited in particular for gemmage since Gallo-Roman times and a LF of Ager in the lower parts of the slopes of the hydrographic network. They were drained and wooded with maritime pines in the 19th century, marking a major mutation from Saltus to Silva as well as a massive privatization of the pastoral "commons". The importance of the LF of Aqua is also remarkable and is declined in 4 species: ocean and lakes of the coast on the one hand and on the other hand a rather regular network of anthropic open ditches (crastes) connected to the natural hydrographic network of the retro-littoral plateau.

Littoral LH are dominated by protective Silva in former parabolic and barkanoid dunes with less differentiated soils and sometimes salt spray. All the retro-littoral LH are marked by an acidic soil pH, an exchangeable aluminum rate presumed to be higher than 50% in the first 50 cm and a marked podzolization especially when drainage improves as in the mesophilic and especially dry moors (alios, garluche). In the drained retro-littoral LF of Silva, there are large blocks of drained, irrigated, fertilized and amended LF of Ager, focused on the production of grain corn, which can yield more than 10 t/ha. The Ager LF also includes vegetable crop LH. In addition to the drainage through the "crastes", the silva LH in pine forest receive phosphate fertilization and show an average productivity estimated at 12 m^3/ha/year, ranging from 7 to more than 16 m^3/ha/year. Its chains are timber and firewood as well as pulp and activated charcoal. The critical size to live solely on forest revenues would be about 400 ha. Retro-littoral pine silva grades into deciduous streamside galleries. Urbs facets are equally distributed as is Aqua between the oceanic-lacustrine shoreline and the retro-littoral plateau. These two geomorphological complexes can be considered as the two LS constituent of the natural region also identified by POTTIER (op. cit.). Their specificity is however based not only on geomorphological and geographical traits but also on agropedological, sociological and urbanistic traits. LI in each of these 2 LS may emerge with their own phenotypes depending on the willingness of actors and stakeholders to manage potential commons.

2.6. Discussion

Landgenics is based first on a metaphor with evolutionary biology implementing the interaction between genotype and phenotype at the level of a landscape instantiation (LI), and between genome and phenome at the level of a landscape species (PS). The identification of local phenotypic traits of the seven types of "potential commons" or landgenic facets (LF) of Ager, Saltus, Silva, Urbs, Hortus, Aqua and Desertum is an essential first step to the adoption of the envisaged model. In this respect, the identification of actors and stakeholders is essential. If multiple LF of the same type are to be distinguished, the issue also arises of differentiating either multiple LI or multiple LS. Not all the LI of a LS are necessarily composed of the seven LF categories. Thus, very large urbanized territories, forests, savannahs, grasslands, steppes or deserts may be free of one or several other LF.
The cartographic representation and its regular updating using a geographic information system (GIS) are recommended to offer an easy tool for managing potential commons and thus follow their self-organization by actors or stakeholders. The intervention of researchers-developers from several disciplinary branches is necessary to elaborate such a tool in its computer design and in the identification of the "character traits" of each LI and LS in agreement with the local actors. These latter constitute the social framework of the potential commons at the level of the living environment that they must recognize with the boundaries of the corresponding LI. The traits of this local social framework alone do not define the genotype if they are not networked with other traits identified by other disciplinary branches (agronomy, geography, landscape, urbanism, etc.). Genotypic traits define one or more landgenic holons (LH) of an LF. It is therefore a matter of considering all disciplinary knowledge and know-how and extracting, selecting, translating and signifying those that can participate in the genotypic traits of the constituent LH of the LF in each LI and LS. The relevance of the genotypic trait networks selected should be estimated by statistical analysis using the GIS tool. The landgenic approach becomes then a transdisciplinary, participative and collaborative R&D with local actors. The LS can be compared to the concept of landscape unit adopted in the elaboration of departmental atlases in France as well as to the concept of landscape territory in the Walloon atlases in Belgium. However, the LS presents a greater number of topological dimensions.

Landgenics can therefore offer an advanced conceptual framework for interdisciplinary cooperation. An explanatory and prospective model can then be elaborated for both public and private approaches to innovation or territorial mutations. Adoption of an ethic of participation and approval of the actors and stakeholders would be a guarantee of success.

3. Soil aluminization

3.1. Ecoclimatic regimes of pedogenesis

Important genomic traits differentiate in soils of the landgenic holons (LH) under the action of anthrobiotes and according to variable ecoclimatic interactions between various compartments of the ecosphere as illustrated in figure 2.4 in the previous section. If the dynamics presiding over the evolution of soils are generally slow, of the order of thousands or tens of thousands of years, the traits that develop through pedogenesis are normally all the more stable in the long term. However, some processes may only take place over a few decades or hundreds of years under the influence of climatic pulses or agricultural practices such as drainage, irrigation and fertilization, or in some particular cases in only a few days (drainage of potential acid sulfate soils). Depending on the trajectories followed, various landgenic species (LS) will be developed into which the soil aluminization process will or will not be integrated. VAN BREEMEN et al. (1983) distinguish three major ecoclimatic regimes to define the orientation of the major genomic trajectories traced by pedogenesis.

3.1.1. Arid and semi-arid highland regime

A first regime is that of the arid and semi-arid upland LH. It is marked by a predominance of evapotranspiration over precipitation and by good drainage conditions. Uplands are terraces of more or less ancient fluvial sediments that are elevated above the current stream banks in such a way that the vadose zone exceeds two meters. Vadose zone is defined by the thickness between the soil surface and the top of a water table at any time of year. The soil of upland terraces may have traces of fossilized hydromorphy in the vadose zone; these terraces will also be considered upland. In the considered regime, the balance between input and output of mineral elements in the soil tends towards a positive surplus, i.e. towards an accumulation. Mineral inputs come from headwater runoff, precipitation or irrigation water. If divalent cations (Ca^{2+}, Mg^{2+}) dominate the monovalent ones (Na^{+}), they precipitate as carbonates and the pH (H2O) remains below 8.5. If, on the other hand, sodium alkali cations dominate, sodium carbonate precipitates and the pH can rise above 9. This last case can occur in case of irrigation with inappropriate water. No aluminization of soils occurs in such a regime.

3.1.2. Lowland regime with current hydromorphy

The second regime is that of lowland LH with current, temporary or permanent hydromorphy. It also concerns the current sediments of amphibious LH of Aqua of littoral mangroves.

Lowland with temporary hydromorphy

Aerobic and anaerobic phases follow one another in temporary hydromorphy. Such a regime causes a sequence of oxidation and reduction reactions. The reduction reactions generate reduced compounds with ions such as ferrous iron Fe^{2+} and sulfides S^{2-}, while the oxidation reactions generate ferric iron Fe^{3+} and sulfites or sulfates. This regular alternation can, however, induce marked alkalinization or acidification reactions of the soil compartment in LH depending on the degree of hydrological confinement. In confined continental environments forming closed hydrological basins, the reduction of concentrated sulphate salts under semi-arid to arid climate on the one hand, and the microbial decomposition of organic matter on the other hand, generate sulphides and carbon dioxide which dissolve into bicarbonates and carbonates during the hydromorphic phase. In the dry phase, sulfides can be evacuated by volatilization (H_2S) as well as carbon dioxide from bicarbonates. This is not the case for carbonates which precipitate first with divalent cations (Ca^{2+}, Mg^{2+}). Then, when the pH increases, in parallel with the concentration of salts, sodium carbonate precipitates in its turn: this is the formation of salty soils with alkalis as described by CHEVERRY (1969) on the northern shores of Lake Chad. JANITZKY & WHITIG (1964), quoted by VAN BREEMEN et al. (op. cit.), have reconstructed the mechanisms in the laboratory, with reference to the saline soils of the Sacramento Valley in California. The latter authors explicitly involve the anaerobic microbial decomposition of organic matter and the presence of sodium sulfates. Such biogeochemical alkalinization processes are also outside the context of soil aluminization. They are in the opposite trajectory of their acidification.

Lowland with permanent hydromorphy

Acidification can be followed by rupture of a permanent hydromorphic regime in the case of drainage of Aqua's LH during the rice cultivation of mangroves, for example, or that of LH with hydromorphic soils in fluvio-maritime lowlands.

3.1.3. Highland regime in humid or sub-humid climate

Finally, an acidification trajectory is also taken under the third ecoclimatic regime of pedogenesis cited by VAN BREEMEN et al. (op. cit.), namely that of well-drained uplands where rainfall exceeds evapotranspiration.

3.2. Landgenic pathways of soil acidification

Soil acidification pathways are those taken by upland or lowland soils in humid and sub-humid climates. In lowlands and even in arid or semi-arid climates, LH soils of Ager, Saltus, Silva or Aqua facets can also acidify. If uplands are well drained, in lowlands water stagnates on the surface or at a shallow depth to form wet LH in LF (landscape facets).
The thickness of the vadose zone can thus reach several meters (at least two by convention) or decameters in upland. On the other hand, in lowlands the thickness of the vadose zone can vary from none during flood periods to a few decimeters or meters during low-flow periods. If the lowlands of the continental LF are drained in the direction of the longitudinal profile of the depressions where the surface water flows (LH of Aqua), they are not confined from the hydrological point of view. In the opposite case of hydrologic confinement, LH exhibit an Aqua facies at least during some period of the year. Without confinement, drainage of the uplands and lowlands occurs naturally through the Aqua streams . Figure 3.1 illustrates the two major land types in unconfined areas.

Figure 3.1: Distinction of uplands and lowlands and generally associated properties for drainage (Photo: Çağlar OSKAY - Unsplash*)*

Two main types of reactions regularly generate protons in the soil of well-drained LH in upland areas: root and microbial respiration and nitritation of ammonium by bacteria of the genus Nitrosomonas. Nitritation is followed by nitration by bacteria of the genus Nitrobacter. These reactions occur also in the LH of lowlands, but at a slower rate. But in the sediments of Aqua such as the bottoms of ponds and rivers as well as in those of alluvium and fluvio-maritime sediments, an accumulation of sulphides of bio-organic and/or mineral origin (seawater) and ferrous iron (II) can be an important source of acidification in case of drainage or polderization: these are the reactions of oxidation of iron sulphides (pyritic) and of ferrolysis. The physico-chemical and topo-hydrological traits of LF soils or sediments will significantly determine the dominant processes of the ecosphere's LS and the acidification pathways. It is important to take into account that these processes take place in open or semi-open systems (hydrological confinement) that constitute the LH and that chemical and biochemical reactions to which they refer therefore only reach temporary stationary equilibria. The possible equilibrium constants will therefore only be given as an indication of trends.

3.2.1. Root and microbial respiration

Root and microbial respiration produces carbon dioxide which dissolves into carbonic acid in the soil water. The dissociation of this weak acid produces protons. The reactions occur as follows:

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ **(R01)**
$CO_2 + H_2O \rightarrow H_2CO_3\ pK_1=1,46$[1] **(R02)**
$H_2CO_3 \rightarrow HCO_3^- + H^+\ pK_2=6.35$ **(R03)**
$HCO_3^- \rightarrow CO_3^{2-} + H^+\ pK_3= 10.33$ **(R04)**

Values of pK_1, pK_2 and pK_3 are those given by BOLT & BRUGGENWERT (1976) at 25°C. Rainwater contains dissolved carbon dioxide in the form of H_2CO_3 and HCO_3^- at a pH of 5.6. It corresponds to a CO_2 partial pressure of 0.3 millibars[2] (0.03%, 300 ppm) according to the above-mentioned authors, whereas in soil water this partial pressure can rise to 100 millibars (10% or 100,000 ppm) under the root system. The **R04** reaction can be neglected under acidifying conditions in the absence of carbonate minerals in the soil. In such a simplified H_2O-CO_2 system, with a steady respiratory flow of carbon dioxide (open system), the chemical reactions **R01** to **R03** establish the following relationship between soil water pH and carbon dioxide partial pressure (pCO_2):

$$pH = 3,9 - 0,5 \log pCO_2$$

Figure 3.2 shows a graph of this.

If carbonate minerals are present (limestone, dolomite, etc.), they will be progressively dissolved by hypogeous respiration and evacuated by leaching (open system). An order of magnitude of the intensity of this respiration in the soil is deduced from a literature review by SINGH and GUPTA (1977): 10 to 40 t/ha/year of CO_2. Other measurements carried out in a Silva LF under a humid temperate climate, published by THIERRON and LAUDELOUT (1996), report higher values: 70 t/ha/year, 90% of which is of root origin.

The partial pressures of O_2 and N_2 in the soil will decrease in depth to the benefit of the CO_2 pressure, which can rise to 100 millibars. In the water table, the dissolved CO_2 (H_2CO_3 and HCO_3^-) will be transferred to the AQUA river that drains the watershed according to the diagram in figure 3.3. At this point, the dissolved CO_2 will return to equilibrium with its atmospheric partial pressure which is much lower (0.4 millibars). This results in a degassing and thus an emission in the atmosphere by inversion of the direction of the reaction **R02**. BORGES et al. (2015a) report pCO_2 values in river water from 12 sub-Saharan African watersheds. These values range from 300 to 16,942 ppm for an overall average of 6,415 ppm, which is still well above the 400 ppm of rainwater. Levels are higher in small tributaries (width < 100m) than in large ones (width>100m), which is consistent with upstream-downstream degassing. There are, however, new inputs through the decomposition of suspended organic matter from hydromorphic lowlands. The waters of the Congo River are described as "black"

1 pK = - log K, ainsi if pK = 1,46, then $K = 10^{-1,46}$
2 At the pressure of 1 atmosphere corresponds approximately 1 bar, that is to say 1 kg/cm2, that is to say a column of 10 m height or 1.000 cm of water on 1 cm2 , which represents 1.000 cm^3. Therefore, 0.3 cm^3 (0,3 millibars) in this column or this unit "atmosphere" represents a height of 0.3 cm or 0.03% or 300 ppm or 0.3 millibars of partial pressure. 10% is equivalent to 100 millibars or 100,000 ppm.

with an acidity that varies from pH 3.6 to 5.9 with an average of 4.4.

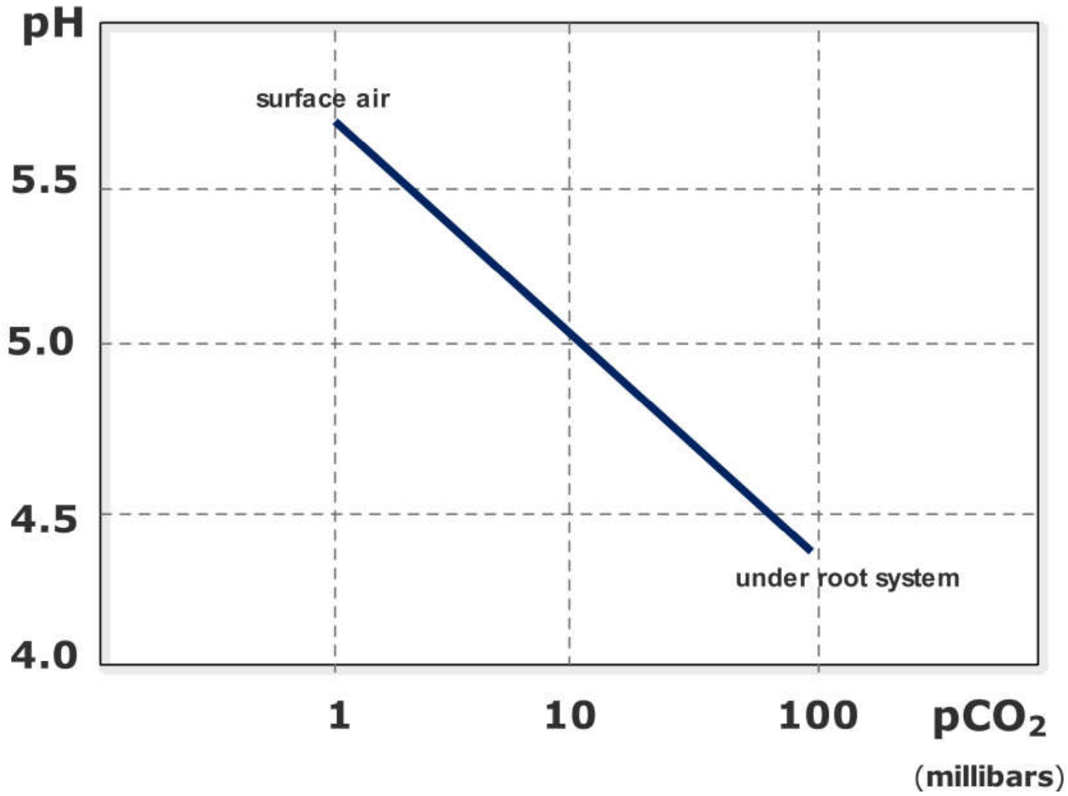


Figure 3.2: Evolution of soil water pH as a function of carbon dioxide partial pressure generated by root and microbial respiration in the absence of precipitated carbonates (simplified system)

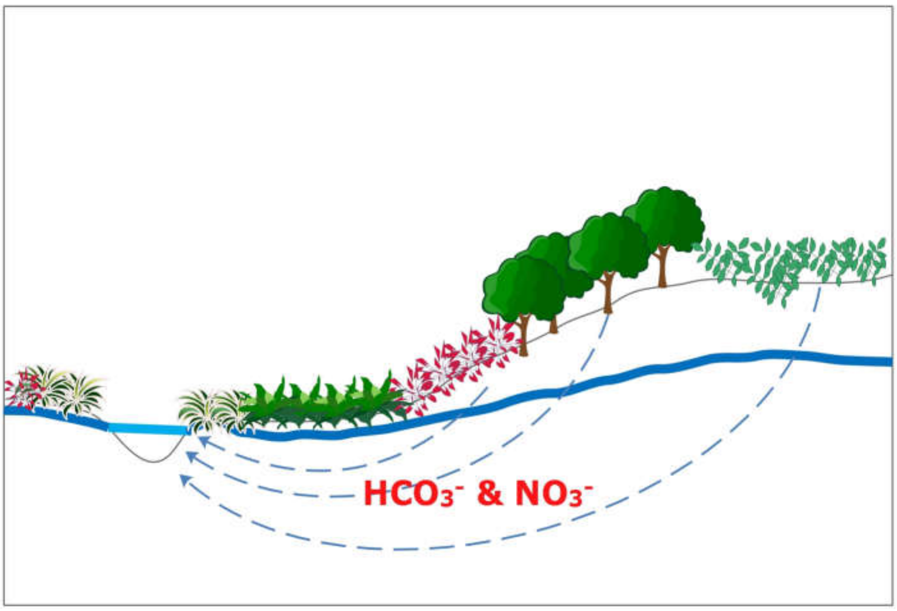


Figure 3.3: Transfers of soil water and its anions from hypogeous biorespiration and biological nitrogen oxidation from soil to a river by groundwater drainage

In another publication, BORGES et al. (2015b) compare CO_2 partial pressure data from the two largest tropical rivers the Amazon (n=136) and the Congo (n=280). Ranges from 0.07 to 16.88 millibars and 1.09 to 22.9 millibars, respectively, are observed. A significant contribution from the wet lowland LH is diagnosed but could not be quantified.

FUJII et al. (2012) describe and detail the various processes of soil acidification. They also state that the rate of acidification is proportional to net primary production and give an order of magnitude of 0.004 to 0.010 mol_c of proton per mole of organic carbon produced.

3.2.2. Ammonium nitrification

Autotrophic nitrification is a biological oxidation of ammonium into nitrate which is evacuated by drainage (figure 3.3). It consists of two successive phases, nitritation or nitrosation by bacteria of the *Nitrosomonas* group and nitration by bacteria of the *Nitrobacter* group (DOMMERGUES and MANGENOT, 1970). The two reactions are written as follows:

$$2\ NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 4\ H^+ + 2\ H_2O \quad \textbf{(R05)}$$
$$2\ NO_2^- + O_2 \rightarrow 2\ NO_3^- \quad \textbf{(R06)}$$

and so globally:

$$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + H_2O + 2\ H^+ \quad \textbf{(R07)}$$

This results in the production of two protons per molecule of ammonium oxidized into nitrate. Several sources of ammonium inputs to the soil are recognized: mineralization of organic matter, nitrogen fertilizers and stormwater.

Ammonium inputs by mineralization of organic matter

Ammonium can be derived from the mineralization of soil organic matter and more precisely from the ammonification of proteins by microbial deamination (**R08**):

$$R\text{-}NH_2 + H_2O \rightarrow R\text{-}OH + NH_3 \quad \textbf{(R08)}$$

and ammonia dissolves in water to form the ammoniac which dissociates into ammonium:

$$NH_3 + H2O \rightarrow NH_4OH\ (NH_{3\ aqueux}) \rightarrow NH_4^+ + OH^- \quad \textbf{(R09)}$$

Ammoniac dissociation is low but is promoted in the soil by the uptake of ammonium by plants, its adsorption to the soil exchange complex and by its nitrification (**R07**) whose acidifying effect is thus mitigated by the dissociating of OH^- (**RO9**).

Ammonium inputs from nitrogen fertilizers

Ammonium can also be provided by fertilizers such as ammonium sulfate, whose acidifying effect is well known. For urea, on the other hand, DOMMERGUES and MANGENOT (op. cit.) mention a hydrolysis by the enzyme urease which produces ammonia and carbon dioxide after an intermediate carbamate stage:

$$CO(NH_2)_2\ [\textit{urea}] + H2O \rightarrow COO(NH_2)(NH_4)\ [\textit{carbamate}] \rightarrow 2\ NH_3 + CO_2 \quad \textbf{(R10)}$$

It is a rather alkaline reaction since two molecules of NH_3 are produced and thus 2 OH^- (**R09**) per molecule of urea. On the other hand, the subsequent nitrification of nitrogen and the increase in the partial pressure of carbon dioxide are acidifying, as seen above. Long-term acidifying effects of urea have been demonstrated by LUNGU & DYNOODT (2008).

Ammonium inputs to stormwater

Atmospheric ammoniac comes from its volatilization from wild or livestock excrements and from the application of fertilizers in the form of urea. In Congo, MEYER and DUPRIEZ (1959) observed an input of 2.9 kg/ha/year of ammoniacal nitrogen. BRINKMANN (1983) reported a value of 1.8 kg/ha/year in an Amazonian forest. VAN MIEGROET & COLE (1985) measured an input of 1.5 kg/ha/yr in a forested site under a temperate oceanic climate 56 km SE of Seattle. More recently, HUANG et al. (2014) cite nearly 10 kg/ha/yr in the forested Fengxingzhuang watershed in subtropical China.

3.2.3. Oxidation of iron sulfides

VAN BREEMEN et al. (op. cit.) identify a possible significant production of iron sulfides in nearshore marine sediments and tidal flats. They are produced by reduction of sulfates from seawater and accumulate as pyrite (FeS_2) in sediments and soils over several centuries. Such fluvio-maritime LH materials are referred to as "potential acid sulphate soils" in case of drainage or reclamation.
SHAMSHUDDIN et al (2004) also specify that the formation of pyrite requires the presence of Fe^{3+}, organic matter and micro-organisms. The latter are sulfate-reducing bacteria whose remarkable "*capacity to use mineral compounds of sulfur as electron acceptors for the oxidation of carbon compounds*" is underlined by GARCIA and ROGER (2000). These two last authors speak thus about "*respiration of the sulphates*" in the "*biotopes rich in organic matter, such as the bottom of the ponds, ponds, water courses, in the fluvio-marine sediments, the zones of estuary*". Under such anaerobic conditions, they attribute to the sulfate-reducing microflora about 50% of the decomposition of organic matter with production of sulfides.
In case of drainage of "*potential acid sulfate soils*", the oxidation reaction of pyrite is presented as follows according to SHAMSHUDDIN et al. (2004, op. cit)

$$2\ FeS_2 + 7\ O_2 + 2H_2O \rightarrow 2\ Fe^{2+} + 4\ SO_4^{2-} + 4\ H^+ \quad (\mathbf{R11})$$

These authors observe a drop in pH from 6 to 3 in the laboratory with a sample of the Cg horizon (hydromorphic parent material) of a "*potential acid sulphate soil*" (after 2 weeks of incubation) and which is maintained at this level during the entire 6-week experiment. For the prolonged exondation of mangrove swamps in the fluvio-marine domain of the lower Casamance in Senegal, MOUGENOT et al. (1990) indicate a strong and brutal acidification of the soils, i.e. from pH 7 to pH < 3 in a few days. These authors consider that this process is irreversible.

3.2.4. Ferrolysis

Reduced iron (II) is a constituent of many primary minerals and thus plays a major role in their weathering. CHURCHMAN & LOWE (2012) indicate that it is easily oxidized to Fe (III) when the soil dries out, for example as a result of the pyrite oxidation reaction (**R11**). This would result in charge imbalances facilitating its hydrolysis. The iron would then precipitate in the form of secondary oxides or hydroxides of which there are amorphous or nanocrystalline forms that persist. This phenomenon is known as "ferrolysis". ESPIAU and PEDRO (1983) have studied experimentally the oxidation phase of ferrous iron which they schematize by the following reaction:

$$2\ Fe^{2+} + 1/2\ O_2 + 5\ H_2O \rightarrow 2\ Fe(OH)_3 + 4\ H^+ \quad (\mathbf{R12})$$

Ferrolysis will be re-examined in the context of aluminization itself.

3.2.5. Acidification observed at several levels of scale

At the scale of two LH (landgenic holons) of the same LF, VAN MIEGROET & COLE (op. cit.) compared two contiguous plantations of forest species, one of red alder (LH n°1, *Alnus rubra*) and the other of Douglas fir (LH n°2, *Pseudotsuga menziesii*) on the same initial acid forest soil. The two LH have indeed an identical forest history and have been differentiated by stand species for 50 years. The alder plantation is rich in nitrogen, which can be attributed to its capacity to fix atmospheric nitrogen by root actinorrhizae with *Frankia* (actinomycete), whereas the fir plantation is poor in nitrogen. A more pronounced acidification of the soil is observed under alders (pH 4.8) compared to firs (pH 5.2). The results of the soil nitrogen content confirm the relative richness of the two plantations and its obvious influence on the soil water effluents measured in 1981 and 1982. Nitrates dominate bicarbonates under alders while they remain absent under firs. Nearly 99% of the protons of internal or external origin are neutralized in the surface soil in both plantations before 30 cm depth, which underlines the buffering capacity of the soil over the short pedogenetic term of only half a century.

In the LF of Silva in the United States of America (temperate forests), following clear-cutting, proton production by nitrification is reported by FUJII et al. (op. cit.) to be of the order of 11 $kmol_c$/ha/year. Higher values are mentioned by these authors for Amazonian deforestation. The same authors also report that agricultural conversion of forest lands causes a positive net proton balance through mineralization of organic matter and subsequent nitrification at the humus Ap horizon (see their Fig. 8b). If the organic carbon deficit reaches 20% compared to the "natural" cover, SANCHEZ et al. (2003) attribute a penalty to the potential fertility of the soil (symbol "*m*").
On a global scale of all LS (landgenic species), BRUNNER & SPERISEN (2013) synoptically present three maps related respectively to the pH of acidic (pH 4.6 to 5.5) and very acidic (pH below 4.5) soils at the surface from 0 to 30 cm (their Fig. 1A), to the pH of acidic and very acidic soils at depth from 30 to 100 cm (their Fig. 1B) and to the density of forest cover (their Fig. 1C). It is remarkable to observe the correspondence between dense tropical, temperate or boreal forest areas of the planet and acidic soils. Moreover, it also appears that forest soils seem more acidic at the surface than at depth, at least at the tropical or equatorial level. However, soil acidity is not limited to Silva, as it extends well into the Saltus savannah shrublands. The very small scale of these globalized data thus produces a kind of cartographic scheme. It is in good conformity with the dynamics of the acidification processes of biological origin reviewed.

3.3. Landscape trajectories of soil aluminization

There are two complementary conceptions of the soil aluminization process that have in common the acidic environment in which it takes place. The first is mineralogical aluminization as used by LANSON et al. (2015) or VIENNET (2015). The second is the physico-chemical aluminization as used by DUFFEY (2002). Both designs are aimed at fine and colloidal fractions of soils. Mineralogical aluminization is marked by the acid hydrolysis of aluminum from soil minerals and its fixation in the expandable sheets of clays such as vermiculite or montmorillonite in the form of hyxo-polymers to form hydroxy-aluminous and interstratified minerals of varying degrees of regularity. The physico-chemical conception is based on the very strong competitive behavior of the monomeric cationic form of aluminum [Al^{3+} or $Al(OH)^{2+}$] for the cationic exchange sites of clays as well as on its power of complexation of organic exchange sites. Aluminization takes place in the continuity of the acidification trajectories of soils and also in those of their pedogenesis at the intimate micro- and nanometric levels.

<u>3.3.1. Acid hydrolysis of primary minerals</u>

Landgenics only becomes meaningful when living organisms colonize a territory or cross it, leaving traces. Its most significant fact is the birth of a soil. It occurs as soon as the hard or loose parent rock is colonized by living organisms on the surface such as microbes, lichens, mosses, plants, insects, etc. This colonization triggers and develops the cycles of carbon and nitrogen drawn from the atmosphere and simultaneously the cycles of phosphorus, potassium, sulfur and almost all the mineral elements extracted by hydrolysis of the embryonic regolith, whether it is indigenous or allochthonous. Acid hydrolysis is marked over time by what WYNS et al. (2014) refer to as subtractive weathering at the regolith level. CHURCHMAN & LOWE (op. cit.) do not mention the biological reactions of root and microbial respiration or even those of nitrification in the hydrolysis of primary minerals. They do, however, suggest an acidic environment at the colloidal clay-humus surfaces of soils during pedogenesis. Formation of regolith by subtractive alteration also produces macro-, meso- and micro-pores in addition to secondary clay minerals (argilization) and also secondary oxides and hydroxides (Fe, Al, Mn, etc.). From the mineralogical point of view, the typical alteration profile will concentrate on the surface the less soluble elements in the transformed or neoformed secondary minerals and the primary minerals resistant to hydrolysis, while at depth the mineralogical composition approaches that of the geological bedrock (primary minerals). Vertical progression of porosity is critical to the retention and drainage of water from the forming soil. CHADWICK & CHOROVER (2001) thus specify that water fluxes condition the evolutionary trajectory of soil weathering. They illustrate this fact by a climosequence in Hawaii in the same lava flow of

170,000 years of age over a long distance through a rainfall gradient ranging from 160 to 3,000 mm/year. They observe that the annual rainfall limit of P=1,400 mm corresponds to a profile leaching threshold over 1 m depth. Beyond this threshold, there is a desaturation of "basic" cations, Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}, in the whole thickness. Below this level, the leaching only produces its effects at less than 1 m, i.e. a vertical redistribution of the cations takes place and thus induces only limited leaching. The authors conclude that it is the effective humidity that favors the acidification of the profile rather than the duration or time above this threshold. The threshold of 1,4000 mm/year has only a contextual value: it can vary according to the age and type of bedrock of the soil. The concepts listed in box 3 are used by these authors to define this threshold in more universal terms as the ratio between the effective wetting depth (V) and the effective porosity (Vo).

Box 3. Concepts of effective moisture and effective porosity used by CHADWICK & CHOROVER (2001)

Effective annual soil moisture = P-PET (PET: potential evapotranspiration)
Effective wetting depth = V (based on effective annual moisture)
Total porosity = [microporosity + mesoporosity + macroporosity] at 1 m depth
Effective porosity = Vo = [total porosity - microporosity] on 1 m depth
Microporosity = % water volume at 15 bars (1.500 kPa) on 1 m depth
If V/Vo=1, then there is just enough P to fill all mesopores and macropores on an annual basis.
When V/Vo=2, all meso- and macropores will have been completely flushed (filled 2 times/year).

Some representative primary or pseudo-primary minerals at the start of a trajectory or new pedogenetic trajectory are briefly described in table 1 based on data from CHURCHMAN & LOWE (op. cit.).
From the chemical compositions of the sample reproduced in table 1, the origins of the mineral nutrients that are base cations, phosphorus and sulfur in soils are thus illustrated in a non-exhaustive way. The most abundant mineral elements constituting the solid framework of soils are silicon, aluminum and iron. The primary minerals as such are considered as a reserve of alterable minerals in soils. It is an indicator of the degree of evolution. It goes without saying that during any vertical or lateral movement of dissolved mineral or organic elements, the cations "give way" to anions among which nitrates and bicarbonates in the first place.

3.3.2. Clays and weathering products

Chemical weathering of bedrock combines dissolution and hydrolysis reactions of primary minerals. The residual solid products of a dissolution are of the same nature as before the reaction when the dissolution is incomplete, while they differ from the initial compounds in case of hydrolysis. The products of hydrolysis are called secondary minerals and include amorphous minerals and clays more or less well crystallized. Argilization is a major process associated with the hydrolysis of primary minerals, which in turn may extend to secondary minerals by aggradation and degradation. CHURCHMAN & LOWE (op. cit.) report, for example, the successive alteration products of a typical group of primary minerals as reproduced in Box 4.

Development of adsorbent or exchange complex

Argilization allows the soil to acquire simple or networked traits such as:
- bonds with humus to form the clay-humus complex
- development of a cationic exchange capacity or "CEC",
- considerable increase of the specific surface.

A higher CEC allows more cations to be retained on the surface of the adsorbent or exchange complex. Negative charges can be permanent or variable with pH. The permanent ones result from isomorphic substitutions in the octahedral or tetrahedral layers of aluminosilicates. The variable ones according to the pH are located on the one hand on the surfaces of hydroxylated or oxy-hydroxylated minerals with crystalline or amorphous character and on the other hand on the carboxyl and hydroxyl groups of humus. The variable charges can also become positive under certain physico-chemical (pH) and mineralogical (oxides and oxyhydroxides) conditions, in which case an anionic exchange capacity develops (pH below the zero charge point).

Table 1. Quelques minéraux primaires ou pseudo-primaires représentatifs

Group	Name	Composition	Note
tectosilicates	quartz	SiO_2	omnipresent
	orthose, albite	$KAlSi_3O_8$, $NaAlSi_3O_8$	alkaline feldspars
	plagioclases	$Na_xCa_yAlSi_zO_8$	calc-sodium feldspars
phyllosilicates	muscovite	$KAl_2AlSi_3O_{10}(OH)_2$	mica, dioctahedral
	biotite	$K(Mg,Fe^{II})_3AlSi_3O_{10}(OH)_2$	mica, trioctahedral
	chlorite	$(Fe,Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$	weak metamorphism
	antigorite	$Mg_3Si_2O_5(OH)_4$	serpentine
inosilicate	hornblende	$(Ca,Na)_{2,3}(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$	amphibole
	augite	$(Ca,Na)(Mg,Al,Fe)(Si,Al)_2O_6$	pyroxene
nesosilicate	forsterite	Mg_2SiO_4	olivine
cyclosilicate	tourmaline	$(Na,Ca)(Li,Mg,Al)(Li,Fe,Mn)_6(BO_3)_3Si_6O_{18}(OH)_4$	rare
phosphate	wavellite	$Al_3(PO_4)_2(OH,F)_3.5H_2O$	marine sediments
carbonate	calcite	$CaCO_3$	rather soluble
	dolomite	$CaMg(CO_3)_2$	rather soluble
sulfate	gypsum	$CaSO_4$	very common
iron oxide	magnetite	Fe_3O_4	ubiquitous
iron sulfide	pyrite	FeS_2	coastal sediments

Box 4. Example of successive alteration products by hydrolysis of olivines, pyroxenes and amphiboles after CHURCHMAN & LOWE (op. cit., 2012)

olivines pyroxenes amphiboles	---- - Mg^{2+},Fe^{2+},(Mn^{2+}) ---->	serpentine, chlorite, et/ou talc	------->	smectite (trioctahedral), + goethite, saponite

Buffering capacity against acidification

It has already been pointed out that the presence of carbonates constitutes a buffering power against acidification as a result of their dissolution. CHADWICK & CHOROVER (op. cit) make an analogy between hydrolysis and an acid-base reaction where the primary minerals first and then the secondary minerals also constitute a buffering capacity which they designate by "ANC" (Acid Neutralizing Capacity). They adopt a similar analogy for primary minerals but where the buffering capacity is provided in some way by salts of silicic acid (H_4SiO_4) and the corresponding appropriate cation. The following example illustrates this ability to reduce or slow down acidification by hydrolysis of primary minerals:

$$2\ KAlSi_3O_8\ [\text{potassium feldspar}] + 9\ H_2O + 2\ H^+ \rightarrow$$
$$Al_2Si_2O_5(OH)_4\ [\text{kaolinite}] + 4\ H_4SiO_4 + 2\ K^+ \quad \textbf{(R13)}$$

Amorphous aluminum

Amorphous hydroxy-aluminum products can appear from the initial stage of hydrolysis of primary minerals. Hence, KAWANO & TOMITA (1996) observe a precipitation of amorphous aluminium hydroxide on the surface of a slightly altered potassium feldspar on samples taken from a granitic rock of the island of Yakushima (small island in the south of Japan). It can be considered that this is already a particular form of mineralogical aluminization. Amorphous aluminum is also associated with other alteration products such as gibbsite and halloysite. The authors conclude that amorphous aluminum is probably formed in the early phase of alteration of potassium feldspars and then transforms into gibbsite as alteration progresses. In previous works, the same authors (KAWANO & TOMITA, 1994) had already identified an initial amorphous aluminic or alumino-silicic phase but this time from sodium feldspar (albite). It

would be amorphous polymers with indefinite stoichiometry.
Amorphous aluminum first and gibbsite thereafter play a role in the buffering capacity or "ANC" of CHADWICK & CHOROVER (op. cit), their solubility increasing with acidification:

$$Al(OH)_3 \text{ [gibbsite]} + 3\ H^+ <-> Al^{3+} + 3\ H_2O \ \textbf{(R14)}$$

The relationship is thus established between the Al^{3+} concentration and the pH:

$$-\log_{10}(Al^{3+}) = 3\ pH - \log_{10}K$$

The solubility of aluminum hydroxide is inverse to its crystallinity. Thus, the pK values quoted by the authors vary from -10.8 (amorphous polymer) to -8.11 (crystalline gibbsite) or from -9.23 to -7.69 according to BOLT & BRUGGENWERT (op. cit.).
The graphical translation is shown in figure 3.4.
The observations of KAWANO & TOMITA (op. cit.) and this graph argue for the control of aluminium solubility by an amorphous phase generated from the early stages of weathering of primary minerals. CHADWICK & CHOROVER (op. cit.) also underline the role of alumino-organic complexes in solid phase in the control of the solubility of aluminium. Kinetics of the secondary neoformations would favour in the first place the precipitation of the amorphous phases which would be the least stable from the thermodynamic point of view: it is the rule of OSWALD (1897). This is how amorphous aluminum polymers are "neoformed" first, which would then be transformed (very slowly) into gibbsite more stable from the thermodynamic point of view.

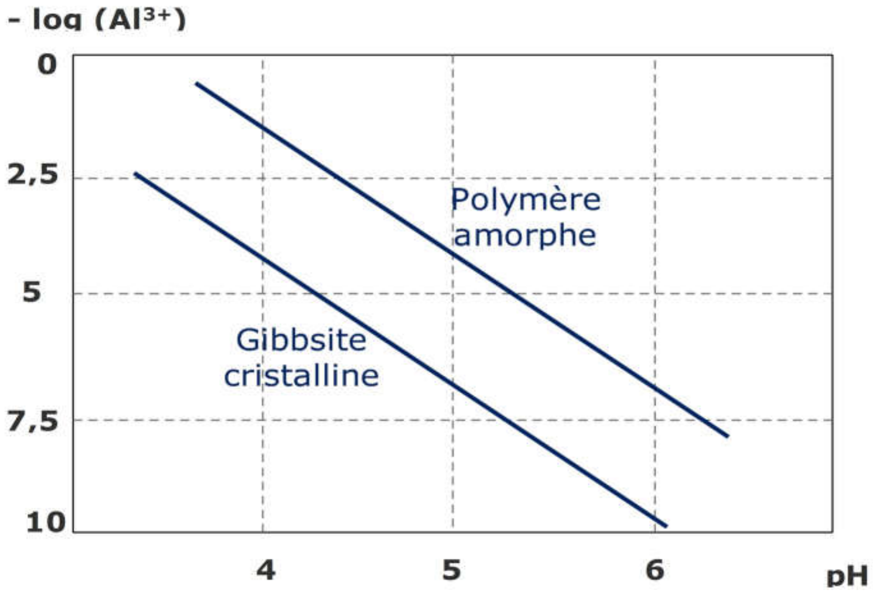


Figure 3.4: Solubility (at equilibrium) of aluminum from gibbsite and amorphous hydroxy-polymers

Amorphous iron

The oxidation phase of ferrous iron in the ferrolysis reaction (**R12**) seen in section 3.2.4. was studied experimentally by ESPIAU and PEDRO (op. cit.). They examined the effects of alternating and repetitive treatment of natural or Ca^{2+} saturated montmorillonites with ferrous lactate as well as kaolinite-Ca for 1 to 2 days. The treatment then includes an air drying for 12 days. This alternating treatment is repeated 14 times in a row. They observe an acidification of the solution to a "buffer" value as well as a disappearance of iron from the solution in the following increasing order: reagent alone (16 ppm) < kaolinite (30 to 36 ppm) < montmorillonite (56 ppm). The retained or precipitated iron far exceeds the CEC and Ca^{2+} exchanged with the solution, indicating its fixation in a ferric hydroxy-polymerized form in accordance with the **R12** reaction. An exchange acidity develops on the adsorbent complex, essentially of protonic nature and very little aluminic. The authors consider however that their experimentation corresponds only to a fast phase whereas ferrolysis under natural conditions is slower and leads to a progressive aluminization of the clays. The aluminized 2:1 minerals can then evolve towards intergrades of pseudo-chlorite type by agradation with a layer of aluminium hydroxy-polymers (hydroxy-aluminic interstratified).

3.3.3. Physico-chemical aluminization

Aluminization is both mineralogical and physico-chemical as previously indicated. It takes place in the context of a coexistence and a reciprocal equilibrium between, on the one hand, amorphous and more or less crystalline forms of aluminium and, on the other hand, cationic forms in solution and on the exchange complex of the soils. Physicochemical aluminization is a process by which the basic cations of the adsorbent complex are displaced in solution by exchange with cationic aluminum [Al^{3+}, $Al(OH)^{2+}$]. It is hypothesized here that this process is driven by depolymerization of amorphous aluminum hydroxypolymers as acidification proceeds. It is supported by observations reporting the aluminization process both in the presence and absence of gibbsite. Moreover, aluminium interacts with organic matter, phosphorus and iron.

Aluminisation rate or "m" Kamprath index

The sum of the exchangeable basic cations, extracted by 1N ammonium acetate or chloride, and the exchange acidity constituted by the monomeric cationic aluminium and the protons extracted together with 1N potassium chloride defines the effective cation exchange capacity (ECEC). The rate of aluminization can thus be expressed by the index "m" of KAMPRATH (1967) which is the percentage of saturation of the net negative charges of the adsorbent complex occupied by the cationic aluminium. These notions are translated by the relations of formulated in the box 5.

Box 5: Effective exchange capacity and aluminization index

$$ECEC = (Ca^{++} + Mg^{++} + K^{+} + Na^{+}) + (Al^{3+} + H^{+})$$

$$m_{\text{(Kamprath index \%)}} = 100 \times Al^{3+}/ECEC$$

Aluminization induces a leaching or a lateral evacuation of the base cations that accompany the bicarbonates and nitrates represented in figure 3.3 and a progressive saturation of the adsorbent complex by aluminum. The rate of soil aluminization progresses with acidification in accordance with the graph shown in figure 3.4. Three key thresholds of correspondence are proposed by OPDECAMP (1997) as indicated in table 2.

Table 2. Relation between 3 pH thresholds and the Kamprath index of soil aluminization (Source: OPDECAMP, 1997, op. cit.).

pH (H_2O) of soil	Kamprath index "m" (%)
> 5,5	0
5,5 à 5,0	0 to 50
< 5,0	> 50

The aluminization process would thus be initiated by acidification as soon as the pH (H2O) of the soil falls below 5.5. The degree of precision can be roughly estimated at 0.5 pH units. Thus, CHADWICK and CHOROVER (op. cit.) make this process start effectively at a pH of 5.5 but it is rather at a pH of 4.5 that they locate the threshold of 50% aluminization.

Amorphous polymerized forms

The appearance of amorphous aluminum as a primary hydrolysis product of feldspars has been demonstrated by KAWANO & TOMITA (op. cit.). Moreover, OSWALD's (op. cit.) rule of stages establishes the early precipitation of amorphous mineral phases compared to crystalline ones. It is therefore relevant to support the hypothesis that if acidification progresses fast enough below pH (H2O) 6.0 or 5.5, amorphous aluminium may depolymerize in favor of the physicochemical aluminization of the adsorbent complex rather than continuing to crystallize as gibbsite or as the octahedral layer of a secondary interstratified. The strength of the buffering capacity and the hydrolysis kinetics would then be determining the type of evolution. Amorphous aluminium polymers mentioned in the literature present a positive charge under acidic conditions and are thus "hypohydroxylated". They correspond to various possible formulae such as $Al_{13}O_4(OH)_{24}^{7+}$ according to AKITT et al.(1972), quoted by BACHE & SHARP (1976) or $Al_6OH_{15}^{3+}$ and $Al_8OH_{20}^{4+}$ according to BROSSET et al. (1954) and MATIJEVIC et al. (1961) quoted by RICHBURG & ADAMS (1970). The generic formulation of the depolymerization of amorphous aluminum under acidifying conditions is therefore proposed as follows:

$$Al_n(OH)_s^{(3n-s)+} + s\,H^+ <-> n\,Al^{3+} + s\,H_2O \quad (\mathbf{R15})$$

Aluminization in the presence of gibbsite

An illustration of the aluminization process is provided by the analytical data reproduced in table 3. These are analytical results from the agricultural chemistry laboratory of the Institut des sciences agronomiques du Burundi (ISABU) from samples taken from several LH (landgenic holons) of test plots at the Institute's experimental station in Gisozi at high altitude. This sequence of soil aluminization profiles is developed on a "peneplaned" surface at an average altitude of about 2,100 m. It is a pseudo-plateau of a few kilometers in width. It forms an internal and irregular meso-relief with several levels of flatness. The surrounding landscape instance (LI) presents a hilly relief. Its composition is largely dominated by a Saltus LF consisting of natural pastures with *Eragrotis olivacea*. These are exploited as rangeland for cattle. However, the summit parts generally form an LF of Ager in LH of subsistence food crops (banana, pea, corn, sweet potato) and locally in LH of tea plantations. Woodlands also dot this space in a mosaic of Silva LH, especially on plateau or ridge tops. A general view of this type of LI is shown in figure 3.5.

Table 3. Ten profiles of increasing aluminization in the ISABU station of Gisozi in Burundi (Source: OPDECAMP, 1988a).

Prof. (cm)	P01 (m%)	P02 (m%)	P03 (m%)	P04 (m%)	P05 (m%)	P06 (m%)	P07 (m%)	P08 (m%)	P09 (m%)	P10 (m%)
7	2	6	25	18	59	49	70	75	89	86
20	5	5	33	21	59	65	73	74	86	86
33	3	9	19	18	34	53	66	77	91	73
46	7	14	8	16	13	37	68	75	87	61
59	12	16	7	16	22	21	63	68	86	72
72	6	13	6	17	11	20	61	78	79	74
85	9	10	7	18	11	20	57	75	80	84
98	9	10	4	14	16	21	52	79	77	78

Many LH often have a deep, dark horizon in the soil showing surface reworking by ancient colluvial input, implying that the soils of other LH have undergone erosive stripping of relative rejuvenation. Beneath this dark horizon is identified as a heavy red to dark red clay containing about 70% particle size clay. A lighter superficial material can be differentiated with a clay content of about 55%. The soils of the aluminization sequence are deep, well drained and said to be " humiferous " because they are impregnated with organic carbon with contents that can exceed 2% over a depth of nearly one meter.
The pH (H2O) varies from 5.7 to 4.4 and ECEC remains between 7.61 cmolc/kg and 0.67 $cmol_c$/kg depending on the aluminization gradient and the depth of the samples taken. In other words, the ECEC decreases as aluminization progresses, just as it decreases in each profile from the surface to the depth. The mineralogical composition of the clays was determined at the time by X-ray diffraction in the laboratory of the "Centre d'études des sols tropical" of the Faculty of Agricultural Sciences of the Catholic University of Louvain in Louvain-la-Neuve

(Belgium). The results indicate that kaolinite and gibbsite dominate the clay fraction throughout the sampled thickness of the soils. The third most important mineralogical species is a thermally unstable chlorite, i.e. a mineral at 14 angström or 1.4 nanometres, non-swelling and destroyed at a temperature lower than 550°C. Such an interstratified mineral is typical of the mineralogical aluminization mentioned above. Presence of goethite and hematite is also detected in most of the samples as well as occasionally another non-swelling interstratified of illite-vermiculite type. Finally, amorphous aluminium "Al_{ox}" contents ranging from 0.64 to 2.24% and amorphous iron between 0.70 and 1.63% are measured after extraction with acid oxalate (pH 3) in the same 10 aluminization profiles reproduced in table 3. The coexistence of gibbsite and amorphous aluminum hydroxypolymers is thus diagnosed throughout the aluminization process.

Figure 3.5: Facets and LH of Saltus, Ager and Silva near Gisozi in Burundi (Photo: Luc OPDECAMP)

Aluminization in absence of gibbsite

In the west of Brazil, the Javari River marks the border between Brazil and Peru and flows into the Amazon near the town of "Benjamin Constant". MARQUES et al. (2002) observed high Al^{3+} contents, extracted with KCl N, of 7 to 18 $cmol_c/kg$ in the superficial horizon (0 to 20 cm) of two soils S1 and S2 of a highland LH (terrace) and a soil S3 of another lowland LH in "recent" alluvium located in the major bed of the Javari River, in a marshy area of an old river meander. The pH (H2O) in S1, S2, and S3 are between 4.4 and 4.7 and the aluminization rate between 50 and 80%. On the other hand, in the soil of two other sites S4 and S5 of a third LH developed in an alluvial levee at the edge of the current course of the Javari River, the pH is higher than 6.0 and there is no extractable Al^{3+}, the physico-chemical aluminization rate being thus null. Everywhere, in the superficial horizon of the five soil sites examined, the ECEC is quite high, in the range of 12 to 22 $cmol_c/kg$. These values are in agreement with the presence of smectite (2/1 swelling clay) in the mineralogical composition of the soils. A smectite-based hydroxy-aluminum interstratified is also present in the fine clay fraction (<0.2 µm) and thus testifies to mineralogical aluminization prior to physicochemical aluminization. The X-ray behavior of the interlayered material is characterized by incomplete swelling after glycerol treatment and incomplete contraction after heat treatment. Kaolinite is also present but no gibbsite. Vermiculite and chlorite are detected in the third LH soil in S4 and S5. The sandy fraction in the two upland soils S1 and S2 is almost exclusively composed of quartz. In site S3, the low sand content does not allow the examination of this grain fraction. On the other hand, primary minerals such as feldspars, mica and chlorite are present in the two sites S4 and S5 of the present alluvial levee, which would confirm their less advanced degree of alteration than the other soils. However, the authors consider that the high aluminization rates of soils S1, S2 and S3 are overestimated and that the extraction reagent (KCl) would include hydroxylated aluminum from the hydroxy-aluminum smectite interlayer. KCl-extracted aluminum would indeed not correlate with its activity in soil solution. They rely on the absence of "serious" symptoms of aluminium toxicity in LH from pastures and plantations in S1 and S2 and in cassava in S3. However, several authors quoted by ROBARGE & COREY (op.cit.) claim that aluminium hydroxypolymers are not extractable by a neutral salt like KCl N. The absence of Al^{3+} in the Ager LH (maize) soil in S4 and S5 would be due to a much less acidic pH, greater than 6. The absence of crystallized gibbsite does not, however, exclude the hydroxylated aluminum in the interbed as its pseudoamorphic and early form in S4 and S5 or persistent in S1, S2 and S3.

Interactions of aluminization with phosphorus

The ten sites of the Burundi aluminization profiles at Gisozi described in table 3 were the subject of another sampling. This consisted of surface samples between 0 and 15 cm of masses of about 500 kg of soil, homogenized and sub-sampled in four composites of 100 samples at a rate of a few grams per sample. They are subjected to a new analytical characterization. The aim is to obtain a sufficient volume of soil to carry out growth tests in vegetation vases in order to study the effects of aluminization on different cultivated species and varieties. Analyses performed include ECEC and exchangeable aluminum to establish aluminization rates as well as two types of phosphorus extractions. "Olsen-Dabin Phospore" is obtained by extraction with a mixed solution of $NaHCO_3$-NH_4F and "Total Phosphorus" by extraction with a mixture of strong acids HNO_3-H_2SO_4. The results are shown in figure 3.6.

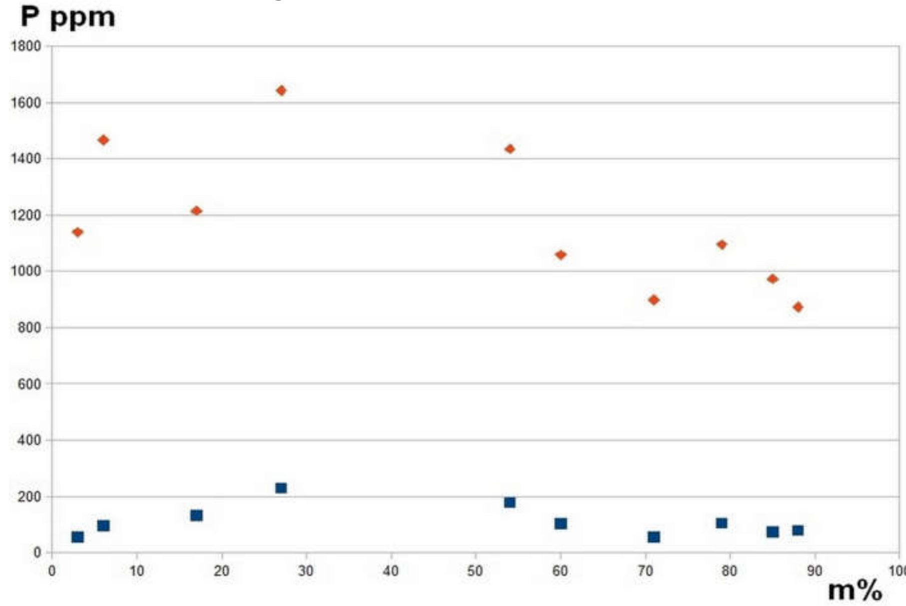


Figure 3.6: Distribution of "total" (diamonds) and "Olsen-Dabin" (squares) phosphorus contents in the aluminization sequence of Gisozi (Burundi) from the results of OPDECAMP et al. (1988)

Evolution of the "total phosphorus" content and that of the "Olsen-Dabin phosphorus" content both show a similar pattern, marked by an increase at the beginning of aluminization up to a threshold rate between 30 and 40%, then by a decrease in this content beyond this threshold rate. The latter corresponds experimentally to a pH(H2O) of 5.0. This behavior of phosphorus in the Gisozi sequence is similar to that observed by ROBARGE & COREY (op. cit.) with an ion exchange resin saturated with cationic aluminum. The aluminized resin is neutralized at

different rates by adding a base [NaOH or $Ca(OH)_2$] in pre-calculated quantities. Then phosphorus is added in the form of NaH_2PO_4 or $Ca(H_2PO_4)_2$. The authors observe an increasing then decreasing affinity of the resin for phosphorus. They highlight a progressive "hydroxy-polymerization" of the aluminum on the resin as the pH increases and thus develops an increasing capacity of adsorption of phosphorus by the treated resin. However, beyond a certain pH, a competition starts between the hydroxyl ions OH^- and the monophosphate ions $H_2PO_4^-$, to the detriment of the latter. The opposite would occur during acidification and aluminization in Gisozi soils, but the increasing then decreasing trend of phosphorus contents would be comparable to that obtained in the laboratory on resin.
The affinity and instability of bonds between phosphorus and the surfaces of oxides or oxyhydroxides of aluminum (NH_4F extraction) and iron of the adsorbent complex is confirmed in the conclusions of SALJNIKOV & CAKMAK (2011). These authors even consider that "aluminophosphorus" compounds can migrate in depth and supply the other reservoirs or extractable fractions of phosphorus. Therefore, in view of the similar evolution of total phosphorus in figure 3.6, it is relevant to assimilate amorphous aluminic hydroxypolymers to intermediate forms towards phosphorus fixation on gibbsite and thermally unstable pseudo-chlorite (or aluminized vermiculite). An amorphous iron intermediate phase is also plausible towards attachment to hematite and goethite for Fe-O-P bonds. Furthermore, amorphous Fe and Al phases as intermediates with crystalline phases are in agreement with the rule of OSWALD (op. cit.). This rule of thumb was confirmed by direct observation by high-resolution electron microscopy of a "nanocrystallization" of $LiFePO_4$ at 450°C by CHUNG et al. (2009) from an amorphous powder preparation. Several phases or metastable transient stages have indeed appeared requiring as many corresponding activation energy levels to finally obtain a stable crystal structure.
The hypothesis put forward here is therefore that the hydrolysis of primary minerals into secondary minerals such as gibbsite or hydroxy-aluminum interlayers passes through an early amorphous phase intermediate of hydroxy-aluminum polymers that control aluminization in the acidification pathways of soils. This intermediate phase would inherit primary phosphorus to adsorb it and form "Al-P complexes". Phosphorus would adsorb more at the expense of hydroxyl anions up to a pH (H2O) of 5.0 below which aluminization would progressively destroy these Al-P complexes by depolymerization.

Interactions of aluminization with soil organic matter

BLOOM et al. (1979) confirm that it is not a simple hydroxide that controls the activity of aluminium in humus-bearing horizons of acid soils, with or without gibbsite, because they obtain a slope of less than 3 between the activity of aluminium in soil solution and pH, such as the one represented in figure 3.4. The slope obtained by these authors is in fact between 1.7 and 2.36 depending on the 0.02 N salt solution used (KCl, NaCl, $CaCl_2$, $MgCl_2$, $CuCl_2$ or $LaCl_2$). The same phenomenon is observed with a forest peat saturated at 100% or 80% by aluminium with respective slopes of 2.09 and 1.64. Furthermore, the addition of leaf humus has the effect of reducing the activity of aluminum in solution, which could result from an increase in organic CEC (carboxyls). Organic aluminum (Al_{org}), which is also exchangeable, thus naturally constitutes a significant fraction of the aluminum in humus horizons of acidic (pH<5.5) or very acidic (pH<5.0) soils, next to the precipitated amorphous phase aluminum (Al_{am}).
An important adsorption of phosphorus ($H_2PO_4^-$) is observed experimentally by BLOOM (1981) on a forest peat saturated at 80% by aluminium. Besides the formation of humic complexes, the possibility of generating an amorphous "pseudo-variscite" is also mentioned. Here are two reactions among others proposed by the author which could explain the phenomenon:

$$R(COO)_3Al + H_2PO_4^- <=> R(COO)_3AlHPO_4^{2-} + H^+ \quad (\mathbf{R16})$$

$$R(COO)_3Al + H_2PO_4^- + 2H_2O <=> R(COO)_3^{3-} + AlH_2PO_4(OH)_2 + 2H^+ \quad (\mathbf{R17})$$

For additions of limited amounts of phosphorus, between 4 and 20 µmol under the experimental conditions adopted, this adsorption decreases very significantly when the pH of the peat suspension is lowered below 5.5. On the other hand, if the pH of 5.5 is raised, phosphorus adsorption tends to decline only slightly. A similar[3] but less pronounced pattern than that observed in figure 3.6 in the Gisozi sequence is thus found. The author concludes that organic aluminium (Al_{org}) contributes with amorphous inorganic aluminium (Al_{am}) to phosphorus retention in humus-bearing horizons of acid soils. He also reports that acidic ammonium oxalate simultaneously extracts both forms of aluminum in soils (Al_{ox}):

$$Al_{ox} = Al_{org} + Al_{am}$$

The significant role of organic matter and amorphous aluminium in phosphorus adsorption is confirmed by HAYNES & SWIFT (1989) with samples of peat and humates saturated with aluminium. Their liming with $Ca(OH)_2$ up to pH 5.5 and 7.0 causes a clear increase in the phosphorus adsorption capacity. However, an experimental amorphous aluminium preparation develops a significantly higher capacity. The combination of organic and inorganic amorphous aluminium also protects phosphorus from being bound to crystalline hydroxides and oxyhydroxides and increases the buffering capacity against acidification. But this association can also reduce the potential sites of phosphorus adsorption. The results are presented in the form of adsorption isotherms which do not allow a fine interpretation of phosphorus adsorption as a function of pH (3.5 - 5.5 - 7.0).
Finally, in 86 samples of humus-bearing horizons of highly acidic sandy and sandy-loam soils [pH(H2O) 4.0-4.2 and m% 47-56], collected from LH in Silva in mountainous central Poland, GRUBA & SOCHA (2016) obtain a good correlation between exchangeable Al^{3+} and organic carbon content. This is an illustration of physicochemical aluminization of an adsorbent complex of essentially organic nature. The exchangeable aluminum is obviously firstly organic amorphous aluminum (Al_{org}) up to 56%, extracted with $CuCl_2$, and also comes from mineral amorphous aluminum up to 44%. These respective percentages refer to the total amorphous aluminum extracted with ammonium oxalate (Al_{ox}). It should be noted that from the mineralogical point of view there are, however, very small quantities of kaolinite (>5%), the rest being quartz and traces of hematite and which develop practically no significant ECEC.

Interactions of aluminization in acid sulfate soils

According to WANG et al. (2000), organic, exchangeable and hydroxy-adsorbed aluminium represent on average 25% of the total aluminium in a series of present-day acid sulphate soils that these authors subjected to sequential fractional extraction. They consider that these forms are the most active during the aluminization of these soils by a strong and fast acidification. FRINK (1973) also reports the existence in acid sulphate soils of several forms of aluminium such as the long-lasting persistence of hydroxy-aluminium compounds more soluble than gibbsite, including several species of amorphous polymers as well as complexes with organic matter and phosphorus. He also reports the mineralogical interfoliar aluminization of vermiculite and montmorillonite (pseudo-chlorites, interstratified). Moreover, he cites a basic mineralogical species, namely the crystalline hydrated aluminium sulphate with the formula $Al_4(OH)_{10}SO_4.5H_2O$ and called "basaluminite". FRINK (op. cit.) also reports at least three buffer levels when an acid sulfate soil is subjected to liming. The first is at the most acidic pH and he attributes it to exchangeable "free" protons or protons in solution, the importance of which is specific to acid sulfate soils. The second buffer plateau during liming is centered on a pH of 5.0 and extends to pH 5.5-6.0. It corresponds fairly well to the neutralization of the first stage of aluminum hydrolysis whose pK corresponds precisely to 5, according to the following reaction:

$$Al^{3+} + H2O \leftrightarrow Al(OH)^{2+} + H^+ \quad (\textbf{R18})$$

Finally, a third lime neutralization buffer plateau is located above pH 6. It is attributed to the weakly acidic groups of humified organic matter ($R\text{-}OH + OH^- \rightarrow R\text{-}O^- + H_2O$). These groups constitute pH-dependent negative charges (and artificially increase the CEC of acid soils when measured at pH 7 with ammonium acetate).
SHAMSHUDDIN et al. (1986) demonstrate the formation of jarosite [$KFe_3(SO_4)_2(OH)_6$] and natrojarosite [$NaFe_3(SO_4)_2(OH)_6$] in conjunction with the oxidation of pyrite (**R11**) in two

3 the curve is inverted because the author doses the phosphorus in equilibrium in the solution rather than the adsorbed phosphorus

coastal soils of the Malaysian peninsula. A strong physicochemical aluminization is measured at pH below 4.0. Gibbsite is present as well as kaolinite, mica and smectite. Titration with KOH shows a buffering capacity at pH 3-4 attributed to aluminium and not to iron, whose content is very low. Jarosite and natrojarosite do not participate in the buffering capacity, these minerals being stable.
ELISA et al. (2016) indicate a wide extension of acidic, pyritic sulfate soils of pH<3.5 in Malaysia. These soils are almost exclusively located on the peninsular coastline. The authors report physico-chemical aluminization in rice-growing LH. What is remarkable is that they present a surface sample (0-15 cm) of such a LH with a pH(H_2O) of 2.9 and an aluminization rate that is certainly significant (36%) but remains moderate. This soil sample develops a ECEC of 11.71 $cmol_c$/kg and an exchangeable aluminium concentration of 4.26 $cmol_c$/kg. Neither the results of SHAMSHUDDIN et al. (op. cit, 1986) nor those of ELISA et al. (2016) suggest an intervention of amorphous organic or inorganic aluminum in the aluminization of Malaysian acid sulfate soils. Yet, carboxyl groups "-COOH" of humified organic matter could act as exchange sites between H^+ and Al^{3+} under the highly acidic conditions involved according to this reaction:

$$3\ R\text{-}COOH + Al^{3+} \leftrightarrow (R\text{-}COO)_3Al + 3\ H^+ \quad (\mathbf{R19})$$

This hypothesis involves Al_{org} and also explains the buffering capacity of the first neutralization level by a base quoted by FRINK (op. cit.) and which should be able to initiate an aluminic (re)hydroxy-polymerization at low pH (reference to a reversed **R15** reaction of the type:

$$n\ (COO)_3Al + s\ KOH \rightarrow Al_n(OH)_s^{(3n-s)+} + 3n\ \text{-}COO^- + s\ K^+ ...$$

3.4. Recap and discussion

Landgenic holons (LH) of uplands and lowlands under humid and subhumid conditions, as well as those of coastal lowlands under semi-arid or arid conditions, evolve under the biological forcing of soil acidification by root and microbial respiration, by nitrogen nitrification, or by the development of potential acid sulphate soils via the sulphate-reducing microflora in the LH of the maritime littorals. The latter undergo a brutal acidification of a few days or weeks in case of artificial drainage, especially for the development of rice-growing LH.
Pedogenomic traits of holons undergo profound modifications marked by loosening of parent rocks, increase of pore volume and specific surface, alteration of primary or pseudo-primary minerals, incorporation of humified organic matter, and argilization. Clays are inherited by microcrystalline reorganization and/or neoformed from hydrolyzed elements in the evolving soil solution. Mineralogical and physicochemical aluminization are essential processes during acidification. Amorphous aluminium "Al_{am}" in the form of hydoxy-polymers as well as organic aluminium "Al_{org}" in the form of humus complexes are most active as soon as acidification progresses below pH (H_2O) 5.5-6.0. These are the probable first steps of the OSWALD rule (op. cit.). These two aluminium species could inherit the primary phosphorus towards which they show a particularly significant adsorption capacity. Amorphous iron would have a similar behavior but its relative activity would be more significant in wet lowland where it is generated by ferrolysis. During the physico-chemical aluminization, the cationic species of aluminium "Al^{3+}" progressively saturates the adsorbent complex to the detriment of the base cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) carried away by vertical or lateral leaching. The latter is mainly done with bicarbonates and nitrates produced by biological acidification.

CHADWICK and CHOROVER (op. cit.) provide a graphical representation of the evolution of soil buffering capacity (ANC, Acid Neutralizing Capacity). It is a kind of synthesis of the weathering and aluminization processes according to an acid-base reaction model. Figure 3.7 is a reproduction translated and adapted by the addition in red of the form of aluminium extractable to the oxalate "Al_{ox}". This last one groups the amophilic form "Al_{am}" and the organic form "Al_{org}". The authors specify that the shape of this curve can vary from one soil to another according to the nature and quantity of the minerals present as well as the dissolution and hydrolysis kinetics. This is why the pseudo-buffer stages are different here from those cited by FRINK (op. cit.) in an earlier paragraph. The three plateaus of CHADWICK and CHOROVER are that of carbonates at pH 8.3 first, then of hydroxylated (polymerized) aluminum and finally of hydroxylated iron (e.g., goethite FeOOH) or Al_{org} as suggested in acid sulfate soils (reaction **R19**). Bauxite landscapes, composed of "$Al(OH)_3$" hydroxide polymorphs and iron-aluminum oxides, are generally mineralized as shown in figure 3.8. The iron hydroxide buffer stage is rather rarely encountered in nature because of the very acidic conditions it implies. These exist in the LH of the fluvio-marine littoral where jarosite is formed, which would be quite stable. On the other hand, rather than an acid-base reaction model, iron oxides and oxyhydroxides are produced by a redox reaction model via ferrolysis.

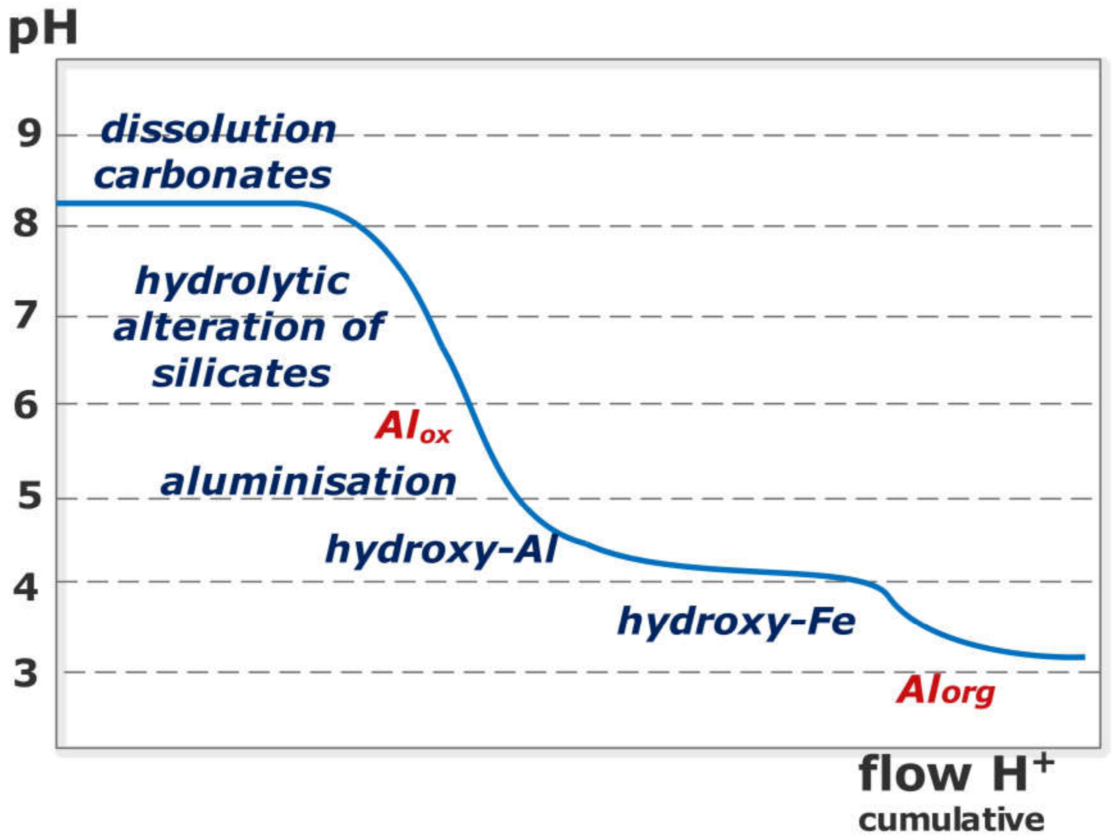


Figure 3.7: Evolution of soil buffering capacity and weathering profile under cumulative proton flux forcing, adapted from CHADWICK and CHOROVER (2001, op. cit.)

Finally, remember that aluminization is not a genomic evolutionary process of LH in arid or semi-arid uplands.

Figure 3.8: Former bauxite quarry in Otranto, Italy (Photo: Fotolia)

4. Phytobiology of aluminization

4.1. Physiological effects of aluminization

Aluminization of soils in landgenic holons (HP) creates significant physiological stress in many Ager species. This stress can extend to symptoms of toxicity when the Al^{3+} concentration of the soil solution becomes critical. KOCHIAN et al. (2005) review the main manifestations and known or suspected mechanisms. A critical aluminium concentration causes more or less severe rhizotoxic effects when the soil pH falls below 5.0, i.e. when the physico-chemical aluminization index (m%) exceeds 50% according to the scale presented in table 2 of the previous point. However, the degree of toxicity varies greatly depending on the species, growth conditions, duration of exposure and solution concentrations. Rhizotoxicity is manifested by an inhibition of root growth as well as the absorption of water and mineral nutrients from the soil. Morphological effects result such as the swelling of the extremities and the reduction or disappearance of the absorbent hairs. It is marked at the level of the root apex by the blocking of the meristematic activity.

Several sites are presumed to be potential targets of aluminum such as the cell wall, the plasma membrane, the cytoskeleton or the cell nucleus itself. While much of the aluminum associated with roots is located in the apoplasm (extracellular medium formed by the pectocellulosic walls and intercellular voids), it is therefore also recognized that aluminum reaches reaction sites in the symplasm (intracellular medium) such as the microtubules and actin filaments of the cytoskeleton. Even more intimate biochemical reactions are also reported, notably with the DNA of the cell nucleus.

4.1.1. Cell wall

The pectocellulosic cell wall has negative charges that determine its cation exchange capacity interacting with Al^{3+} from the soil solution at the root periphery. Thus, cationic aluminum can displace calcium from the wall and modify its structure and mechanical properties. The wall can then become more rigid to the point of limiting its possibilities of elongation and expansion in general. This type of interaction has been observed in pea, wheat and corn roots.

4.1.2. Plasma membrane

Several mechanisms are evoked at the level of the plasma membrane, the structure of which is shown in figure 4.1. Like the wall, this membrane also develops a cation exchange capacity by polarization of the phospholipid double layer that constitutes it. When exposed to Al^{3+} an instantaneous depolarization has been observed in sugar beet and wheat. Aluminum can thus interfere in a damaging way in the surface ionic composition and the process of ionic transfer between the apolasm and the symplasm. For example, callose synthesis in the apoplast requires the presence of Ca^{2+} and if Al^{3+} dislodges it from the membrane, callose accumulation is favored. This is what is observed in maize and bean. The callose can then block intercellular transfers via plasmodesms, as has been shown in a susceptible wheat.
Active proton transport across the plasma membrane generates a proton gradient that is active in secondary ion transfer. This consumes energy in the form of ATP (adenosine triphosphate), so that this activity is performed by a plasma membrane enzyme called *H^+-ATPase*. Aluminum can inhibit this activity and consequently alter the ionic balance of root cells. Such a phenomenon has been demonstrated in pumpkin and wheat roots.
Protein channels in the plasma membrane are involved in the root uptake of cations such as Ca^{2+}, Mg^{2+}, K^+ and NH_4^+. A direct interference of several proteins acting as transport channels with the aluminic cation is likely to block this mechanism as observed in the absorbing hairs and roots of wheat and corn.

Aluminum is also associated with the production of reactive oxygen derivatives (ROD) or free radicals. They are damaging to the lipid membrane as observed in soy. Lipid peroxidation is not instantaneous after exposure to aluminum but can occur after 24 hours, as observed in pea and soy. Free radicals can also cause mitochondrial dysfunction.

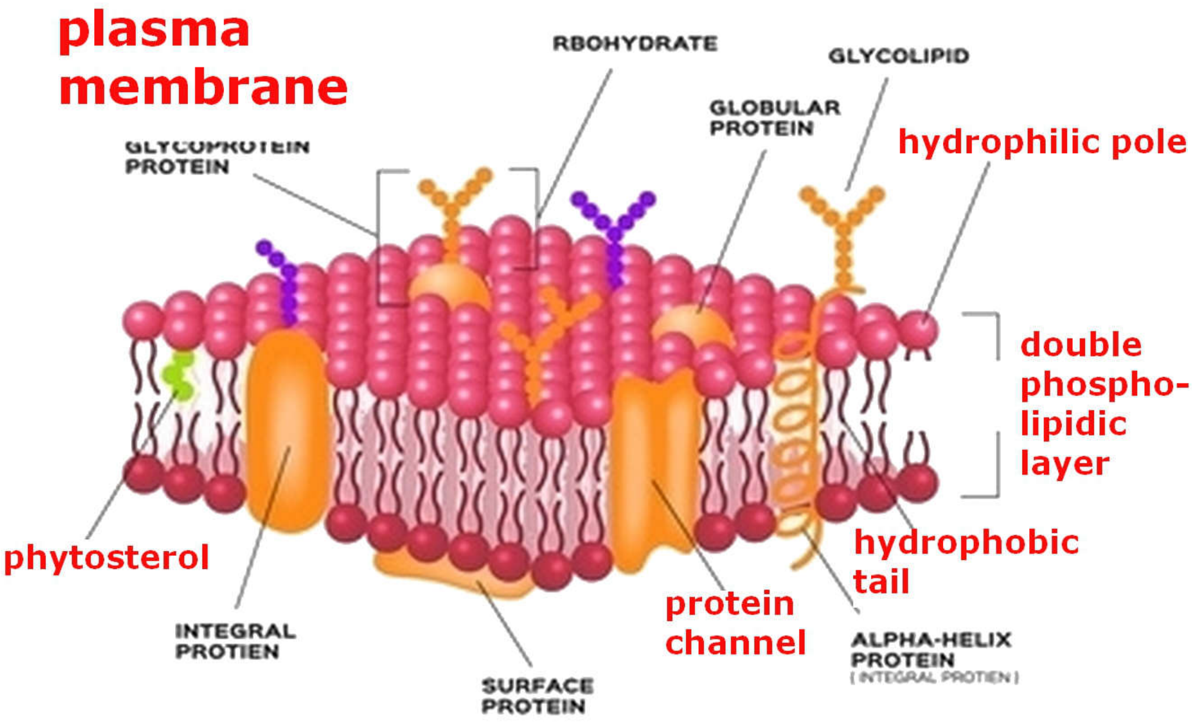


Figure 4.1: Structural scheme of the plasma membrane (Source: Fotolia)

4.1.3. Root cytoskeleton

Aluminum induces changes in the structural organization of root cells by interactions with actin filaments, microfilaments and microtubules, which explains morphological malformations such as swelling already mentioned.

4.1.4. DNA from the nucleus

Aluminum can also interfere with structures in the cell nucleus such as the microtubules of its membrane or chromatin. This can result in errors in protein recognition and transport, destabilization of the cytoskeleton and dysfunction in cell division processes. Studies of these interactions have been conducted in particular on barley.

4.1.5. Discussion

Numerous cellular mechanisms involved in root growth and multiple possible interactions with aluminium, as reviewed by KOCHIAN et al. (2005) and briefly mentioned above, do not make it possible to define a single universal process to explain the aluminium toxicity phenomenon. BRUNNER & SPERISSEN (op.cit.) consider that the mechanisms put forward remain speculative or hypothetical, notably because of the differences in sensitivity of plants. However, they recognize as an ecological indicator of potential aluminium toxicity a value of "m" higher than 50%, or rather, which is equivalent, a ratio lower than 1 between the sum of the basic cations and the exchangeable aluminium in the soil. The main argument in favor of such an indicator remains the interference between basic cations and aluminum at the plasma membrane. In addition, these authors point out the little knowledge acquired on native species, joining in this the remarks and observations of HARIDASAN (2008) for the cerrado (wooded savannah) of Brazil.

4.2. Aluminization resistance and tolerance

KOCHIAN et al. (2005, op. cit.) also review the two mechanisms of resistance and tolerance to aluminium, the first being its exclusion by root exudation of carboxylates and the second its chelation in the symplasm also through carboxylates. HARDISAN considers that the communities of native species are resistant or tolerant to the acidity of soils by the same two mechanisms of exclusion or accumulation of aluminium. He specifies that aluminium-accumulating species can concentrate from 1,000 to 4,000 ppm in their leaves. EVRARD et al. (1967) even report concentrations of up to 70,000 ppm in leaves. BRUNNER & SPERISSEN (op.cit.) also agree on the mechanisms of exclusion by exudation of carboxylates and accumulation by chelation before transport and sequestration in less sensitive parts of plants or in subcellular compartments. However, they consider that, apart from the exudation of organic acids, most of the mechanisms mentioned do not have physiological evidence or genetic support. They also point out that most studies have focused on cultivated species (Ager) or on the model plant *Arabidopsis (thaliana)*.

4.2.1. Resistance by exclusion of aluminum

According to KOCHIAN et al. (2005, op. cit), it appeared in several studies that aluminium carboxylate complexes are not absorbed by the roots. But this is contradicted by DEKOCK P. C. & MITCHELL R. L. (1957), quoted by SIVASUBRAMANIAM & TALIBUDEEN (1971), who observe an uptake of aluminium chelates by the roots of mustard, an aluminium tolerant species. Exudation of carboxylates at the root apex is more important in cultivars of several crop species known to be resistant than in sensitive genotypes: citrates (rice, maize, sorghum, bean, soybean, Miscanthus), malates (wheat, *Arabidopsis thaliana*), citrates & malates (oats, rye, triticale, sunflower, radish), oxalates (colocase or taro, buckwheat). The following decreasing order of aluminum chelation efficiency is established: citrate > oxalate > malate. The same carboxylates are excreted by various woody species and forest species. For mycorrhizal roots the following species are mentioned: *Pinus densiflora* (citrate), *Pinus sylvestris* (oxalate), *Picea abies* (succinate). For the non-mycorrhizal roots of evergreen trees and shrubs: *Camellia sinensis* -tea tree- (oxalate), *Citrus sinensis* -orange tree- (citrate, malate), *Cinnamomum camphora* -camphor tree- (citrate), Eucalyptus (citrate, malate, oxalate), etc. Citrate and oxalate are also excreted in several species of poplar and conifers.

An overexpression of genes coding for enzymes such as citrate synthase or malate dehydrogenase was observed in some cases. A delay in the activation of resistance genes seems to be necessary after exposure to aluminium in some species such as rye or triticale while in other species the exudation of carboxylates remains constant. The first aluminium resistance gene was identified in wheat. It is "TaALMT1" which encodes a plasma membrane protein responsible for malate exudation (SASAKI et al., 2004). Protein anion (carboxylate) channels in the plasma membrane are rapidly activated by exposure to aluminum. Following symplastic exclusion, apoplastic accumulation of aluminum in the cell wall was observed in relation to its pectin content and degree of methylation (pectin and pectin methylesterase). A potential for aluminum accumulation exists in both non-woody crop species and shrub and forest species.

4.2.2. Resistance by increasing pH in the rhizosphere

BRUNNER & SPERISSEN (op.cit.) refer to the activation of a proton influx in the root apex of *Arabidopsis* mutants as an aluminium exclusion option. This process causes an increase in pH in the rhizosphere, which reduces the activity of aluminum. However, these authors point out that there is no evidence for such a process in *Arabidopsis* ecotypes or in the roots of woody forest species.

4.2.3. Aluminium accumulation tolerance

Hydrangea (*Hydrangea macrophylla*) flowers are red to blue depending on the soil pH. In acidic soil they are blue due to the accumulation of aluminium in the sepals in the form of an

aluminium complex with an anthocyanin pigment. KOCHIAN et al (op. cit.) report that this plant can also accumulate in its leaves up to 3,000 ppm of Al^{3+} in the form of a 1:1 complex with citrate, and that buckwheat (*Fagopyrum esculentum*) can accumulate in its leaves up to 15,000 ppm of Al^{3+} in the form of a 1:3 complex with oxalate. The 1:3 Al-carboxylate complexes are stable and therefore ensure a lasting neutralization of aluminum equivalent to a detoxification process. The 1:1 or 1:2 complexes remain potentially toxic. Storage of the 1:3 complex with oxalate is 80% in the vacuoles. If it is formed in the roots of buckwheat, the transport of aluminium in the xylem is in the form of citrate, which suggests a double exchange of ligands (chelating cation) first at the root level and then at the leaf level. Ligand exchange is also apparent in tea plants, for example. In addition, other aluminium complexing agents are detected in tea plants such as flavonols. Aluminium complexes with flavonols are also demonstrated in the root apices of camphor.
SILVA et al. (2004) conclude in the tolerance to aluminium of several Eucalyptus species by internal complexation with malate at the root level.
HARIDASAN (1982) identifies the significant presence of aluminium accumulating species in the Brazilian cerrado and their belonging to the main families that CHENERY (1948) had already identified before and that EVRARD et al.(op. cit.) have also confirmed at least partially within the Congolese flora: Vochysiaceae (all species of this family are Al accumulators), Rubiaceae (647 accumulator species in 91 genera), Melastomataceae (441 accumulator species in 105 genera). To this must be added the Theaceae (family of the tea tree and Camellia).

4.2.4. Tolerance by activation of specific metabolic pathways

BRUNNER & SPERISSEN (op.cit.) indicate that moderate concentrations of aluminium are not fatal and that root growth can recover through the activation of new metabolic pathways. Thus, they quote GRISEL et al. (2010) who exposed young *Populus tremula* (aspen) plants to increasing concentrations of 100, 250, 500 and 1000 µM of $AlCl_3$. At 100 µM, there is no effect. At 250, 500 and 1000 µM, there was an inhibition of root growth after 6 h of exposure. At more than 2 days of exposure, there is a recovery of growth with 250 and 500 µM but no recovery with 1,000 µM. In a test performed with 500 µM $AlCl_3$ under permanent stress, there is 68% inhibition of root growth after 6 h; a recovery from 68 to 50% after 2 days of exposure and a recovery from 68 to 36% after 10 days, compared to the control without stress.
During stress of constant exposure to a 500 µM concentration of $AlCl_3$, the same authors explored the genetic activity of poplar. They observed a down-regulation of the expression of 202 to 27 reactive genes between 6 h and 2 days while other reactive genes were up-regulated. The rapid regulation of reactive genes involves the control of three main processes: (1) the softening of the cell wall by enzymatic agents (2) the active transport of cations such as K^+ and particularly Mg^{2+} and (3) an up-regulation of genes controlling reactive oxygen derivatives (RDO) and in particular the gene controlling an alternative oxidase to lower RDO production at the mitochondrial level.

4.2.5. Discussion

BRUNNER and SPERISSEN (op. cit.) propose a summary diagram of resistance and tolerance mechanisms, of which figure 4.2 is a slightly modified representation. It should be pointed out that these mechanisms remain partly speculative and are based essentially on experiments in the plant physiology laboratory. They take place at nano- and micrometer scales similar to the acidification and aluminization reactions reviewed earlier. The coupling between soil aluminization and the phytobiological adaptations to stress that it induces is coherent. It is even quite obvious when one realizes that soil aluminization is subject to biological forcing via bio-acidification. The intimate co-evolution of the terrestrial biosphere and lithosphere is thus illustrated.
It is also worth noting that the process of aluminium exclusion by exudation of organic acids is quite widespread, even in genotypes or cultivars considered non-resistant but at simply lower intensities. The cited authors agree on the acceptability of the 50% aluminization index "m" as an ecological indicator of potential aluminium toxicity according to the scientific literature they reviewed. They also agree that there is significant variability in sensitivity to cationic

aluminium among plant species and in particular between native and cultivated species.

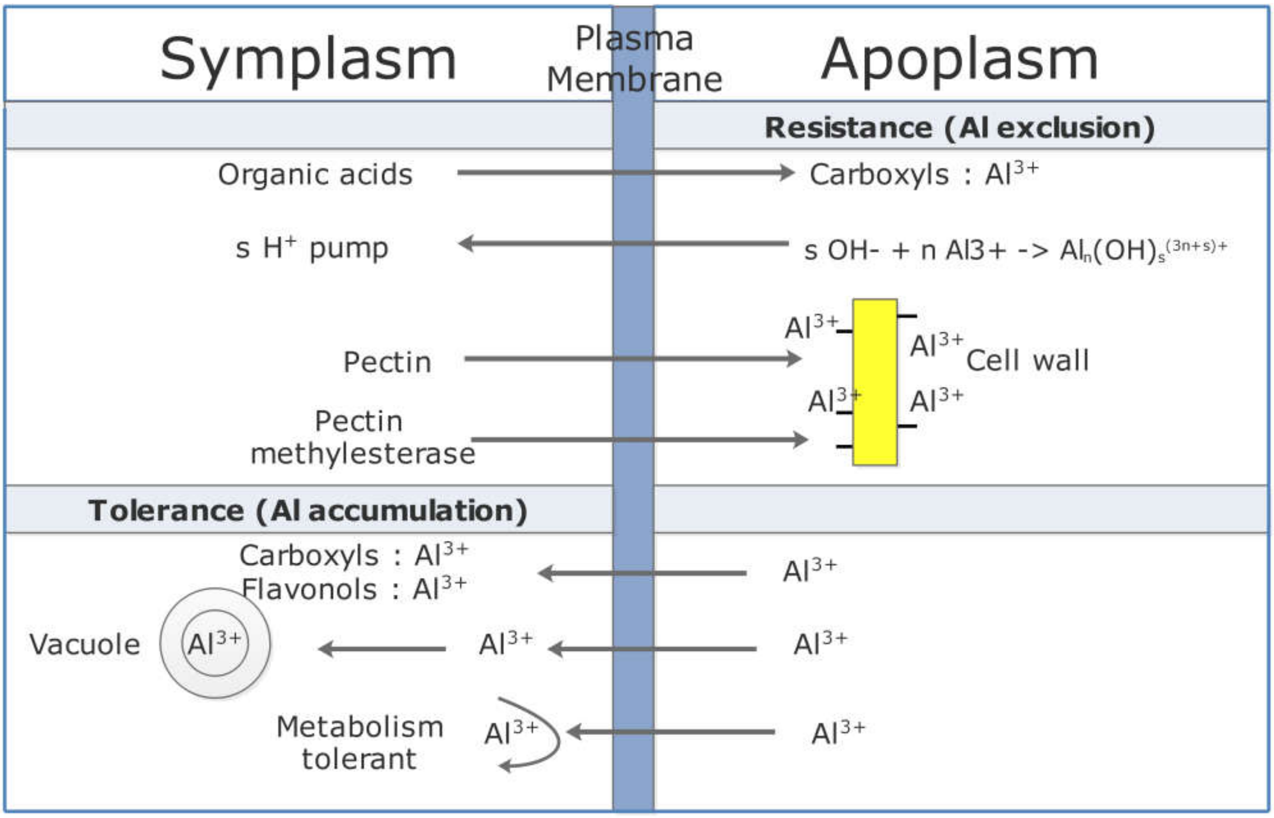


Figure 4.2: Scheme of the resistance and tolerance mechanisms to aluminization according to BRUNNER and SPERISSEN (op. cit.)

The aspen (*Populus tremula*) genotype is representative of aluminum resistance & tolerance induced by regulation of a large number of "locus quantitative traits" (LQT). While such resistance in wheat, barley or rye is practically dominated by a single major trait at a particular chromosomal locus, rice shows a complex regulation of 27 LQT as reported by KOCHIAN et al. And the metaphor operated with such a system of genetic control by LQT in figure 2.3 (point 2) for landgenics thus finds a double concrete illustration here.
The important genetic adaptation of native species should be a major focus of research and development. However, it should be possible to quantify the thresholds of resistance and tolerance to the degree of aluminization of soils for each genotype or cultivar selected in order to remodel the holons and landgenic facets (LH and LF), if necessary and with full knowledge of the facts.
Finally, Saltus forage species do not yet appear to have been specifically investigated for aluminum resistance and tolerance processes.

4.3. Growth sensitivity to aluminization

4.3.1. Sensitivities of species in vegetation vases

As indicated in the fifth sub-section 3.3.3, the aluminization sequence consisting of ten soils at Gisozi in Burundi was macro-sampled in 1986 with approximately 500 kg of soil taken from 0 to 15 cm depth to explore the sensitivity of several Ager species and cultivars in vegetation vases. For each species or cultivar, the device includes 5 dm^3 PVC vases filled with soil. In each of them, several seeds are planted in four repetitions, i.e. 40 vases per genotype. A thinning is made shortly after emergence to keep 2 to 15 plants/vase depending on the species. No particular treatment is applied except biweekly watering. The above-ground biomass was harvested, dried and weighed after a wide range of growth times depending on the species,

from 25 to 240 days. The plant material covers 23 genotypes including 11 cereals, 4 food legumes, 2 potatoes, 4 forage legumes, 1 forage grass and 1 tea cultivar. The results are published by OPDECAMP et al. (1988) in a technical note from the Institut des Sciences Agronomiques du Burundi (ISABU). Figure 4.3 shows a representative sample for 4 genotypes including tea (*Camelia sinensis*).
The juvenile growth of plants seems to be initially stimulated by aluminization and then progressively inhibited beyond an optimal aluminization threshold. For the tea plant, this optimal threshold is not well marked, as its growth seems to stabilize at an optimum from 55-60% aluminization. The optimal thresholds calculated by a multiple regression of parabola type vary for the other genotypes from 0% (*Vicia sativa*) to 39% (*Arachis hypogea* and *Panicum maximum*). The interspecific variability of the sensitivity to soil aluminization is at first sight more important than the intraspecific variability. The rather basic experimental set-up only allows us to identify rough trends or tendencies, but these are nevertheless obtained with about ten increasing rates of aluminization. They are quite progressive if we except a gap between 30 and 55%.

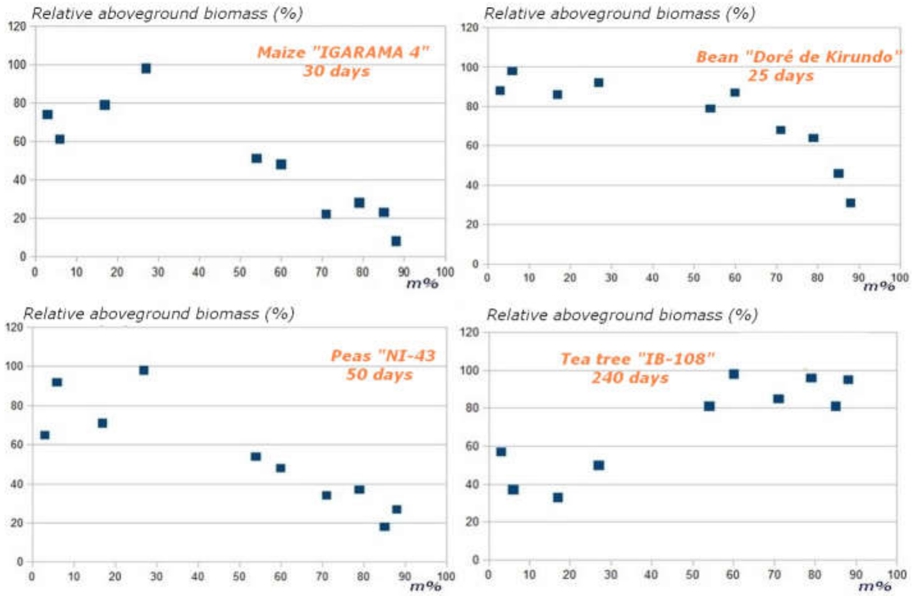


Figure 4.3: Average and relative aboveground biomass produced in vegetation vases from seeds of four cultivars and species as a function of soil aluminization index, based on the results of OPDECAMP et al. (1988)

SIVASUBRAMANIAM & TALIBUDEEN (1971) carried out a double experiment with tea plants, also in growing vases but with a single soil sample with an initial pH of 3.95. Small and large plants were grown for 6 months with two daily additions of solutions combining two concentrations of K_2SO_4 (20 and 400 µM) with four concentrations of $Al_2(SO4)_3$. (0, 50, 125 and 250 µM) and a general weekly addition of 10 mg nitrogen per vase in the form of $(NH_4)_2SO_4$. Highly significant negative effects are seen on the biomass produced with the highest Al^{3+} inputs. A positive effect of potash input is then observed. However, a beneficial trend of Al^{3+} supply was observed for lower concentrations in the small plant group, which could mean that an optimum threshold also exists in tea.
Measurements of Al and K contents in the first leaf indicate competition in the uptake of these two elements. After 6 months of cultivation without external phosphorus supply, the authors observed a highly significant correlation between P and Al uptake in the small plants.
A second experiment then prolonged the first one during 4 months with this case an external contribution of 0.5 gr of P/vase either in the form of inositol phosphate (cyclic organic phosphate with 6 carbon atoms) or in the form of sodium monophosphate (NaH_2PO_4). No particular effect is obtained with inositol phosphate, but monophosphate produces a strong increase in aluminum uptake in the first mature leaf. The authors suggest uptake of an Al-P molecular complex with an Al/P ratio of 1, of low or zero charge. Aluminum would then be chelated by organic acids and flavonols as already reported in the resistance mechanisms.

Stimulating effect of soil aluminization on growth could therefore be attributed to an indirect improvement of phosphorus uptake. It is important to note that the reduction in total and Olsen-Dabin phosphorus levels in the Gisozi sequence at the highest aluminization rates (figure 3.6) does not mean that it is less available to the tea plant. Soil phosphorus determinations would then lose much of their indicative value for mineral nutrition.

PAVAN et al. (1982) explored the sensitivity of coffee (*Coffea arabica*) on the basis of a 7 month growth experiment of germinated seedlings. The study was carried out on 6 soils sampled between 0 and 30 cm depth in the South of Brazil and placed in vegetation vases. Liming was also carried out with limestone ($CaCO_3$) in several doses as well as treatments with $MgCO_3$ and gypsum ($CaSO_4.2H2O$). An NPK contribution completes these treatments. A foliar and soil analysis is also performed at the end of the experiment. The 6 soils used have pH (H2O) at the beginning between 4.0 and 4.3. Their aluminization index varies between 37 and 79%. Their texture is clayey for 4 of them. One soil consists of a silty sand and the last one of a sandy-clayey silt (USDA textural triangle). From the mineralogical point of view, kaolinite is largely dominant while hematite and gibbsite are also present.
In terms of soil results, increases in pH, reductions in aluminum and increases in exchangeable calcium or magnesium are obviously recorded following $CaCO_3$ and $MgCO_3$ treatments. But the gypsum treatment also reduces the exchangeable aluminum and would induce an ion pair formation with the sulfate, namely $AlSO_4^+$. For the effects on coffee growth, critical aluminization thresholds between 3 and 25% after treatments were calculated on a statistical basis. These thresholds vary from one soil to another but if they are related to the corresponding concentration of aluminium in soil solution, they are close to a range between 7.0 and 12.7 µM. There is an excellent positive correlation (0.98***) between the activity (function of the concentration according to the degree of dilution) of aluminium in soil solution and its foliar concentration measured at the end of the experiment. This concentration reaches 225 ppm for the highest activity of Al^{3+} and between 62 and 100 ppm for the critical threshold. If there is a critical threshold above which growth is significantly inhibited, its stimulation below this threshold is not diagnosed. The formation of an Al-P complex in solution is however predicted from the calculations of the GEOCHEM program of speciation of the Al^{3+} ion. The arabica coffee tree thus appears to be a rather sensitive species, especially in comparison with the tea tree, which is an outright accumulator.

4.3.2. Species sensitivities in culture solutions

KONISHI et al. (1985) also studied Al-P interactions in culture solutions with cuttings of one-year-old tea plants. The plants were subjected for nearly 4 months to 4 levels of aluminum concentration of 0, 200, 400 and 800 µM with a level of 100 µM P and to 5 levels of aluminum of 0, 800, 1,600, 3,200 and 6,400 µM with a level of 800 µM P. At the end of the experiment, the leaves, stems, roots and young leaf shoots were harvested separately for analysis. Optimal growth is obtained with a concentration of 400 µM Al at 100 µM P and 1,600 µM Al at 800 µM P. A stimulating effect of aluminum on growth is diagnosed as well as a positive interaction between P and Al. Aluminum also increases nitrogen uptake in young shoots and potassium uptake in roots. But an antagonism is observed between Al on the one hand and Ca and Mg on the other hand.
TSUJI et al. (1994) worked on the Al-P synergy in root growth with sterilized root shoots of tea plants in culture solutions. This is confirmed and the authors attribute it to the exudation of protons promoting the dissolution of an aluminophosphate precipitate that appeared on the surface of the roots.
An interesting complement of information is provided by the work of TOLRA et al. (2011) who demonstrate the preferential accumulation of aluminum in the cell wall of the leaf epidermis of tea plant by low energy X-ray fluorescence. They also note its possible passage into the symplasm by its presence detected in small quantities in the phloem. The translocation of aluminum from the roots to the leaves would be done by the evapotranspiratory flow via the xylem in chelated form with citrate.

A key paper for other species is that of OSAKI et al. (1997) who work with culture solutions containing aluminium as sulphate and phosphorus as sodium monophosphate at mutual

saturation so that an Al-P precipitate appears, removed from the solution by filtration. These researchers grew 13 plant species in aquaculture for 2 to 4 weeks from germinated seeds with 3 concentrations of Al3+: zero (0 ppm), low (3 ppm) and high (15 ppm). According to the results obtained, the 13 species are classified according to their sensitivity to Al^{3+}.
Barley (*Hordeum vulgare*) showed very little resistance (low exclusion potential), its growth being inhibited at low aluminum concentrations. Four species were found to be moderately sensitive, including sarassin (*Fagopyrum esculentum*) with a moderate potential for accumulation. The other three are recognized for their moderate exclusion potential, namely *Stylosanthes guianensis*, *Leucaena leucocephala* and *Ischaemum barbatum*.
The other eight species tested are considered insensitive to aluminum and even for the most part stimulated by it. Three of these species act by strong exclusion: rice (*Oryza sativa*), cajuput (*Melaleuca cajuputi*) and *Acacia mangium*. Three others by accumulation in the roots, without being able to specify the localization: the American cranberry (*Vaccinium macrocarpon*), the grass of Congo (*Brachiaria ruziziensis*) which is tolerant but not really stimulated and *Polygonum sachalinense*. Finally, two species accumulate both in roots and leaves: hydrangea (*Hydrangea macrophylla*) and Singapore Rhododendron (*Melastoma malabathricum*). The authors observe that most of the species stimulated by aluminium benefit from an increased uptake of N, P and K with a particular mention for phosphorus.This is remarkable for the Singapore Rhododendron whose organ phosphorus content is extremely low in the absence of aluminium.
This last species was also the subject of a comparative study with barley by WATANABE et al. (2005) and always in culture solution. They observed in Singapore Rhododendron a stimulation of the growth and the absorption of phosphorus but not of nitrogen or potassium. On the other hand, in barley, aluminium inhibits its growth as well as the absorption of N, P and K.

For all the Eucalyptus species studied by SILVA et al. (op. cit.), a beneficial effect on root elongation is observed for low to moderate concentrations of aluminium in the culture solution, but no link with phosphorus uptake is sought.

Singapore Rhododendron and Chinese reed (*Miscanthus sinensis*) are two species adapted to acid sulfate soils. Photographic illustrations of these are shown in figure 4.4. These species were grown with solutions in the presence of not only increasing concentrations of aluminum but also iron by WATANABE et al. (2006). It turns out that if Rhododendron is sensitive to ferrous iron in the absence of aluminum, it becomes tolerant in its presence in high concentration. The latter would act in an antagonistic way but the mechanisms remain unknown. On the other hand, the Chinese reed tolerates both high concentrations of ferrous iron and aluminum.

For rice grown in acidic sulfate soils, ALIA et al. (2015) demonstrate that during 14-day hydroponic growth of seedlings at increasing concentrations (0, 20, 40, 60, 80 and 100 µM) of Al^{3+} or Fe^{2+} and without nutrient addition, aluminum and iron toxicity are marked as well as conjugation of the two. It is expressed by a clear inhibition of root growth and is reduced by increasing the pH of the hydroponic solution. However, the resistance mechanism of rice is highlighted by the exudation of organic acids (citric, oxalic, malic). This effect is confirmed when the hydroponic solution is made up of water taken (pH 2.98) from an acidic sulfate soil from rice cultivation in the northeast of the Malay Peninsula, which is highly aluminized (m>95%) to a depth of more than 65 cm.

In the same rice plant, the effect of aluminum on its mineral nutrition and biomass production was studied by TANG VAN HAI et al. (1989). They used very dilute crop solutions to simulate soil solution conditions as closely as possible. Rice seedlings of three cultivars obtained after germination were placed in groups of 5 in a phytotron culture set-up with 8 increasing Al concentrations of 0 - 1 - 2 - 3 - 5 - 10 - 20 and 40 ppm, which produced dry biomass of 3.25 - 3.8 - 4.4 - 4.5 - 4.5 - 3.8 - 2.1 and 1.4 in gr per 5 seedlings, respectively, for the cultivar B6044 after 65 days of growth. A stimulation is clearly observed up to a concentration between 3 and 5 ppm of Al^{3+}, followed by an inhibition beyond this optimum which becomes strong as soon as 20 ppm is reached. This same pattern is reproduced for phosphorus uptake. Three

levels of phospate of 1, 3 and 5 ppm are also tested. These 3 concentrations do not modify the pattern of the response to aluminum except for a widening of the optimum "peak" and a significant increase in biomass produced. Phosphorus uptake by the rice plants was also significantly increased, as was potassium uptake.
A more surprising effect is the marked increase in aluminum uptake with increasing doses of phosphorus. The authors cite a number of previous studies in many species reporting a physiological stimulating effect of aluminum before its toxicity becomes apparent. The concomitant stimulation of phosphorus uptake to the critical threshold is also reported in the literature cited by these authors and suggests that aluminium and phosphate passively enter the roots as a low charge complex as already suggested by SIVASUBRAMANIAM & TALIBUDEEN (op. cit.) for tea.

<u>Figure 4.4</u>: Illustrations of two species tolerant to simultaneous high concentrations of aluminum and ferrous iron in acid sulfate soils (Photos: Fotolia): Miscanthus sinensis or Chinese Reed (A & B), Melastoma malabathricum or Singapore Rhododendron (C & D)

Rice has also been the subject of a recent and quite extensive study by MORENO-ALVARADO et al. (2017) using 4 Mexican cultivars. The study involves first germinating the seeds on artificial growth medium and then transferring the seedlings to a culture solution (pH 5.5) for 13 days. Then, the seedlings are grown in solution with or without exposure to aluminum at 200 µM (pH 4.2) for 20 days. This concentration is chosen based on the results of a preliminary test of exposure to increasing concentrations of 0, 25, 50, 100, 200 and 400 µM which revealed a systematic stimulating effect except for two cultivars inhibited at 400µM. Plants were sampled for NAC gene profiling before and 24 hours after exposure to aluminum. NAC is an acronym for three transcription factors involved in growth and development processes in response to biotic or abiotic environmental signals. Transcription factors are proteins that bind specifically to DNA sequences and thus control the degree of transcription of their genetic information into messenger RNA. These proteins act alone or in a complex group by activating or inhibiting the recruitment of RNA polymerase to certain genes.
After 20 days of cultivation with or without exposure, growth and biomass were measured, as well as tissue contents of Al, P, K, Ca and Mg, chlorophyll a and b, total amino acids, proline and total soluble sugars. The stimulation of rice growth by the chosen concentration is well confirmed and statistically significant both on the size and biomass of roots and epigeal parts where tillering is favored. Growth stimulation was particularly strong (>90%) for the roots of all four cultivars. Chlorophylls a and b concentrations were also higher due to aluminum except for one cultivar out of the four. No stimulating effect was detected on amino acid contents, while those of total free sugars increased.
At the root level, aluminium concentrations are all clearly marked (around 600 ppm in these roots) by exposure, whereas they are almost zero without this treatment. Nitrogen levels are

not modified. P and K concentrations are increased, Ca and Mg concentrations are little or not affected.
In the aerial shoots, there is a tendency for aluminum to increase, but this is not statistically significant: from about 600 ppm in the roots, it drops to 30-50 ppm. The presence of aluminum in the aerial parts without exposure may be due to its presence in traces in the culture solution or in the seeds. There is also no significant effect on N, P, K and Ca at this stage of juvenile tillering development. Only the Mg content was significantly higher for 2 out of 4 cultivars after exposure to aluminium. For nutrients, the authors confirm the Al-P synergy and the positive effect of Al^{3+} on P uptake at the root level without any effect on aerial shoots. Finally, the modification of the expression of 25 out of 57 NAC genes was observed following 24-hour exposure to aluminium and thus seem to be influenced by this element.

A recent review by BOJÓRQUEZ-QUINTAL et al. (2017) of the effects of aluminum on plant growth is finally worth mentioning. It further confirms and completes the information and data mentioned in this point and especially those related to the stimulating effects of aluminum on the growth of trees such as *Tabebuia chrysantha* (national tree of Venezuela), *Betula pendula* (white birch) and *Quercus serrata* (Japanese Oak).

4.3.3. Discussion

The results of the reviewed works can be interpreted in a consistent way. Aluminization causes co-precipitation of phosphorus with aluminum in the soil and is also observed in crop solution. Most if not all species can dissolve this Al-P precipitate by exudation of organic acids and thus indirectly promote the uptake of P solubilized in parallel with aluminium in the form of an Al-P complex. When the concentration of the latter becomes critical, a toxic effect then reduces growth. This phytobiological phenomenon is under genetic-cellular control and is expressed with very variable intensity, firstly according to species and then according to varieties, via transcription factors sensitive to biotic and abiotic signals (NAC) and acting at the level of "quantitative trait loci". The phenotypic variability of the critical rate of aluminization on the growth of the species and varieties observed is thus explained quite simply.

However, it is necessary to consider the general criticism of the dogma that a trait corresponds to a character, as carried out by SUING (op. cit., p. 27): "*The transcription factors that are supposed to regulate the expression of genes are either not to be found, or in fact attach themselves everywhere on the DNA without any selectivity for this or that gene*".

One should also be careful about any disjunctive view between exclusion and accumulation, between apoplastic or vacuolar concentration on the one hand and symplastic chelation or translocation from roots to leaves on the other. Similarly, the possibility of direct uptake of cationic Al-P complexes such as $[AlH_2PO_4]^{2+}$ and $[Al(OH)(HPO_4)]^+$ suggested by SIVASUBRAMANIAM & TALIBUDEEN (op. cit.) should be kept in mind in parallel with the possibility of separate uptake of ionic species such as Al^{3+}, $Al(OH)^{2+}$, $H_2PO_4^-$ and HPO_4^{2-} via cationic protein channels in the case of the former, and anionic channels in the case of latter.

Accumulative species concentrate aluminium for a part in the leaves.
A change of ligand in the root symplasm can occur during translocation to the leaves: this is the case of buckwheat where the root Al-oxalate chelate is transformed into Al-citrate chelate during translocation and then again into Al-oxalate chelate to be concentrated in the vacuoles of its leaf cells. In tea, several ligands are also mentioned but the concentration is mainly in the cell wall of the leaf epidermis. Rice shows quite efficient mechanisms of resistance by exclusion not only to aluminium but also to ferrous iron, which allows it to be cultivated in hydromorphic regimes and in acid sulphate soils of the coast.

5. Ecological dynamics of aluminization

5.1. Ecological space-time levels

5.1.1. Change of spatio-temporal scale

Moving from a study of phytobiology of aluminization in the laboratory or under greenhouse cover to natural habitats and geomorphological landscapes means making a considerable change of scale in the level of organization of systemic interactions.

Firstly in time because aluminization in biotopes and the evolution of species according to their niches are more or less synchronous, but their speeds are not constant and vary according to populations, communities, geomorphological and climatic conditions. They require taking into account temporalities sometimes geological over millions of years (Ma) or sometimes morphoclimatic over thousands of years (Ka). It can take on a sudden character following catastrophes or cataclysms such as volcanic eruptions or meteorite falls. Just like the evolution of species and communities, the acidification and aluminization of soils do not take place in a linear way. Accelerations and slowdowns occur as a result of orogenesis, erosion cycles and associated climatic pulsations.

Then in space because from a closed system in the laboratory, the ecology of aluminization leads us to a wide open system. The volume of a few dm^3 of soil used in vegetation vases increases considerably to several thousand m^3 in the smallest biotope. This volume thus acquires topographical and climatic traits and characters whose variability induces heterogeneity in the three-dimensional geometry of the biotopes and, a fortiori, of the even more extensive ecozones. From a few individuals in greenhouses we also move to populations and communities of species that lead to consider biodiversity whose natural tendency is to increase both in space and in time. The dynamics of biodiversity "γ" (gamma) as a biogeographic reservoir of species potentially available outside a given biotope or habitat, can interfere with its biodiversity "α" (alpha) specific to the community of species of the biotope considered. Finally and in accordance with the meanings given in particular by HAINZELIN and NOUAILLE (2013) as well as by JAMONEAU (2010), one must also imply the biodiversity "β" (beta) as the number of communities i.e. also of biotopes of a given area. These are therefore relative notions from a geographical point of view. A schematic representation of these three types of biodiversity is shown in figure 5.1.
MARCON (2015) states that there is no strict scale for observing biodiversity α, β and γ .

5.1.2. Niche and biotope

At the systemic levels of organization of ecological complexity, the notion of "hypervolume" is introduced by HUTCHINSON (1957), in reference to ecological niche theory. COLWELL & RANGEL (2009) discuss HUTCHINSON's conceptualization of the duality between niche space and biotope space. For HUTCHINSON, each species or population has only one niche in the niche space (except for evolutionary polymorphism). Evolutionary dynamics and diversity of abiotic values in ecological hyperspace also provide opportunities for environmental conditions, resources and adaptation gradients such that no empty niche should exist. JAMONEAU (2010) defines a niche as "*a hypervolume within a multidimensional space, the axes of which represent gradients of an abiotic variable (or resource)*". The niche is thus delimited by intervals of values of "n" abiotic variables and thus defines a particular ecological hyperspace. COLWELL & RANGEL (op.cit.) specify that for HUTCHINSON each niche space point can be associated with several space points of a biotope. The same niche area can thus be present in various locations of a biotope. Moreover, all the points of a niche are not necessarily represented in a given biotope. The same species can therefore be found in several biotopes, but within each biotope there may still be free niche spaces. All the ecological hyperspace or hypervolume of a species is therefore not necessarily occupied within the group constituted by all the biotopes of the planet.

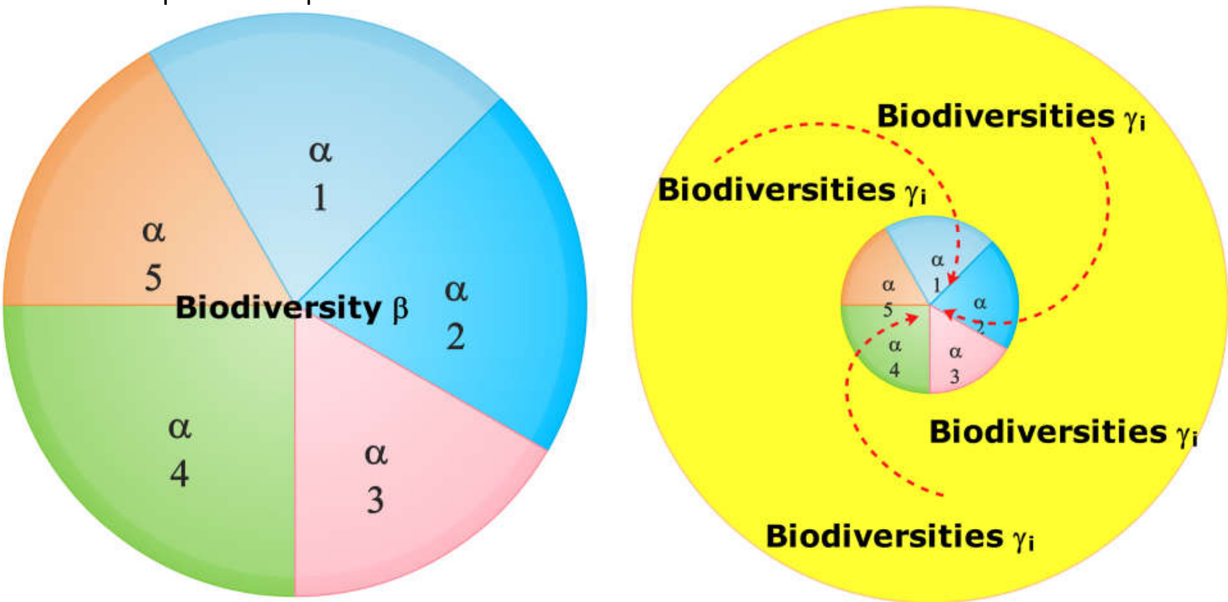


Figure 5.1: Schematic presentation of the three types of biodiversity in a biodiversity area β with 5 biodiversity biotopes $\alpha 1$, $\alpha 2$, $\alpha 3$, $\alpha 4$ and $\alpha 5$ (left) within a regional biodiversity reservoir ecozone γi (yellow, right)

Figure 5.2 represents the dimensional axes of the biotopes and those voluntarily reduced and simplified of the niches (of the "n" variables) at a given time. The interactive evolution of the biotopes and niches constitutes a fundamental fact of the evolutionary dynamics.
HUTCHINSON distinguishes, within the niche space, the R-niche with interactions between species (realized niche) and the F-niche without interactions (fundamental niche). The consideration of interspecific interactions in the R-niche is that of the so-called "bionomic" factors that operate within the physical space of biotopes: primary producer and secondary consumer relationships, predator and prey, mutualized partnerships, interspecific competition, etc. These bionomic interactions are captured in biotopes in the R-niche space. But, there is no complete reciprocity in the duality between the F-niche and the biotopes. The R-niche contains all the biotopes where the species under consideration is present. The F-niche is larger and corresponds to a potential of realization that is probably never reached according to the three causes cited by COLWELL & RANGEL (op.cit.): (1) there are physical barriers (landforms, oceans, climatic zones, etc.) to the dispersal of species, (2) certain areas of a fundamental niche are not found in any contemporary biotope, (3) the potential geographical space of a niche is truncated by bionomic factors (interspecific exclusions).
REINEKE et al. (2016) investigated the geographic variation in R-niche patterns along their soil pH(KCl) axis between 0 and 10 cm depth and within an experimental range of 2.8 to 6.0 established at 1458 forest plots. This pH range should extend from highly aluminized soils to neutral to calcareous soils. Indeed, in the absence of data allowing to establish the rate of aluminization, it is necessary to take into account that the pH(KCL) is lower than the pH(H_2O) of approximately one unit and this difference is normally reduced for the most acid pH. The biogeographic area concerned spreads along a latitudinal gradient over 4 zones between northern France and the Swedish boreo-nemoral limit corresponding roughly to the temperate deciduous forest biome. The R-niches are those of 42 species selected in the herbaceous understory. The configuration of an R-niche is determined by its position which is the $pH_{optimum}$ at which the maximum frequency of occurrence of the species is measured. The pattern also depends on the width, which is the range of pH values on either side of the $pH_{optimum}$ where this occurrence falls below 25% of the plots in each zone. The authors distinguished "acidophilic" plants ($pH_{optimum}$<4) and "neutrophilic" plants ($pH_{optimum}$>5), as well as intermediate species ($pH_{optimum}$ between 4 and 5). Data analyses show a retreat of neutrophilic species from acidic biotopes with increasing latitude, i.e. as they approach the northern environmental margin, but without being able to establish their expansion towards basic biotopes of pH(KCl)>6 towards the south, due to lack of appropriate data. The results also establish an expansion of

acidophilic species towards basic biotopes with increasing latitude, probably due to a bionomic cause of less competitiveness with neutrophilic species.

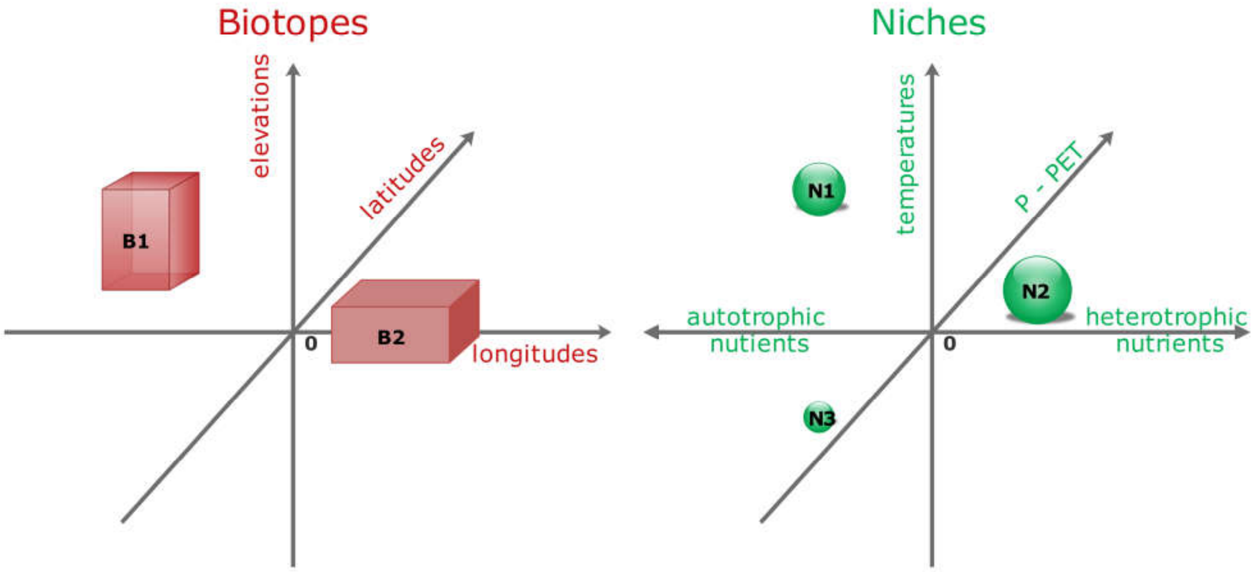


Figure 5.2: Dimensional axes of biotopes and niches (limited axes). Biotopes B1 and B2 are delimited by two geographical spaces. B1 is limited by two northern latitudes (positive), two western longitudes (negative) and is deployed between two positive elevations corresponding undoubtedly to tropical hills of medium altitudes such as one could find in the islands of the Caribbean like Cuba or Haiti and the Dominican Republic. The second biotope B2 is located in the southern hemisphere between low latitudes (negative), in a range of longitudes East consistent enough but low altitudes in part negative (below sea level). These would be the lowest parts of the central Congolese basin of the DRC and the Congo River estuary including some areas flooded by the Atlantic. The Mangroves Marine Park is an integral part of this B2 biotope.
The N1, N2 and N3 niches are represented in an ecological hyperspace according to the variables of temperature, water balance between annual precipitation (P) and potential evapotranspiration (PET), and mineral (autotrophic) or organic (heterotrophic) nutrient composition. The autotrophic N3 species or population survives in icy polar or boreal conditions probably in permafrost and with a fairly precise range of mineral nutrients. The Niche N1 population is an autotrophic primary producer that lives in humid subtropical conditions. As for the Niche N2 population, it consists of secondary consumer individuals (heterotrophs) in temperate semi-humid climates.

5.1.3. Ante-prehistoric temporalities of the ecosphere

Biosphere and soils interact permanently and inseparably. Biological macroevolution has taken place in a sometimes spectacular way on a geological time scale of a few million to several thousand million years (Ma). This evolution is already becoming more discrete on the scale of morphoclimatic cycles that take place in a shorter time frame, of the order of thousands of years (Ka). The building of the great reliefs during the orogenies linked to the meeting of continental plates and the great climatic changes are thus associated with macro-evolutionary phenomena of the biosphere such as the mass extinctions briefly recalled in table 4. Plate tectonics and the profound changes it induces in ocean currents are recognized as the basis of major climatic and geomorphological upheavals (BERGOEING, 2004). Volcanism is also generated by plate tectonics and convective movements of magma in the mantle beneath the continental or oceanic crust. For the eruptions of super volcanoes, an extinction of species leads to a disappearance of ecological niches, which is then compensated by the appearance of new living kingdoms, classes, orders, families, genera and species, and therefore also new niches. The biotopes distant from the eruption can be temporarily modified by fall of luminosity while the proximal biotopes are durably modified by the thickness of the deposits of ashes or lava. These manifestations are however brutal as well as the fall of meteorites of great mass like Chicxculub at the place of what corresponds today to the Gulf of Mexico. BERGOEING (op. cit.) specifies that its diameter exceeded 10 km and that its speed at impact was 10 km/sec. According to this author, the fifth mass extinction that resulted would still have taken place over several million years during which mammals survived.

Table 4. Geochronology of the appearance of the biosphere and its five mass extinctions, adapted from BARNOSKY et al. (2011), acronym conventions: BP = before present, Ma = millions of years

Geologic Era	Dating	Events
Precambrian	4.000 Ma BP	Marine emergence of life in bacterial form
Primary	440 Ma BP	Mass extinction n°1 (marine) of the late Ordovician
	360 Ma BP	Mass extinction n°2 (marine animal) of the late Devonian
	250 Ma BP	Mass extinction n°3 (marine & terrestrial) of the late Permian
Secondary	200 Ma BP	Mass extinction n°4 (marine & terrestrial) of the late Trias
	65 Ma BP	Mass extinction n°5 (dinosaurs + marine) of the late Cretaceous

In the Tertiary, the Alpine orogeny takes place, which presides notably over the formation of the Pyrenees, the Alps, the Urals and the Himalayas. The current configuration of the continents is also acquired. Macroevolution during this era includes the evolutionary radiation of mammals and the African emergence of australopithecine hominids. During the Tertiary, morphoclimatic oscillations of great amplitude took place, of which there are few traces in Europe. They are reported in the general conclusions of ALEXANDRE-PYRE (1971) in the form of a morphoclimatic cycle of lateritic armouring in the high plateau of the present-day savannahs of southern Katanga (DRC) covered by sandy material. Median of the evoked cycle is a semi-arid climate of steppe under which dominate erosive phenomena of flattening. It evolves in the cycle towards an arid desert climate where aeolian contributions of dune sand, a cuticular ferruginous deposit on the cuirasses, a possible silicification in polymorphous sandstones and a sedimentary flooding predominate. The return of the semi-arid steppe climate continues the flattening and then always evolves the above-mentioned cycle towards a sub-humid savannah climate where a moderate thickness alteration occurs. Finally, we note that a temporary hydromorphy is necessary for the individuation of iron.

However, it is in the pedological temporality that the alteration profiles of hard or soft rocks are differentiated at very variable speeds of the order of several thousand years (Ka). It was agreed that the aluminization of soils only starts when the pH (H_2O) falls below 5.5. As a reminder, it is part of an acidification trajectory under a humid or semi-humid ecoclimatic regime in upland areas as well as in lowland areas under a temporary or permanent hydromorphic regime and under the condition that the environment is not confined from a hydrological standpoint. Depending on the initial age of a soil and its buffering capacity, as well as on the type of vegetation, acidification to pH 5.5 can be relatively slow or rapid. It should be noted, however, that the pH of potential acidic sulfate soils can collapse by several units within days or weeks following drainage. But more generally, the time that elapses before aluminization starts on the surface and spreads over several tens of centimeters of thickness can be counted up to several tens of Ka depending in particular on the space-time amplitude of climatic oscillations.

5.2. Hazards and necessities of evolution

5.2.1. The Darwinian couple chance/selection

During point 3, the integration of biotic and abiotic processes during the acidification of soils and their subsequent aluminization was exposed. SUING (op. cit., p. 56) reminds us that Darwin referred to the couple chance/selection as a descriptive law of evolution. It was neo-Darwinism that made it the driving force of evolution, not Darwin himself. SUING goes beyond

this couple with the interactions between living matter (biotic) and non-living matter (abiotic) to explain a necessary and reciprocal evolution of these two "matters". This idea fits perfectly into the framework of this book and can be supported by further developments.
SUING (op. cit., p.33 and following) bases the evolutionary movement of living matter primarily on a tendency to conserve its structure over time. This tendency is negentropic in that it is opposed to the disorganizing movement of matter in general according to the second law of thermodynamics. There is therefore a permanent self-correcting movement. In order to survive and thus to keep its "existential" structure, it is necessary to change at all levels and this in an increasingly efficient way.

At the cellular level, when an environmental stress occurs, the genetic systems for correcting accidental mutations (SOS, SRM, etc., p.53) are disoriented. There is then opportunely an explosion of variability, making the Darwinian couple chance-selection operational. At the level of the pluricellular organism, structural conservation is ensured by numerous physiological functions: homeostasis, hemostasis, regeneration, immunity, etc. They work against "*cell death and anarchic proliferation by promoting further cell proliferation but also programmed cell death.*"
These are the same mechanisms that cause the structure of the organism to change during embryogenesis. Sexual reproduction also preserves the structure in a way since it is at the origin of populations coexisting in the same biotope. The cooperation between individuals of a population in a superstructure or social framework also promotes the structural integrity and longevity of each.

At the level of the population finally, there is a polymorphism of the individuals which is at the base of a microevolution progressively distancing the successive populations from the average type towards the appearance of new species. This polymorphism which could lead to the appearance of too differentiated forms is tempered by sexual reproduction which establishes a reproductive barrier. However, there are advantageous phenotypic differentiations (sexual dimophism, social insect castes, division of labor, etc.) as well as profound macromutations such as the phenomena of neoteny (conservation of juvenile characters, acquisition of sexual maturity at the larval stage) or apomorphosis, linked to chromosomal rearrangements that result in ontogenetic upheavals in the genus's plan of organization (level superior to the species).

Variability in phenotypic traits results in "noise" among populations that can be an evolutionary advantage under environmental stress as reported by FRASER & KÆRN (2009). WEINSTEIN & PAVLIC (2017) report that noise can moreover be a key to ensuring evolutionary transitions in other dynamic natural systems such as climate and that it can also manifest itself as a key factor in social change in, for example, the behavior of individuals in an ant colony.

The essence of the evolutionary movement of living matter as conceived by SUING thus seems to lie in the fact that an "environmental" stress accelerates mutagenesis and amplifies polymorphism. One of the new forms (phenotype) turns out to be adapted to this stress and only then is this form selected. Mutations are amplified by adverse changes in environmental conditions but are not directed per se. Mutations are therefore necessary and not just the result of chance! The mutations would go in all directions because the cellular machinery is disorganized. One or the other of the induced mutations can be adapted to the stress in question and will thus be selected as long as this stress is lasting!
One could add that the mutation could pass through an epigenetic stage of regulation in the expression of genes, an intermediate stage of ecotype before becoming properly "hereditary". Figure 5.3 is therefore proposed as a diagram of the evolutionary engine.

We can understand then that KUPIEC and SONIGO (2000, p.110) relativize the role of the genome as an essence or program of the living matter compared to the phenotype which would formalize its existence. In this respect, they quote ATLAN's (1972) criticism that "*consists in putting the maximum causality on the second term...*". ATLAN therefore considers that the "program" is actually located in the cytoplasm and not in the DNA of the cell nucleus.

"*His theory of self-organization by noise integrates chance, but this chance comes from the environment*". It is thus possible to conceive that "*the information in the DNA ... would correspond to the data, with non-random content, supplied to this cytoplasmic program*" (ATLAN, 1995).

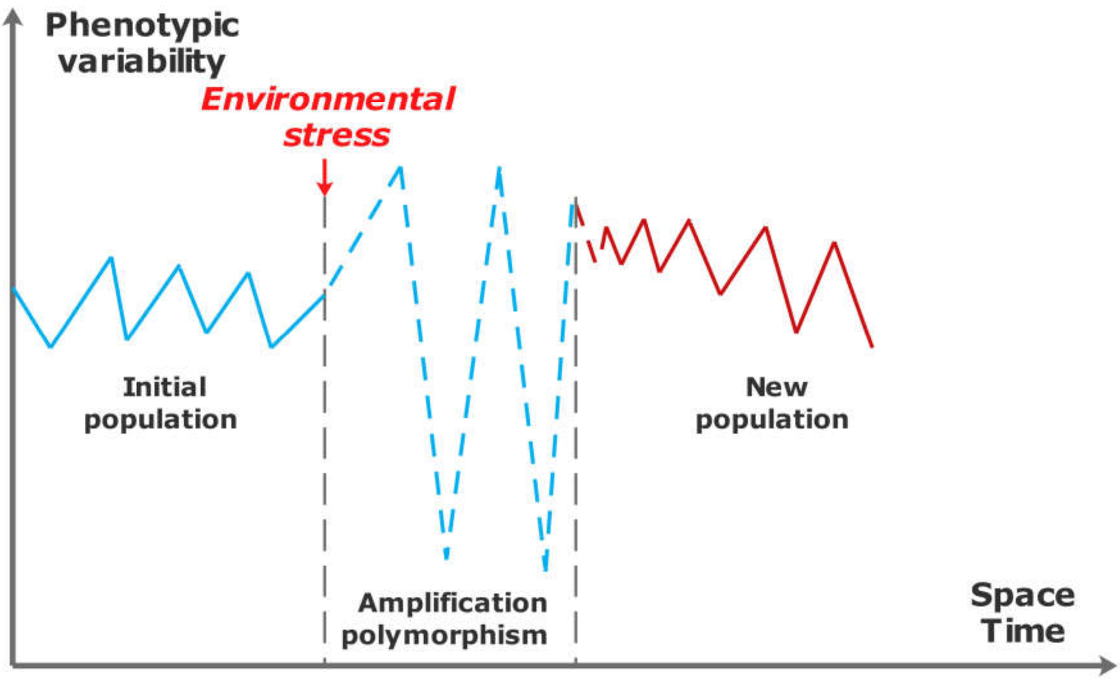


Figure 5.3: Diagram of the engine of evolutionary dynamics

As for the rates of species evolution, they can be highly variable and not necessarily very slow. For example, LALLENSACK (2018) reminds us that ecologists have recently observed very rapid speciation rates, over a few generations, through interactions with the environment, in the realized or simulated niches of species such as sticklebacks (*Timema cristinae*), algae and their rotiferous predators when the former increase in genetic diversity, aphids, water fleas, fishes such as sticklebacks, the small aquarium fish guppy (*Poecilia reticulata*), etc.

5.2.2. Spatial dynamics of evolution

If we agree with ATLAN that chance comes from the environment, considering the biotope as the environment of the biota would be abusively reductive. The biota and the biotope are both constituents of the ecosystem, interacting and evolving together. The evolutionary stress can therefore only come from an adverse and lasting brutal modification of the biotope for the biota, or during the invasion of another biotope by a species which would encounter adverse conditions there via the migratory and colonizing flow of its diaspores, i.e. at the margin of its R-niche (realized) or outside its F-niche (fundamental) constituted by its hyperspace.

The importance of diaspore migration flows can be illustrated by the forest recolonization of the Krakatoa Islands after the volcanic eruption of 1883, the various chronological phases of which are described in box 6. However, it is likely that the involuntary transport of diaspores by humans disrupted or accelerated this recolonization, and that it cannot be fully qualified as "natural" as in ante-prehistoric times. Moreover, the lacunar recolonization in Dipterocarpaceae can be explained by their weak power of dispersion as reported by BLANC (1997).
The heterogeneity of ecosystems in space is undeniable, not only because of the existence of vast biogeographic zones and regions or provinces at the global and continental level, but also because of the multiple biotopes of varying sizes within each region. The latter are differentiated by the combined effects of irregularities in relief and climate, wind, water or glacial erosion, the seasonal beat of the water table, the differential resistance of rocks and deposits to physical and chemical alteration and thus also their buffering capacity with respect to acidification and aluminization induced by biota, etc. The spatial diversity of biotopes and

biota is of course reflected in the contrasts between the soils that make up the soilscapes. Diaspora flows are part of the realization of the fundamental niche of the species and are maintained by dispersal agents such as wind and water from the sea, rivers, animals and especially fruit-eating birds, etc. These flows are a source of species evolution by environmental stress when colonizing seedlings encounter adverse conditions such as drought, excess moisture, salinity, raw rock, fires, acidity, aluminum or iron concentrations in solutions, etc.

<u>Box 6</u>:. Chronology of observations of forest regeneration on the main island at Krakatoa following a volcanic eruption according to RICHARDS (1996, p.341 and following)

The violent volcanic eruption of August 1883 in the KRAKATOA islands cut the main island PULAU RAKATA (9 km by 5 km with a peak of 822 m altitude) in two, 40 km from JAVA and SUMATRA (Indonesia). One half disappeared into the ocean and the other half was covered by volcanic deposits on a thickness of 60 to 80 m: these deposits lengthened the island towards the south on 4,6 km.
Chronological synthesis of the observations:
- before the eruption: the vegetation must have been similar to the present forest covering parts of JAVA and SUMATRA;
- eruption of August 1883 (t0): it is generally admitted that any form of life disappears;
- june 1886 (t0+3years): 9 species of angiosperms (flowering plants) identified on the coast (+ seeds and fruits of other species); in the interior of the island, crusts of cyanobacteria (blue-green algae, of which the genus *Anabaena* for example) and upper stage dominated by ferns, very locally some species of angiosperms;
- 1897 (t0+14years): on the coast, development of a typical tropical sandy beach community with forest species including "*Casuarina equisetifolia*"; in the interior of the island, dominance of a bio-diverse herbaceous formation, sometimes high (savannah type), including "*Imperata cylindrica*", while on the steepest slopes cyanobacteria and ferns remain dominant;
- 1906 (t0+23years): differentiation and enlargement of the littoral forest colonization -> 2 distinct formations, the denser one dominated by "*Casuarina equisetifolia*" and the other one, more interior, by "*Barringtonia asiatica*" very similar to the one of the JAVA coast. There are also various climbing, bushy and herbaceous species. Some typical but rather isolated species of Malaysian secondary forest are identified more inside ("*Macaranga-Ficus*"). In the interior of the island is developed a savanna of "*Saccharum spontaneum*" which constitutes the essential of the grassy formation identified in 1897. Explored in further inland, a very little diversified forest colonization characterizes erosion gullies. The shrub "*Cyrtandra sulcata*" is newly identified, which later becomes very abundant. Above 400 m of altitude, ferns remain dominant, which seem to be "pushed back" by the savannah-grass formation;
- 1919 to 1932 (t0+36 to 49years): the 2 formations "*Casuarina*" and "*Barringtonia*" regress spatially by coastal erosion, it is observed that they do not include all the species of the corresponding formations of JAVA and SUMATRA; moreover the formation with "*Casuarina*" gives place locally to "*Barringtonia*" or to "*Macaranga-Ficus*". The latter formation (typical Malaysian secondary forest) also grows inland into the "*Saccharum and Imperata*" grassy savanna and will completely replace it. Shade species appear under the trees, such as the orchid "*Nervilia aragoana*". The forest trend is more accentuated in the ravines. The highest part of the island is invaded almost exclusively by the shrub "*Cyrtandra sulcata*", but "*Neonauclea calycina*" which accompanies it develops abundantly. A tropical rainforest of mountain begins to take shape;
- 1951-1952: (t0 +70years): the interior of the island became almost entirely forested and dominated by "*Neonauclea calycina*", 15 m high and common in other parts of Malaysia! Four altitudinal zones can be distinguished: (1) elevation 0-50 m, mixture of Neonauclea and "*Terminalia catappa*", some representatives of "*Macaranga-Ficus*"; (2) elevation 50-200 m, Neonauclea is almost the only tree, but its trunk is more developed; (3) elevation 200-500 m, Neonauclea and presence of "*Maranthes corymbosa*" and "*Ficus spp.*", with lush understory of ferns and "*Selaginella*"; (4) altitude from 500 to 700 m, Neonauclea with the best developed trunks covered abundantly with Bryophites (mosses), abundance of the epiphyte "*Asplenium nidus*". At higher altitudes: shrubs of "*Schefflera polybotrya*" and secondarily of "*Cyrtandra sulcata*" already detected in 1906 at lower altitudes and formerly dominant at higher altitudes between 1919 and 1932, while being in competition with Neonauclea. This altitudinal stratification is mainly attributed to variations of humidity and clouding;
- later, little change in forest cover except in size and extensions of previous strata: still littoral communities and inland forest zone dominated by Neonauclea. It is however established that the stage of reconstitution of the primary forest has not been reached (no Dipterocarpaceae identified).

An amplification of mutations can then increase the polymorphism of the populations and produce in the long run new "native" species as mentioned in the previous paragraph. There is then no need to evoke a brutal temporal modification of biotope because the evolution proves to be necessary at the meeting of unfavorable "environmental" conditions during the dispersal process of the diaspores. Appearance of new species or ecotypes is much more difficult to detect than their extinction. But both phenomena have in common a low population size, the first one decreasing and the second one increasing. However, the rapid differentiation of ecotypes, in 40 years, of the poaceous "sweetflower", *Anthoxanthum odoratum*, in relation to variations in soil pH was demonstrated by SNAYDON (1970) in the experimental grassland park of the Rothamsted station in Great Britain. A more recent review of the evolutionary dynamics in this grassland park was carried out by SILVERTOWN et al. (2006). A strong differentiation between ecotypes for environmental adaptation traits has also been observed by several authors cited by POOZESH (2007, p.93) such as CHARMET & BALFOURIER (1994) in ryegrass, *Lolium perenne*, SAMPOUX (2006) in fescue, *Festuca*, or LIU et al. (1997) in *Agrostis*.

5.2.3. Evolution of biodiversity with aluminization

Several articles cited by OPDECAMP (1998) indicate an inverse relationship between soil pH and biodiversity, at least in the humid tropics. FITTKAU (1973) suggests that the scarcity of basic cations in acidic soils leads to their maximum recycling in the vegetation thanks to an abundance of species, especially in central Amazonia. Perhaps a certain complementarity or cooperation develops rather than competition between species when the conditions of mineral nutrition become unfavorable.

HUSTON (1980) argues that under conditions of abundant mineral nutrients in soils, growth rates are higher and tend to favor competition between species, leading to lower biodiversity. This author examines the results of 46 mature forest sites in Costa Rica for which detailed literature data exist in terms of the number of forest species and the average analytical characteristics of the soils over a thickness of 100 cm.

HUSTON's forest sites vary from low to high elevation and also include swamp forests and "dry forests". Base cations K^+, Ca^{2+} and Na^+, their total sum (including Mg^{2+}) and phosphorus content were found to be negatively and significantly correlated with the number of tree species but not pH. Removal of data from dry forest, swamp and mountain sites did not alter the correlations. With regard to pH, as it is also an average over a depth of 100 cm, this data has no real meaning because of its logarithmic scale and the heterogeneity of the physical and chemical conditions over such a thickness, since several "horizons" are then vertically differentiated. The author recognizes that correlation does not mean cause and effect, but he does not think that these are parasitic correlations and develops several coherent arguments in this respect. Of interest to the author is that species-rich forest sites are all characterized by low levels of basic cations and of phosphorus, whereas in soils with higher levels the number of tree species is always much lower.

PROCTOR et al. (1983) characterized the soils and biodiversity α of trees, shrubs, lianas and grasses at four lowland forest sites (50-300 m) in Gunung Mulu National Park, Borneo Island (Sarawak, Malaysia). It is remarkable to observe in their fig. 6 the contrast between the high specific biodiversities of the most acidic upland sites (pH < 5.0 in DF and HF) and the much lower specific biodiversities of the most basic uplands (pH>6.0, on limestone outcrops LF). However, the total phosphorus content of the latter is much higher. Such results are therefore in line with those of HUSTON (1980, op. cit.). It is a pity that neither of these two studies provides data on the aluminization rates of the soils.

FABER-LANGENDOEN & GENTRY (1991) report aluminization rates of 69 and 80% at pH (H_2O) below 5.0 in the surface horizon (0-10 cm) of two adjacent 1 ha plots of forest assessed as primary in Bajo Calima, Colombia. Both plots are located in the upper part of a fairly steep slope (upland) at a low altitude (50 m) in a hilly region and under a particularly humid ecoclimatic regime (P > 7,000 mm/year). A very high biodiversity α with a dominant presence of Vochysiaceae (aluminium accumulators) in one of the plots was observed. The authors refer to HUSTON (1980, op. cit.) to explain this high biodiversity in such physicochemical soil conditions.

LALIBERTÉ et al. (2013) attempt to explain by which processes biodiversity can increase with lower nutrient availability in the soil in relation to soil age and the degree of pedogenetic evolution. Biodiversity follows a general trend of increase between the poles and the equator.

The available data cited by these authors in their first box show a high biodiversity α in deeply altered soils. In particular, the high forest biodiversity of the "Yasuni" region in Ecuador, where the soils are very acidic and highly aluminized, is cited.
The general increase in biodiversity with soil age is a common trend that also occurs in boreal, temperate and subtropical or mediterranean chronosequences.

The Jurien Bay dune chronosequence in southwestern Australia, of a mediterranean shrubland type, is cited as an illustration by these same authors and deserves a particular comment thanks in particular to the analytical data provided by TURNER & LALIBERTÉ (2015). Indeed, it is a chronosequence of Quaternary age that extends from the beginning of the Pleistocene (2 Ma) to the mid-Holocene (<6.5 Ka), passing through the mid-Pleistocene (120 to 500 Ka). Its soils decalcify and acidify with age, going from a pH of 9.1 to 5.6 (pH H_2O). But the ecoclimatic regime is semi-arid with drier phases during the Pleistocene glaciations. However, primary minerals such as feldspars and amphiboles have disappeared and the soils are also decarbonated except in those dated from the Holocene where they remain present even on the surface. There is no detectable aluminization which is consistent with a pH that remains above 5.5. The parent material is essentially sand: clay contents remain below 3%. The ECEC varies from 1 to 13 $cmol_c$/kg and is hardly attributable to organic matter. ZEMUNIK et al. (2016) do observe in this chronosequence a growth of biodiversities α, γ and even β with soil age.

5.3. Ecosystem progression and retrogression

PELTZER et al. (2010) attribute a predominant role to changes induced by pedogenesis in the evolutionary phases of ecosystems. These authors focus mainly on the phenomenon of their retrogression characterized by a decline in overall biomass after a passage through a production maximum. They exclude from this phenomenon the negative impact of an unfavorable climate as well as the slowing down of biological processes linked either to the age of the vegetation, or to the decline in the ratio between photosynthesis and respiration, or to the slowing down of the mineralization of organic matter, etc. This retrogression cannot be reversed by the temporary effects of a secondary succession (a few decades or centuries) linked to a slash-and-burn operation in a tropical forest for example. In order to reverse it, a real rejuvenation of the soil is required with marked effects on the parent material (glaciation, sedimentary or alluvial deposition, volcanic eruption, geological uplift, peatland stripping by incineration, etc.). The authors apparently give key roles to phosphorus and nitrogen. In any case, they agree to include the study of pedogenetic processes to understand the causes and consequences of retrogression.

WARDLE et al. (2004) describe a geomorphic rejuvenation of the soil as a catastrophic phenomenon, causing a new primary succession leading in an initial phase to a maximum of primary production. But in the prolonged absence of a new catastrophe, they agree in diagnosing a retrogression phase whose processes are poorly understood. They study the evolution of six chronosequences established on the basis of the different ages of soil parent materials under their present climate, even though these sequences experienced different climates prior to the reset catastrophe (rejuvenation) in their more distant past. These sequences represent maximum ages between 6 Ka and 4 Ma. They are developed under various macroclimatic conditions and are named as follows in relation to their location: (1) *Cooloola* (tropical - eolian dune sands in Australia), (2) *Arjeplog* (boreal - resetting of secondary succession following fires on a lake island in northern Sweden), (3) *Glacier Bay* (boreal - glacial retreat in Alaska), (4) *Hawaii* (tropical - volcanic outwash material), (5) *Franz Josef* (temperate - glacial retreat in New Zealand), and (6) *Witutu* (temperate - marine deposition terrace). Four views of the Franz Josef glacial valley are shown in figure 5.4.
The authors observe a general parabolic pattern for the evolution of the basal area of trees as a proxy for their biomass (increase, maximum, decrease). The decline occurs after Ka or tens of Ka and is expressed until the trees disappear at the most evolved stage. The authors suggest that the retrogression is due to less favourable soil conditions, and they mainly refer to lower availability of phosphorus and nitrogen and a tendency to increase the N:P or even C:P ratio in litter and humus during retrogression. A decrease in soil biomass and microbial

respiration is also suggested. Unfortunately, neither the degree of acidification nor the rate of aluminization is measured in the two articles mentioned above.

Figure 5.4: Four views of the Franz Josef Glacier valley in New Zealand at an altitude of about 250 m as well as the Waiho River flowing through it and the humid temperate forest vegetation with Podocarpaceae (Photos: Fotolia)

ZEMUNIK et al. (op. cit.) find that while retrogression does occur in forest chronosequences with relatively low understory biodiversity, in some chronosequences retrogression can also be associated with a general increase in biodiversity. These authors use the three causes postulated by WARDLE et al. (2008) to explain it: (1) competition with trees decreases with retrogression, (2) spatial heterogeneity increases with nutrient decline and (3) competition for light is reduced by the reduction in the number of large trees.

Finally, RICHARDSON et al. (2004) diagnose a progressive phase until the forest cover reaches its maximum height when the soil reaches an age of 12,000 years at the level of the alluvial terraces of the glacial valley in the *Franz Josef* chronosequence (figure 5.4). A regressive phase follows between 12 and 120 ka. They also find a maximum diversity of woody species at 5 ka. The inflection at 12 ka is located in the ancient moraines of the late Pleistocene and is probably attributed by the authors to a decline in phosphorus in the soil. The progressive phase, however, involves a rapid acidification of the soil between 0 and 10 cm with a pH (H_2O) that goes from more than 6.5 to less than 5.5 in only about 100 years and then drops below 5.0 after 130 years of age. The pH stabilizes at around 4.0 after 1,000 years, when the soil would already be highly aluminized, well before the regressive phase. However, no data on exchangeable base cations and aluminium are provided by the authors to corroborate this hypothesis.

5.4. Synthesis and conclusions

With ecological dynamics we enter the hyperspace of fundamental niches (F-niches) and their realization (R-niches). When it is more concretely a question of examining how the R-niches are realized in the terrestrial geographical space, it is necessary to consider not only the interactions between biotic and abiotic factors, between biota and biotopes, but also the bionomic (interspecific) interactions. The neo-Darwinian evolutionary model seems to ignore geographic heterogeneity in mutagenesis, its necessity rather than mere randomness in its course. This is particularly striking when one arrives at the margins of an F-niche. Through windows in hyperspace, such as the one pivoting on the soil pH axis, an instability is observed in the configuration of R-niches. If this instability becomes critical in the face of environmental change, i.e. the change becomes a source of increasing stress on the cellular metabolism (phenotype) of one or more species, then an amplification of mutations would be induced and could lead to epigenetic (ecotype) and genetic (genotype) modifications in the populations concerned. The evolution of species induced by environmental stress would be underestimated while the driving role of DNA would be overestimated as a "program". DNA would rather function as a data bank.

Evolution is an ongoing process. However, drastic stresses of great geographical extent and of geotectonic and/or astro-climatic origin are recognized to have marked the major stages in the evolution of the ecosphere. These are essentially the five great mass extinctions and the subsequent radiations, each time generating a vast renewal of biodiversity and therefore also of the F-niches.
The notions of biodiversity α, β and γ are elastic because their limits are not determined in an absolute way from the geographical point of view. It is also almost impossible to measure them in a complete and exhaustive way. This results in important difficulties of identification that lead to partial characterizations of biota, most often limited to vascular or even woody species with a minimum diameter of a tree trunk. To the reductions due to the partial identification of these are added those of the equally partial identification of biotopes in the practices of ecologists and in particular at the hypogeous soil level. However, many systemic interactions need to be studied, and this is normally the purpose and interest of the ecosystem concept, in which soils are a key compartment. They play a role not only in the definition of its boundaries but also in the integration of biotic and abiotic factors that they operate in their evolution.
The trends of an increase in tree biodiversity with the degree of acidification and aluminization of soils are there to prove it. However, if they are detected by several authors, they remain poorly documented to the point that a decrease in major nutrients such as phosphorus or even nitrogen is evoked to explain the phenomenon. The increase in biodiversity with aluminization could be understood by a complementarity of species in the exploitation of mineral nutrients. These are particularly scarce at the highest aluminization rates and where growth is generally slowed down, which would reduce interspecific competition.

Superficial acidification of soils under primary forest colonization seems to be quite rapid and the same can be assumed for subsequent aluminization, of the order of a hundred years in parent materials probably poorly buffered even under temperate thermal conditions as in the famous *Frans Josef* chronosequence of New Zealand.

The progressive evolution of ecosystems with soil age in terms of biomass production is marked by a regressive inflection at a certain stage of acidification that the literature most often attributes to a decline in mineral nutrients such as phosphorus or nitrogen. This parabolic pattern of biomass or vegetation height evolution is reminiscent of the growth curves of many species in culture solution or in vegetation vases, where aluminium seems to play a key role, precisely in interaction with phosphorus. It is therefore also regrettable that the available studies on the retrogression phenomenon do not provide the rate of soil aluminization. However, evolution of soil pH in these chronosequences are indicative of a similar phenomenon, which would confine phosphorus to a role secondary to that of aluminium.

6. Landgenic traits and characters of aluminization

6.1. Overall history of landgenic facets (LF)

6.1.1. Prehistoric human settlement in the Pleistocene

Very recently, the appearance of the species *Homo sapiens* has been estimated at 315,000 years by fossils discovered in Morocco (CALLAWAY, 2017), against 200,000 years before in East Africa. It is thus in the Quaternary era and during the Pleistocene that the realization of the human niche starts while glacial periods such as the "Riss" and the "Würm" are still taking place at high latitudes. For TASSIN (2014), the anthropization of the planet is a movement that starts in Africa 70,000 years ago. Men leave this continent to join Southeast Asia. The movement continues 30,000 to 50,000 years ago to New Guinea and Australia. The natural ecosystems are progressively modified by vegetation (asexual vegetative multiplication). Yam and taro thus spread in humid tropical climates by cuttings alone, which is confirmed by ROBERTS et al. (2017). The so-called virgin tropical forests have in fact been reworked for a long time by the activity of grubbers and the itinerant practice of slash and burn. They are similar to very slow-rotation agroforests, i.e., long-term forest fallow where humans have inserted themselves into nature (ROSSI, op. cit.). The dog was the first animal species to be domesticated at least 30,000 years ago. The habitat of man is still rudimentary and integrated into nature, consisting of caves and huts of very different structures and forms depending on the people. However, they are all identical in the same community (LAMING, 2015).

6.1.2. Evolution of Ager, Hortus and Saltus since the Holocene

TASSIN (op. cit.) describes the major chronological stages of the domestication and propagation of plant and animal species by Man. The Holocene starts at 8 ka BCE (before the current era = B.C.) and is marked by the sedentarization of agriculture and the advent of cereal farming by a mode of sexual reproduction this time. It transforms hunter-gatherers into farmers in the Neolithic period: small spelt, starch, barley and in parallel lentils, peas, vetch and chickpeas spread from Syria and Turkey to Europe, North Africa and Eastern Asia. In the migratory wake of Homo sapiens, granivorous insects, pathogens, weeds from which rye and oats originated, as well as rice favored by the irrigation of tuber plants such as taro, spread. Around the year 500 EC (current era = A.D.), the Polynesians faced the immensity of the Pacific, colonized more than 500 islands and propagated many species such as sugar cane, banana and sweet potato brought back after having reached America. Among the animal species, after the dog, it was the turn of the goat (8 ka BCE) to be domesticated, followed by the sheep (7 ka BCE), the pig (5.5 ka BCE in Syria), the ox (4 ka BCE), the horse (2.5 ka BCE), the donkey (1.5 ka BCE) and the dromedary (1 ka BCE). Geographical realization of the human niche and the plant and animal niches associated with it follows the history of the peoples. The Romans in their Empire: cabbage, beans, chard, leeks, celery, lentils, asparagus, onions, artichokes, olives, parsley, coriander, oregano, sage. By the development of Islam: spice plants, many vegetables, cauliflower, spinach, carrot, artichoke, watermelon. Amplification of introductions by the great maritime navigations of the 15th century: in Europe, the potato from Peru, corn from Mexico; in Java, the coffee tree from Yemen; in Southeast Asia, the rubber tree from Ecuador via Kew; in Africa, the banana tree from Asia. An anthropic selection of cultivated and domesticated species is taking place. Not only the realization of their niches is considerably amplified but the very evolution of these species is directed by crossbreeding and hybridization decided by Man.

GOLDEWIJK et al. (2017) evaluate the surface evolution of several human land use types over the Holocene starting from current occupancy observed in satellite scenes at 300 m ground resolution. Then they model past evolution with historical data and estimates of demography and population densities. Their results do not, however, include forested areas (Silva) or uninhabited lands such as Antarctica, deserts or rocky outcrops. Saltus can be deduced from

their "rangeland" data and Ager from those for cultivated land and artificial or temporary grasslands (Ager grassland). To distinguish Saltus, the authors state that "rangelands" are characterized by low livestock loads per hectare and include natural grasslands, shrublands, wetlands, and drylands. The vegetation is native rather than man-made. In addition, they use the following criteria: an aridity index of less than 0.5 (P/PET) or, if this index is higher than 0.5, a (human) population density of less than 5 inhabitants/km².
The useful agricultural area (UAA) is obtained by summing the areas in Ager and Saltus. Their results, interpreted in this way, are shown graphically in figure 6.1, with the total land area estimated at around 13,500 Mha , compared with the generally accepted 14,900 Mha.

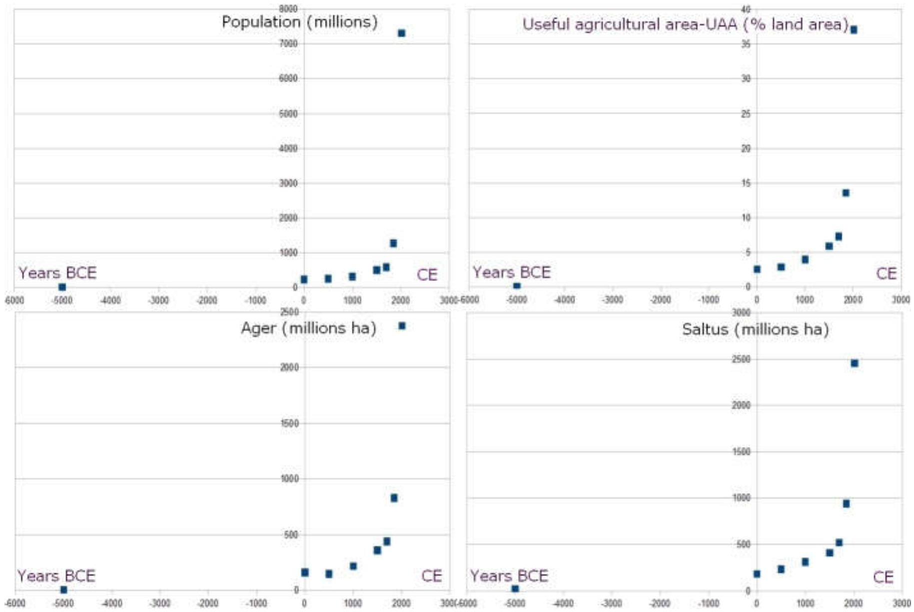


Figure 6.1: Estimated realization of the human niche since the Holocene: population, Ager, Saltus and UAA (Useful Agricultural Area = Ager + Saltus), based on data from GOLDEWIJK et al. (2017)

It is interesting to observe the similarity of the four curves sketched by the model. But since the model is based on population density, it could hardly be otherwise. The "UAA" remains less than 40% of the land area and land settlement really starts with the Common Era (CE). FAO (2016) also estimates this relative area dedicated to agriculture at 37.7% in 2010 CE. Historically, it increased exponentially from 1700 EC. It more than doubles from the Industrial Revolution onwards at 1850 EC which is the penultimate point reproduced in figure 6.1. The LF (landgenic facets) of Ager and Saltus are estimated to be approximately equal in area, or nearly 2,500 Mha each. These are rough estimates at the global scale of the GOLDEWIJK et al. study (op. cit.). To give an idea of the variability according to sources and methods, RAMANKUTTY & FOLEY (1999) provide a global estimate for the year 1990 at the end of their table 3b of 1,792 Mha for Ager's LF, referred to as "cropland" and defined as the sum of "arable" and "perennial crop" land, with the exception of trees exploited as timber or fuelwood. The "arable" land also includes the LF of Hortus as well as temporary (< 5 years) hay or pasture land. At the same time, their "savannas/grasslands/steppes" category could be assimilated to Saltus' LF, which these same authors estimate at 2,671 Mha. The UAA for these authors would therefore be 4,463 Mha in 1990, which represents 33% of the 13,500 Mha of land considered. Table 5 summarizes the data quoted. The question of whether the "UAA" can still increase is a topical one in the world food outlook for 2050, when the population is expected to reach 9 billion. But by the same 2050 time horizon, WATSON & VENTER (2017) report that naturalists want 50% land set-aside to conserve biodiversity according to an ecocentric or biocentric ethic. The latter goal seems compromised based on the shape of the curves in figure 6.1. These also seem to indicate an incompatibility with the first objective of meeting the 2050 food challenge according to an anthropocentric ethic, except demographic transition or landgenic innovations.

6.1.3. History of Silva since the Holocene

FAO (2016, op. cit.) puts forward an estimate of 1,800 Mha of forest area loss at the global level since 3,000 BCE, while UAA is increasing well beyond that to about 4,500 Mha according to table 5. The difference is easily explained by the growth of UAA in arid, semi-arid and boreal areas and the expansion of Urbs' LF. However, the latter occupies only a relatively insignificant area, of the order of 0.55% with 75 Mha according to SCHNEIDER et al. (2003) cited by SCHNEIDER et al. (2010). Still according to the FAO, the current total of forest area in the landmass would amount to a little less than 4,000 Mha taking into account a recent deforestation of 129 Mha between 1990 and 2015. If we then refer to table 5, the LF count of Ager (and Hortus), Silva, Saltus and Urbs would be estimated at between 8,500 and 8,900 Mha out of 13,500 Mha of land area, i.e. between 63 and 66%. We can conclude an estimate of 34 to 37% of the global surface of the Desertum's LF.

Table 5. Estimates of absolute and relative global areas of Ager (+ Hortus), Saltus, Silva, Desertum and Urbs LFs inferred from interpretation of data from GOLDEWIJK et al. (2017), RAMANKUTTY & FOLEY (1999), FAO (2016) and SCHNEIDER et al. (2003) based on an area of 13,500 Mha of land area and Urbs neglected

LF	Absolute areas in Mha	Relative surface areas in %
Ager (+ Hortus)	1.792 à 2.378	13 à 18
Saltus	2.454 à 2.671	18 à 20
Silva	~ 4.000	~ 30
Desertum	~ 4.590 à 4.995	34 à 37
Urbs	~ 75	~ 0,55

6.1.4. Conversions of Silva in humid tropics

For the tropical rainforests of Africa, Asia and America, forest-savanna conversions following drier paleoclimates and natural burns (lightning, volcanic eruptions) or customary anthropic practices (hunter-gatherers and pastoralists) are attested by several indicators, notably of a geomorphological (sediments, hydrography) and palynological (pollens, seeds) nature. CHARLES-DOMINIQUE (1997) reports the great sensitivity of Amazonia to climatic variations but specifies that they take place at different times in Africa or Asia, which allows to induce the existence of different or shifted humid tropical climatic systems from one continent to another.

Africa

SCHWARTZ (1997) reports that in the Congo (Brazzaville) the climate dried up during the Upper Holocene (1000 BCE), causing a forest regression with a conversion to Saltus in the form of savannah. He attributes this landgenic modification to the concomitant practice of anthropogenic fires. However, non-landgenics savannas (non-anthropogenic), of a different type, more wooded and natural, were previously established to the detriment of Silva, during the great glaciations, especially in the Upper Pleistocene.
Recent deforestation of African rainforests, between 1990 and 2010 EC, is the subject of an article by MAYAUX et al. (2013). The authors provide the following areas of Silva: nearly 200 Mha in total in 2005 mainly concentrated in the Congo River basin. Deforestation measured between 1990 and 2000 is 590,000 ha/year which is 4 times less than in Latin America. And this deforestation is still reduced by almost half to 290,000 ha/year between 2000 and 2010. Madagascar is the region with the highest deforestation rate, respectively 1.63% and 1.08% for the two periods considered. A critical threshold of rural population density is detected at 8.5 inhabitants/km² beyond which deforestation accelerates. This threshold is close to the 10 inhabitants/km² that JOUVE (op. cit., p.89) evaluates for the reconstitution of sufficient forest cover in slash and burn agriculture. Beyond this point, the permanent conversion of Silva into Ager becomes necessary and seems to take place in parallel with the conversion into Urbs, according to MAYAUX et al. (op.cit.), along the old colonial roads and near urbanization centers. It seems likely to us that such conversions, conducted somewhat "haphazardly", are

not necessarily sustainable. Deforestation for the production of firewood and charcoal in particular is significant near large cities. For the city of Kinshasa, it extends to a radius of 300 km. The authors do not specify the future of the deforested areas, but indicate possible reconversions, notably to cocoa, coffee, oil palm and rubber plantations, depending on market developments. FAO (2016, op. cit.) reminds us of the influence inherited from the colonial period on the mechanized exploitation of forest reserves and the establishment of agricultural plantations mentioned above. Nigeria, for example, has lost more than 90% of its "primary" forest. However, for the FAO, deforestation in sub-Saharan Africa has remained less pronounced than in other tropical regions.

America

Natural paleo-fires detected by buried layers of charcoal in Guyana and Amazonia are reported by CHARLES-DOMINIQUE (op. cit.) between 8,000 and 6,000 BCE and between 4,000 and 2,000 BCE while human presence is only attested since 500 BCE.

For Central and South America, FAO (2016, op. cit.) reports significant deforestation between 1700 and 1900 CE with an overall reduction in forest cover of 75 to 70%, but which then increases in the 20th century with an overall reduction of up to 50%. For the Brazilian Amazon, TSAYEM DEMAZE (2008) synthesizes and documents the evolution of several recent deforestation modes resulting from a deliberate policy of economic and social development. First, and since 1953, a colonization encouraged by public pioneer fronts of conversion into food Ager and Saltus for cattle, then by private fronts. The latter have been facilitated since 1974 with a conversion to Saltus in the form of very large "ranching" operations of several thousand hectares each and dominating nearly 70% of the deforested areas. Since the 1990s, there has been the invasion of an intensive monoculture of soybeans with high levels of inputs and cattle livestock for an export agribusiness. The same author also reports the development of Urbs in cleared areas with the creation of villages, towns and "ruropolis" which are larger agglomerations. As for the exploitation of the Amazonian Silva, it is traditionally centered on the roçà, i.e., subsistence slash-and-burn agriculture for 2-3 years with a forest fallow of several decades. Compared to the population density of 10 h/km² cited as critical for slash-and-burn agriculture in Africa, TSAYEM DEMAZE (op. cit.) suggests a lower threshold of 3-4 hab/km² for this same sustainable forest fallow system in the Amazon. Forestry exploitation also includes, and more recently, a significant production of tropical wood, of which Brazil has become the world's leading producer.

Asia

FAO (2016, op. vit.) gives China a population of 1.4 million in 2000 BCE and a forest cover of 60%, while in 1840 BCE it was reduced to 17% with a population of 413 million. DÉRY (1996) reports that in the middle of the 20th century Silva represented only 5 to 10% of Chinese territory. The fading of the Chinese Silva, specifies this author, took place between the 14th and 19th centuries because of the strong demographic growth. A migration of populations was marked by the agricultural colonization of the large central plain constituted by the lower reaches of the Huang He (Yellow River) and the Chang Jiang (Blue River) as well as the peripheral areas.

For the FAO (2016, op. cit.) forest area in South Asia is estimated to have further decreased by more than 50% since 1500 CE, in part due to the exploitation and export of timber during European colonization. However, forest traditionally used for slash-and-burn agriculture has been maintained in many parts of Asia.

In Southeast Asia, DÉRY (op. cit.) states that the population rose from 32 million in 1800 EC to 83 million in 1900 and then to more than 470 million in 1995 with an average density of 105 h/km². The recent decline in Silva, between 1960 and 1990, is essentially to the benefit of agriculture, but it is geographically nuanced. It remained rather stable in Burma, Cambodia and Laos. In contrast, Ager more than doubled between 1960 and 1990 in the rest of the region (Indonesia, Malaysia, the Philippines, Thailand and Vietnam). A review of recent major changes in general landgenic characters in Indonesia and Malaysia by WICKE et al. (2011) reports a surge in oil palm plantations. Its area increased globally from 3.5 Mha in 1975 to 13.1 Mha in 2005. This rapid transition was largely achieved by converting Silva into approximately half plantation Ager in Sumatra and Kalimatan and half rice Ager on a total of about 40 Mha in Indonesia. This represents 30% of the original forest area. A lesser deforestation of 5 Mha has occurred in Malaysia, but oil palm plantations have also converted former rubber and coconut plantations. In addition, deforestation in Malaysia has slowed since the early 1990s. Figure 6.2 shows a young oil palm plantation in a deforested area of Malaysia. At the global or regional scale of the WICKE et al. study, one is faced with a labyrinth of possible causes and a diversity of modalities and forms of deforestation related to geographic heterogeneity.

Figure 6.2: Young oil palm plantation in Johore Labis, Malaysia (Photo: Jean-François Kreit)

GARRITY et al. (1997) report the maintenance of *Imperata cylindrica* savannahs in tropical Asia in the form of mega, macro or meso Saltus areas. These savannahs are associated with forest recruits from shifting agriculture and also include other grassy species. They may occur as large, relatively uniform patches (mega) with fires, or as fine mosaics associated with shrub patches (meso), or even as micropatches integrated with Ager-Hortus and Urbs in villages where their control is a matter of weed infestation at farm level. Species *Imperata cylindrica* is referred to as "*alang-alang*" in Indonesia, "*cogon*" in the Philippines and "*lalang*" in Malaysia and "illuk" in Shri Lanka. Figure 6.3 shows the Saltus of "*cogon*" in the Philippines. Imperata savannas also occur in India, southern China, Vietnam, Thailand, and Laos. The authors estimate that in tropical Asia the areas reached globally 35 Mha, which represents only 4% of the considered territory and are grazed mainly by ruminant livestock at various scales.

Figure 6.3: Panoramic view of Saltus with Imperata in the Philippines (Photo: Fofolia)

6.1.5. Silva conversions in European region

In Europe and its surroundings (Near East and North Africa), KAPLAN et al. (2009) situate the installation of the first agrarian societies in the mid-Holocene (circa 4000 BCE). A succession of conversion cycles from Silva to Ager or Saltus and of abandonments as well as reconversions to Silva took place thereafter. The authors reconstruct the history of the anthropization of this region between 1000 BCE and the industrial revolution of 1850 CE. The date of 1000 BCE is chosen as the starting point because permanent agriculture (Ager & Saltus) is well established everywhere in the region, except in Iceland and the Faroe Islands. The main dynamic factor of the model used is still population growth, but its relationship with deforestation is modified in the sense of an acceleration by innovations in agrarian techniques around the four dates of 350 BCE and 1000, 1350 and 1830 EC. A reduction of the population by the Plague between 1350 EC and 1450 EC is marked by a pause in the great forest clearings of the Middle Ages. DÉRY (op. cit) describes the deforestation at this time as "massive" in the flat lands (plains) and establishes a link with the invasion of cereals, especially in Germania. KAPLAN et al. (op. cit.) establish the intervention of factors other than population growth, and first of all that of the suitability of the land for Ager (Scrops). The latter is established in their model on the basis of four soil-climate variables: (1) the potential number of growing days when the average daily temperature is higher than 5°C, (2) the water availability index by the ratio between actual and potential evapotranspiration, (3) the soil pH and (4) the soil organic carbon content in kgC/m². For Saltus suitability, only the first two climate parameters are used. Lands assessed as unsuitable are preserved from deforestation in their model. In their figure 9, KAPLAN et al. show several countries at 1500 EC and 1850 EC that are distinguished by higher population densities than those that were previously consistent with their quasi-linear relationship with their suitability for Ager. At 1500 EC, Norway, Scotland, Switzerland, Austria, Belgium and the Grand Duchy of Luxembourg, as well as France and Italy, stand out. And by 1850 EC, many others were added that rendered the initial relationship almost caducous, such as Finland, Sweden, Denmark, England and Ireland, or Poland, Czechoslovakia and Hungary. This dislocation of the relationship between population density and aptitude for Ager is obviously attributed to the development of trade and urbanization as well as to industrialization. The model explaining the conversions of Silva to Ager and Saltus thus breaks down completely with the industrial revolution. DÉRY (op. cit.) mentions, however, that the colonial period allowed for a supply of wood and various agricultural commodities from the colonies. Finally, the same author indicates that the European Silva has become quite stable and has even increased by 15% between 1965 and 1983. This phenomenon of agricultural decline is to be related to the intensification of agriculture, particularly within the European Union. Such a phenomenon could take place because of the second agricultural revolution that Europe experienced in the middle of the 20th century.

6.1.6. Advent and historical co-development of Urbs and Hortus

From the first villages to the first cities

It is reasonable to suppose that the first built sites were linked to the sedentarization of agriculture. But both MERLIN (1991) and LAMING (op.cit.) argue in favor of the emergence of Urbs around a religious place of worship. Thus the site of Göbekli Tebe, illustrated in figure 6.4, in South Anatolia and dated to about 10,000 BCE, indicates a common building constituted by a temple with its sanctuary. It could thus be the religious need that provoked the emergence of the first elements of community building rather than the sedentarization of agriculture, to give rise to the first cities of humanity. Among the great first ancient cities, LAMING cites Damascus as probably the oldest (10,000 BCE). The important urban sites are settled in the fertile plains (Ager) near the big rivers (Aqua). Still according to LAMING, the initial communication route is fluvial, the oldest known land route is located in Egypt and would date from 2500 BCE after the domestication of the horse and the invention of the wheel around 3500 BCE. However, VIDAL (2014) closely links the history of Ager and Urbs from the beginning of the Holocene by sedentarization in the form of villages, the most productive and best organized of which develop into cities. Indeed, villages need artisans for foundries, forges and other workshops as well as merchants and infrastructure for trade and transport. It must well be admitted that an initial critical size is necessary for a religious link to be useful in binding a community together. VIDAL cites four hotbeds that will spread: the Mesopotamian with wheat, the Chinese with rice, the Aztec with corn and the Inca with potatoes.

Figure 6.4: Archaeological site of Göbekli Tebe dated to the beginning of the Neolithic in the south-east of Anatolia, present-day Turkey (Photo: Fotolia)

Fruits and vegetables are also domesticated and are the object of particular attention and care distinct from the fields of Ager. This is how gardens dedicated to them emerge in and around the villages. It is the advent of Hortus in the intimacy or the proximity of Urbs. Hortus is used to describe any highly intensive agricultural practice within, near or at a distance from cities. Hortus LF in the city is considered as urban agriculture. This includes high value-added crop and animal production per unit area, such as vegetables, fruit, seaweed, fish, poultry, pigs and horses (formerly for transport), flowers and ornamental plants, and sometimes even wood. The LF of Hortus is thus more or less intimately integrated or associated with that of Urbs and this since the Middle Ages, even Antiquity, according to the study of SMIT et al. (2001). The latter authors indicate that in 19th century Paris, the annual production of fruits and vegetables can be estimated at 50 kg/year per producer in the Marais district and other marshy areas around the city. It is from this name that the term "maraîchage" is derived. This supply exceeded the demand. Assessments of the relative area of Hortus in Urbs by MARTELLLOZO et al. (2014) result in a global average of about 30% to meet the fruit and vegetable needs of urban dwellers worldwide. However, there are huge disparities between countries with extremes of 1.2 to 397.4%. The authors conclude that many cities in the world are not at all self-sufficient in fruit and vegetables.
LAMING (op. cit.) highlights the importance of the availability of local resources for founding and developing cities, such as the proximity of a river and fertile land for agriculture and livestock, which will allow exchanges between peasants and city dwellers. The local context will thus give specific characteristics to the cities: climate, nature of the materials, type of livestock, trade, political system, etc. In this respect, LAMING regrets the monotony of current cities in a context of globalization where the identity of cities has become indifferent to this local context.

E*volution of Urbs during the Holocene*

The rate of urbanization is defined by UNITED NATIONS (2008) as the percentage of the population living in urban areas. The global evolution of urbanization and its geographical distribution since the beginning of the Holocene is assessed by GOLDWIJK et al. (2010). Figure 6.5 illustrates the results at global level and more specifically for Western Europe, China and tropical Africa. For comparison, we need to take into account the variations in size on the y-axis. It is double for Western Europe (0 to 80%) compared to China (0 to 40%). In tropical Africa, the y-axis only varies between 0 and 30%, while for the whole planet it varies between 0 and 50%.

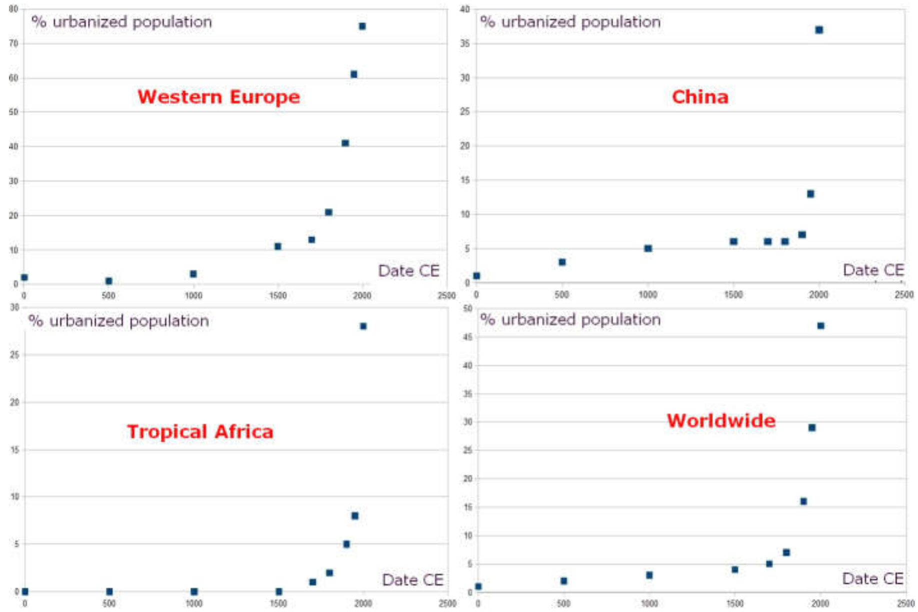


Figure 6.5: Historical trends in urbanization rates in Western Europe, China, tropical Africa and the Worldwide, based on data from GOLDWIJK et al. (2010).

It is remarkable to observe the similar pattern of evolution of urbanization rates with those of population, Ager and Saltus in figure 6.1, i.e. with the rate of anthropization or realization of the human niche.

Before the Common Era (BCE), the rate of population urbanization was insignificant overall. It reached 10% in Western Europe at the end of the Middle Ages (1500 CE), while in China it was still only 5%. Urbanization accelerated in Western Europe with the industrial revolution and the colonization of Africa. China, on the other hand, has only seen real growth in urbanization since the second half of the 20th century. Today, half the world's population is urbanized, and the rate even exceeds 75% in Western Europe. Similarly high rates of urbanization are also reported for the populations of North and South America, Russia (71%), Korea (73%) and Australia (82%). The same authors estimate the global surface area of Urbs at 4,000 km² in the year 1 EC, but with an uncertainty of 75% (±3,200 km²) on the exact area. During the 19th century, with the industrial revolution, the global surface area of Urbs tripled, from 16,000 (±2,400) to 47,000 km² (±2,300). In 2000 EC, the authors estimate it at 535,300 km² (± 5,353), which is less than the 75 Mha (750,000 km²) estimated elsewhere and presented in table 5. The difference probably stems from the criteria used to identify Urbs (urban/rural Urbs) and probably also from the varying size of the minimum identifiable area, depending on the degree of ground resolution of the studies. If we take the median world population estimate of GOLDWIJK et al. (2010, op. cit.), i.e. 6.145 billion, and consider that half live in Urbs, the overall average population density for this LF would be 5,740/km². These authors also mention a maximum density of 40,000/km² (urban Urbs).

From the characters of the ancient city to the industrial city in Europe

MERLIN (op. cit.) refers to FUSTEL DE COULANGES (1885) to characterize the ancient city. In both Egypt and Rome, ancient cities were ordered with rectilinear layouts, rectangular squares and axes often oriented according to the four cardinal points, reflecting a religious influence. The city would be "*the projection on earth of the space where the divinities live*". However, this rectangular plan was not always applicable, particularly in Greece, due to topographical or geomorphological constraints. In contrast, Rome adopted a regular geometry based on two

rectangular axes: the cardo (north-south) and the decumanus (east-west). The space around the city became more organized with the domestication of animals, which enabled produce to be transported over greater distances. VIDAL (2014, op. cit.) describes a concentric organization around Urbs from Roman times onwards, as shown in figure 6.6.
Urbs thus develops into Ager.
Urban dwellers are in direct contact with horticulturalists, mainly market gardeners, while peasants are further away, and shepherds and pastoralists even more so. An important point to note is that this pattern of spatial organization marks a major centripetal gradient in population density, in relation to both density and types of employment. The ancient agrarian revolution evoked by MAZOYER and ROUDART (2002, p.292) confirms the emergence of these various landgenic facets.

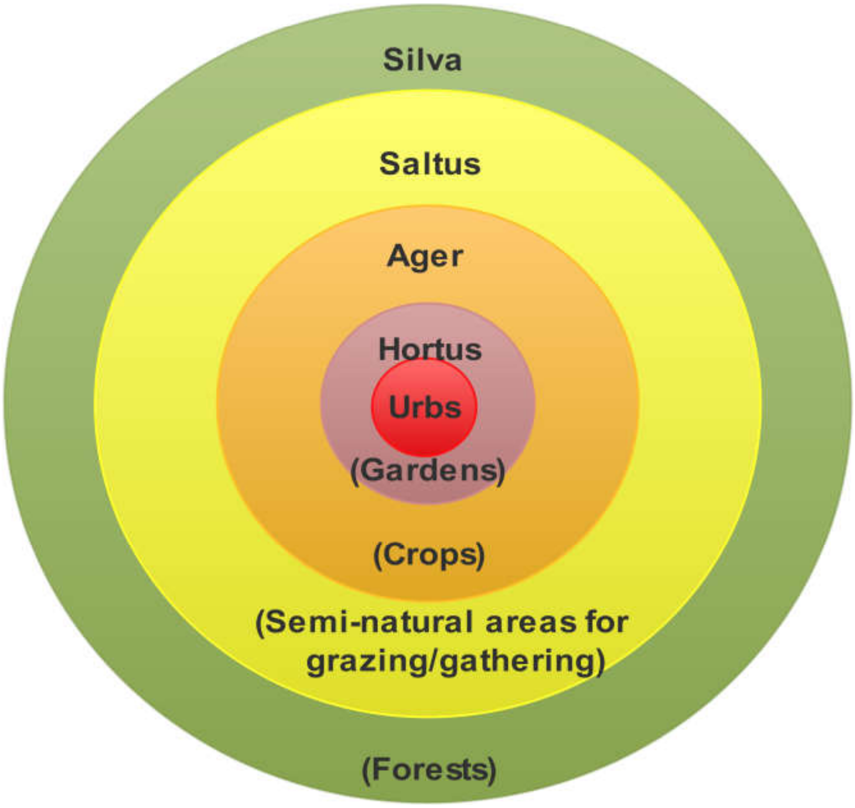


Figure 6.6:.Schematic concentric organization of space around towns from Roman times

In the Middle Ages, the city was encircled by walls, and buildings were crammed in for security (LACAZE, 1990, p.25) against the threat of barbarian invaders. The city's commercial character was affirmed by the development of the market square, along with the cathedral and the sovereign's castle (MERLIN, op. cit., p.9). Ambrogio Lorenzetti's fresco, "*Allegory of Good and Bad Government*" (1337-1339), reflects the principles of exchange and moderation promoted by the commune of Siena to achieve osmosis between country and town. An extract is shown in figure 6.7.

According to LAMING (op. cit.), the Middle Ages were a period of urban decline, while the countryside grew stronger. But MERLIN describes the towns of this period as endowed with a certain harmony, with a homogeneity of materials in small buildings of simple architecture around narrow, winding streets. Their layout was well adapted to the topography, and avoided being too windy. The "*commercial districts are located close to the gates, in contact with the roads and the countryside*".

With the Renaissance, starting in 15th-century Italy (Quattrocento), LAMING points out that "*neighborhoods became specialized according to trade, the cosmopolitan population grouped* *together in communities, social classes stratified*" and the risk of famine also increased. MERLIN points out that the architectural movement that originated in Florence initially inserted itself modestly into the medieval city. It then reintroduced orthogonal or radiating geometric plans, whose military dimension produced star-shaped structures in fortress towns. This was followed by the emergence of the Baroque style, which dominated southern Europe, particularly Italy, in the 17th and 18th centuries. For MERLIN, there is no such thing as Baroque urbanism, but simply an overlay of straight lines and circular arcs on the medieval urban fabric. On the other hand, for LACAZE (op. cit., p.26), Baroque urban planning, made up of "*large breakthroughs through the fabric of old quarters*", is a system whose success has proved long-lasting. Wide, rectilinear lanes formed axes oriented towards churches, castles, towers or great monuments. In France, MERLIN distinguishes an architectural evolution not towards the Baroque, but towards a classical style linked to a Cartesian concern for order and reason. This style can be seen in VAUBAN's fortress towns, the Palace of Versailles, the great squares of Paris (Dauphine, des Vosges, Vendôme, etc.), and the royal squares common in provincial towns, also mentioned by LACAZE. At the same time, the Classical style saw the city's medieval ramparts overcome or disappear in favor of large boulevards. MERLIN also cites the reconstruction of London in neoclassical style after its fire in 1666, or the district of large circular canals during the 17th and 18th centuries.

Figure 6.7: Partial view of Lorenzetti's fresco focusing on the the effects of good government in the city (Photo: Fotolia)

With the first two industrial revolutions (coal/steam engine, oil/explosion engine) and the rural exodus enabled by the agricultural revolutions associated with them from the mid-18th century, urban planning (urban Urbs) faced the challenges of expanding large cities. MERLIN evokes the new technical and utilitarian concerns, notably for water supply and wastewater collection networks, public transport and the mobility of horse-drawn carriages and then automobiles, new housing for workers and employees "*outside the walls*", and so on. New "industrial" towns were created near the mines or grew out of the transformation of the ports.

6.1.7. Discussion

LF dynamics in the quaternary era

With the appearance of *Homo sapiens* in the Pleistocene, the world's various natural facets began to mutate into landgenic facets. The first mutation took place before the end of the ice ages. It concerned the primary tropical rainforest, which became Silva under the influence of hunter-gatherers and planters. They practiced slash-and-burn agriculture. The natural savannahs then mutated into Saltus as livestock pastoralists set fires to maintain grass cover. Human migration spread outside Africa, towards Asia, thanks to cultivation of plants such as taro and yam. Human sedentarization and the concomitant appearance of Ager and Urbs thanks to cereal cultivation mark the beginning of the Holocene at 8 ka BCE. Anthropization of the planet progressed from four major centers of Ager and Urbs: wheat in the Middle and Near East, rice in China, maize in the Aztec country (Mexico) and potatoes in the Inca country (Peru). In humid and sub-humid climates, tropical and temperate, human colonization is marked by the expansion of Ager and Saltus areas in forests and grass formations, but a significant part also becomes Silva through abandonment and reforestation. The dynamics of Hortus are linked to those of Urbs.

The speed of colonization of the *Homo sapiens* R-niche seems to have increased exponentially with the first industrial revolution. It's reasonable to assume that this R-niche will soon reach "saturation point". And so, to envisage a demographic transition in future decades, i.e. a change in the balance between mortality and birth rates for our species. But it's also possible to envisage landgenic innovations involving the mutation of Silva or Saltus into Ager.

Figure 6.8 shows a schematic diagram of the possible dynamics between the different landgenic facets generated by the anthropization of the ecosphere since the Pleistocene. This diagram applies to humid and subhumid climatic regimes of uplands or lowlands with permanent hydromorphy, as well as to certain unconfined environments with temporary hydromorphy, i.e. the various ecoclimatic conditions favorable to soil aluminization (see paragraphs 3.1.2. and 3.1.3. in point 3).

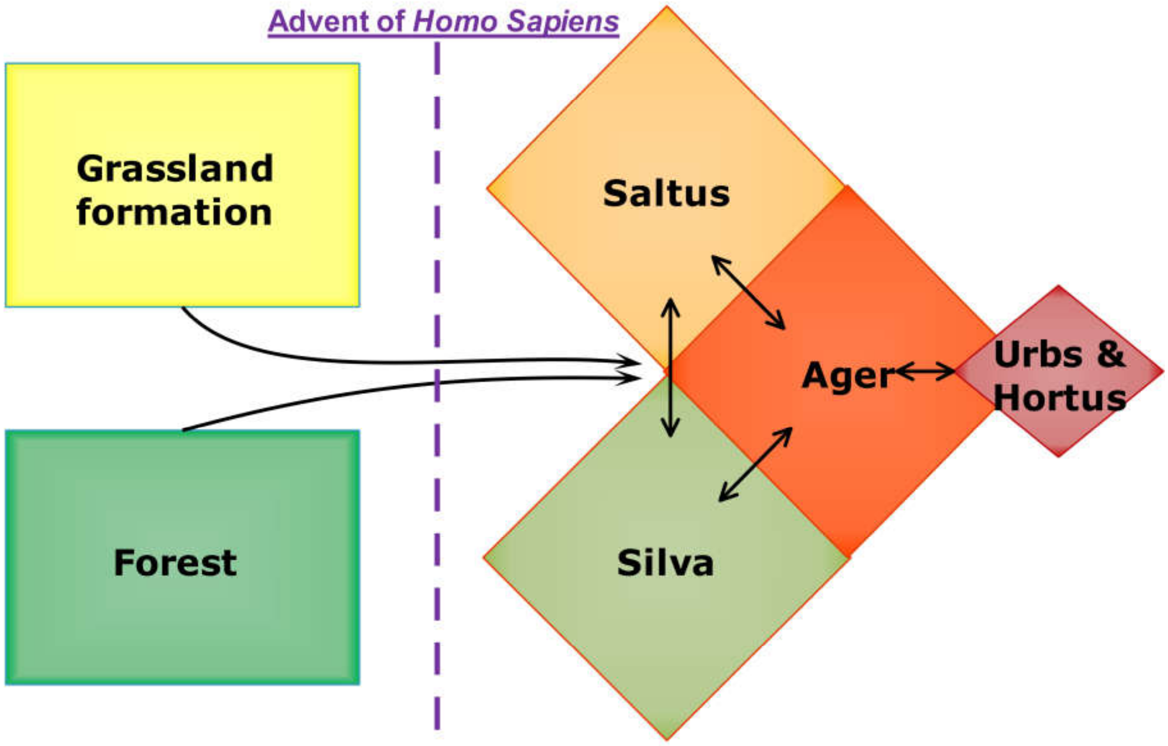


Figure 6.8: Diagram of possible LF dynamics following anthropization of the ecosphere under ecoclimatic conditions favorable to soil aluminization.

It is also partially applicable outside, but neglects the Desertum and Aqua LF. As such, this

schema has only descriptive value and does not provide keys to explain the various transformations of natural space by *Homo sapiens*.
Its ambition is simply to demonstrate the relevance of the LF concept to the vast regions that make up the globe. The keys to landscape mutations cannot be found on the global scale addressed, as it is far too small in the face of the extraordinary geographical diversity of landgenic species (LS). While soil aluminization takes place over vast areas that can be identified on a planetary scale, the processes involved generate landgenic results that are too varied to be discernible on this scale. It is at the local level of landgenic holons (LH) that certain data relating to landgenic traits can be examined to explain, at least in part, the territorial dynamics adopted by the various LF. But it already seems clear that the diagram proposed in figure 6.8 does not envisage any fixity of the LFs and therefore also of the LSs that make them up. Arable land (Ager) can be converted into any other LF, and vice versa. The landscape model is fundamentally evolutionary.

Controversies on the Anthropocene concept

The concept of the Anthropocene as a new geological epoch is proposed by CRUTZEN (2002) cited by MALM & HORNBORG (2014) and PREISER et al. (2017), but remains unrecognized by geologists. CRUTZEN suggests that this era began with the invention of the steam engine by James WATT. This invention marked the advent of the first industrial revolution and effectively led to the mining of coal, followed by the mining of oil with the second industrial revolution of the internal combustion engine. DIOT and TASTET (1995) also point out that the beginning of the Holocene is marked by global warming, leading to the end of the Pleistocene glaciations and to a rise in sea levels, giving way to a marine transgression with the deposition of marine and continental sediments until 6000 BCE. The suggestion of the advent of the Anthropocene is also understandable in view of the exponential evolution of human population and UAA (Ager + Saltus) in figure 6.1, and of Urbs in figure 6.5. But this concordant pace is due to the major role given to human demography in global LF evolution models. For MALM & HORNBORG, an Anthropocene could begin with the mastery of fire, and thus the energetic use of carbon stocks produced by the biosphere. But these authors insist more on the advent of a "capitalist" fossil economy with the industrial revolutions since the 19th century. An economy decided by an infinitesimal minority of the population who possess the necessary means and financial investment powers. The same authors underline the epistemological break that denaturalizes climate dynamics. But the latter is immediately "re-naturalized" by the inclusion of fire control in the genotypic traits of the human species, via the theory of anthropogenic global warming! What's more, according to these authors, this "re-naturalization" brings the sociology that observes human behavior into the natural sciences. Anthropocene becomes thus a post-Cartesian concept, abandoning the distinction between Culture and Nature. The same reasoning would apply to the global erosion of biodiversity caused by the anthropization of the planet. This has led to the elimination of habitats for non-domesticated species, which has also triggered a counter-movement to conserve Nature. This gives rise to the concept of planetary socio-ecosystem, evoked by PREISER et al. (op. cit.) as one of the four perspective frameworks for ensuring a "good" Anthropocene.
Finally, NEKOLA et al. (2013) conclude that the planetary globalization of human civilization could mark the end of the Darwinian-Malthusian dynamic that has enabled humanity to overcome the successive collapses of civilizations (Mesopotamian, Egyptian, Greek, Roman, Mayan, etc.). In the authors' view, this type of dynamic succeeded because civilizations were localized, whereas today's crisis would be globalized. But they also recognize that we are still living in complex adaptive systems of a fundamentally unpredictable nature. So the debate between Malthusians and Cornucopians (or abundantists) is not yet over, especially as globalization can in no way erase the differences between the natural and cultural resources of the regions, sub-regions and localities of the world's various countries.

6.2. Local agropedological focus

LH (landgenic holons) are a level of organization underlying LF. These last ones are identified at the local level, i.e. infra-regional in the sense that it is less than or equal to that of a natural region. Criteria of administrative subdivision do not come into play. However, it can be argued that, in the administrative sense, the local level is infra-departmental or infra-provincial, but it

can also be inter-communal or inter-village within the same LI (landgenic instantiation). LI itself belongs to a level below an LS (landscape species), according to the hierarchical organizational structure diagram proposed in figure 2.5, point 2. The LS level itself is also lower than or equal to that of a natural region. The LH is a level imperceptible to an observer devoid of knowledge of the empirical practices of actors working in the various types of LF to model them according to the desired phenotypic traits. Identifying LH requires expertise to identify the genomic traits that underpin the expression of LH traits conferred by the corresponding actors. This brings us to the landgenic traits and characters specific to the LF of an LI or, more broadly, an LS. Under the specific angle of the soil acidification and aluminization processes described in point 3, the interactions between the aluminization rate trait and other agropedological traits are examined. The dynamics generated are also discussed from the same agropedological perspective. Aluminization does appear to play a role in landgenic differentiation, through its effect on plant growth and thus on primary biomass production and, ultimately, on "yields". However, aluminization seems to promote biodiversity in woody species, as suggested by the data in point 5.
An LF only emerges if the traits of its constituent LH are inter-compatible, and if the characteristics on which they are based support a production capacity that is accepted and desired by the stakeholders from a socio-economic and cultural point of view. Production concerns plant and/or animal foodstuffs, textiles, energy or construction products, etc. To varying degrees, it includes primary or minimally-processed products, as well as non-market commodities or commercial services with sufficient market outlets.
In point 2 of the general presentation of the landscape model, a symbolism is suggested for the representation of LH. It uses a succession of letters in two groups separated by a comma, such as "iAg,abcde..." for holons in an Ager LF, for example (see point 2.4.1.). The "iAg" before the comma represents a potential common of intelligent agents (symbol "i") of an Ager LF holon (symbol "Ag"), and the succession of adjacent letters "abcde...", after the comma, represents for each letter a holon-specific feature, regardless of the vertical compartment to which that feature relates. The various traits symbolized refer not only to a cropping system with its technical itinerary, but also to topographical, pedological (degree of aluminization, pH, depth), socio-economic (cash or subsistence production, for example), etc. depending on the various expert disciplines involved. As a result, the dynamics of holons are much more rapid than those of LF, since a cropping system can be modified at the mercy of economic conditions, technological innovations and so on. The same type of reasoning applies to holons in other LF with specific intelligent agents (Silva, Saltus, Urbs, Hortus, Desertum or even Aqua).

Another word on the traits and characters of Ager, Saltus, Silva or Hortus LHs, to refer again to JOUVE (op. cit., p.73). The logic of the practices that shape traits is that of the decisions taken by farmers (or horticulturists, pastoralists and foresters). Practices are not the fruit of chance. Decisions are based on an empirical perception of environmental traits. The knowledge acquired reflects a peasant's rationality: "*peasants are not learned enough to reason out of order*" (Montesquieu). Among the constraints to which these actors are subject, the main ones are pedo-climatic, phyto- and zoo-sanitary adversities, the volatility or scarcity of markets, and so on. Practices and their evolution are driven by strategies and fluctuations or changes in the objectives pursued. Work can become more limiting than the land (e.g. sowing the same species in as diverse terrains as possible, so as to choose to weed only where growth is best). The internal logic may favour meaning through functions rather than cause through effects, which sets the systems approach apart from the classic positivist scientific approach. There is a need to combine explanatory elements from different disciplinary fields (JOUVE, op.cit., p. 73). In addition to science, religion, art and culture can also play a role in motivating LH characters.

6.2.1. Traits of Silva's landgenic holons (LH) in slash-and-burn

Ancestral practices of slash-and-burn agriculture, hunting and gathering date back to the Pleistocene in the humid tropical forest regions of Africa, as already mentioned (point 5.1.1.). FEARNSIDE (1985) draws up a fairly complete picture of these ancient traditional practices in the Amazon rainforest, as well as new alternative practices. DE ROUX (1991) describes the slash-and-burn system for the Taï forest in south-west Côte d'Ivoire, in the lower Cavally river basin bordering Liberia. ALONGO (2013) looks at the intensified system of grubbing at

Yangambi near the Congo River, in the central Congolese basin (DRC), resulting in forest fragmentation.

Geomorphological situations and frameworks

FEARNSIDE (op. cit.) distinguishes between practices in the highlands (terra firme, uplands) and those in the lowlands (várzea, floodplains). He thus emphasizes a more varied relief than is usually assumed. SANCHEZ et al. (1982) represented this relief schematically in figure 4, which is reproduced and adapted in figure 6.9. Uplands with flat to undulating relief account for 50% of the basin's surface area, while the same authors report that 75% of the Amazon basin is made up of acid soils rated as "infertile". The rate of aluminization is such that it is toxic for many species cultivated in the *terra firme* (uplands).
Lowlands are made up of present-day alluvial deposits that are regularly flooded by high water. They also include recent alluvial terraces that are more occasionally flooded, and whose ecoclimatic regime is marked by temporary hydromorphy. Lowlands with permanent or temporary hydromorphy account for around 25% of the Amazon basin's surface area. A similar picture applies to the Taï forest in Côte d'Ivoire, except that the landscape here is capped by lateritic ridges. The distinction between up- and downlands is also used by DE ROUW (1991). Up-Lowland in North Vietnam has also been adopted by CASTELLA (2005), but without further specifying the HP of the agropedological point.

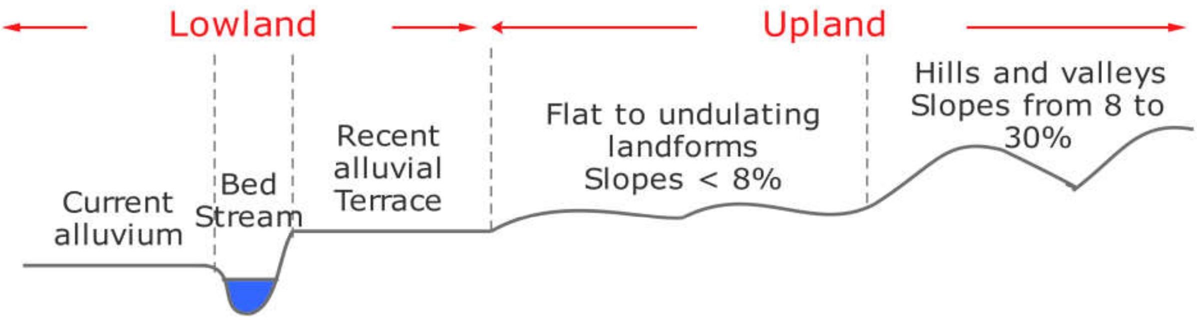


Figure 6.9: Schematic representation of the relief of the Amazon basin after SANCHEZ et al. (1982, fig.4)

For the Yangambi region in the DRC, a general location is shown on a hydro-orographic background in figure 6.10.

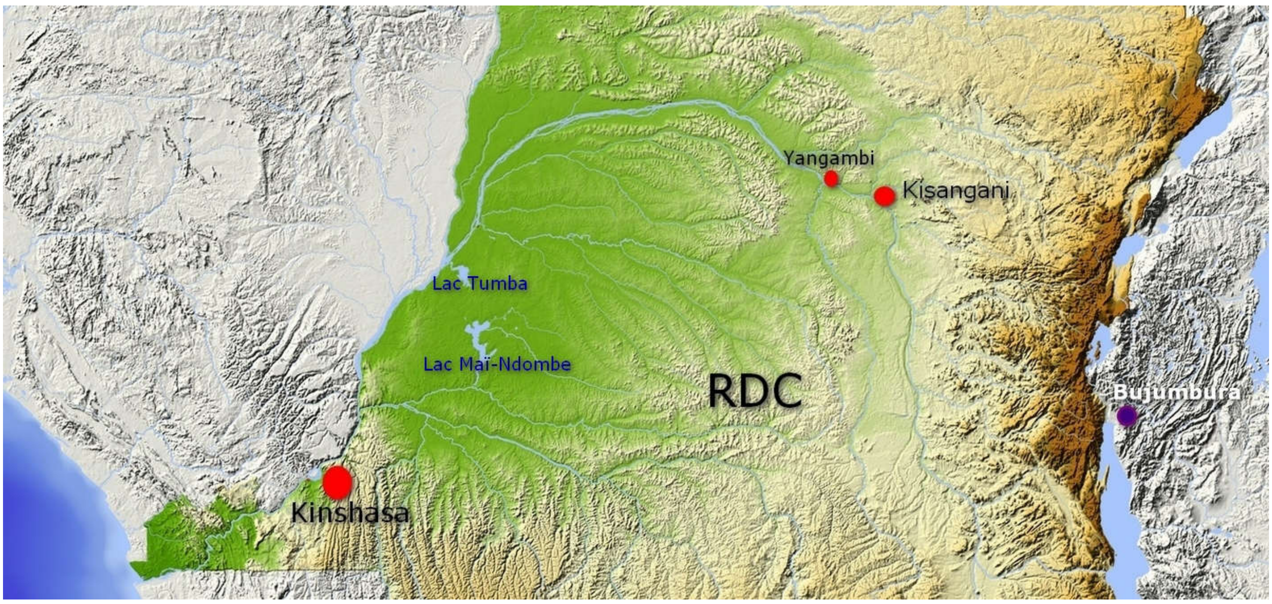


Figure 6.10: Location of the Yangambi region in the Congo River basin, DRC (Source: Fotolia)

ALONGO (op. cit.) describes the central basin as an immense, generally forested depression of

900,000 km². It is bounded by the 500 m contour line and drained by the Congo River and its tributaries. It corresponds to an ancient inland sea, of which lakes Tumba and Maï-Ndombe are the residual remains. The author distinguishes two soil series in the study area: the "Yangambi" series occupies plateau soils of clayey-sandy sediments, while the "Yakonde" series occupies the upper slopes of the same plateau with gradients of between 3% and 7%, this time made up of sandy-clay sediments reworked by colluvium.

A long and regenerative rotation of the forest

Traditional practices in tropical rainforests are dominated by slash-and-burn agriculture. This consists of a very slow rotation marked by a long phase of forest regeneration after a short period of 1 to 3 years of food crops. Table 6 distinguishes 5 dynamic stages in this rotation, starting with an initial slash-and-burn that produces a clearing.

FEARNSIDE (op. cit.) justifies the short duration of annual cropping essentially by two constraints suffered by itinerant farmers, namely the low fertility of LH for food crops due to the markedly acid pH of the soils, and the invasion of crops by weeds. These hypotheses are confirmed by SANCHEZ et al. (1982, op. cit.).
In his study of the forest vegetation of Taï in Côte d'Ivoire, DE ROUW (op. cit., p. 55) points out that a first period of decline in pioneer species occurs at the "invasion" stage, after agricultural abandonment, but that at this stage the number of grassy weed seeds present in the soil is still too high for recultivation, in this case of rainfed rice (during a single year, more rarely two). The Taï farmer would rather choose the "young forest" stage for a new slash-and-burn operation. Later, slash-and-burn would become more labor-intensive due to the development of harder woody species. Moreover, slash-and-burn homogeneity is compromised in older, primary-structure forests. DE ROUW (op. cit., p. 108) estimates that 10 to 30% of the poorly burned surface area offers little or no yield under acid soil conditions.

Tableau 6. Forest regeneration stages from a slash-and-burn shifting cultivation plot based on literature data from OPDECAMP (1997, op. cit.)

Dynamic stage	Chronology (years)	Brief description
Clearing	0 à 5	annual slash-and-burn cultivation and post-cultivation clearance
Invasion	5 à 15	small, fast-growing, herbaceous plants, short-lived shrubs and small trees
Young forest	15 à 30	tall heliophilous fast-growing biomass trees
Mature forest	30 à 50	multi-layered forest ecosystem with moderate biomass growth rates
Old forest	> 50	structure and biomass of a slow-growing "primary" forest in terms of net annual biomass

One theory is that, after a slash-and-burn operation, annual crop yields decline rapidly from one harvest to the next, to the point where the work involved is no longer profitable. A long rotation allows forest regeneration, the accumulation of mineral nutrients in forest biomass and a decrease in herbaceous seminal potential. Such a rotation is also equivalent to crop rotation over large areas. The result is the low population densities already reported, with critical thresholds of 10 hab/km² for JOUVE (op. cit., p.89), 3-4 hab/km² for TSAYEM DEMAZE (op. cit.) and 8.5 hab/km² for MAYAUX et al. (op. cit.). Nonetheless, semi-sedentary villages can be formed, supported by remote camps in the forest, as described by DE ROUW (op. cit.), to establish and maintain fields further from the village, preferably in low-lying areas for rice, near rivers. According to NICHOLAIDES et al. (1985), in the Amazon, it is also the young forest LH (14 to 21 years old) that are normally subject to felling and slash-and-burn, which means a rotation of around 20 to 25 years.
However, in the Yangambi region (DRC), ALONGO (op. cit., p.31) reports a fairly wide range of associated crops grown after slash-and-burn, including cassava, banana, rice, maize, yams, taro, sweet potatoes and groundnuts. Recently, they have become even more diversified with

soybean and cowpea. The cassava-banana-corn-rice association ensures first harvests of rice and corn 4 to 6 months after sowing/planting, cassava after 18 to 24 months and bananas after 15 to 36 months. From the third year onwards, the plots return to fallow, but only for 3 to 6 years. The author therefore reports fairly short rotation times with the forest regrowth. The latter is limited to the "invasion" stage. He even points out that a new cropping system called *zongisa* tends to eliminate all tree fallow, in favor of grass fallow. In such a case, we'd be changing LF altogether, mutating Silva to Ager!

Temporary effects of forest burning on the aluminization rate of LH

SANCHEZ et al. (1983) report the results of experiments carried out in 3 plots separated by around 300 m at the Yurimaguas research station in the upper Amazon basin, at an altitude of 180 m. These 3 plots, known as "Chacras I, II and III", vary in size from 1 to 2 ha. They share the same geomorphological position, the same soil type, and the same initial vegetation, i.e. a young regeneration forest 17 years old and 30 m high in 1972. The soil material is sandy on the surface, ±11% clay, 24% silt and 65% sand, but becomes silty before a depth of 50 cm. A slash-and-burn operation was carried out on the 3 plots in 1972, 1973 and 1975 respectively, before continuing the experiment by comparing different technical itineraries, in particular with regard to mineral fertilization. Table 7 shows the effects of slash-and-burn on pH and aluminization rates.

Table 7: Effects of burning a young forest (17 years old, 30 m high) at Yurimaguas on soil pH and surface aluminization index (0-10 cm) "m%", from SANCHEZ et al. (1983)

Plot	**pH (H_2O)**		**m (%)**	
	Before burning	**After burning**	**Before burning**	**After burning**
Chacra I	4,0	4,5	82	59
Chacra II	3,9	4,9	55	13
Chacra III	4,1	4,6	41	24

A significant reduction in the aluminization rate was observed in all 3 plots, as was an increase in pH. The authors do not provide depth measurements, however, where the initial aluminization rate is well over 80% in the "Chacra I" plot, according to the graphical data in their fig. 4. Variability between plots is attributed to the uneven quality of the slash-and-burn and to the inheritance of the past, particularly in the superficial part of the soil. This inherited variability can be particularly significant in an agricultural research experimental station. It should be noted that the soil characteristics taken into consideration relate soil thicknesses over 100 cm in their scientific classification such as the Soil Taxonomy (SOIL SURVEY STAFF, 2014), the French reference system (AFES, 2009) or the world reference system (FAO, 2018) and thicknesses of over 50 cm in their technical classification (SANCHEZ et al., 2003, op.cit.). A tolerance of variability is applied in the identification criteria of the classified categories between the limits of a tolerated interval. It must therefore be concluded that these three plots have an identical aluminization trait in their technical classification: >60% before 50 cm depth. If we apply a similar tolerance for topographical, parent material and technical itinerary traits, the three plots under consideration belong to the same LH.
As cultivation progresses without fertilizer or amendment, the surface aluminization index returns to its initial values after 3 or 4 years, according to fig. 2 in SANCHEZ et al. (1983, op. cit.). The effect is therefore very temporary, and its duration corresponds to the traditional cultivation period before the clearing was abandoned by itinerant farmers. The latter will then evolve towards an "invasion" as shown in table 6. Neutralization of aluminum by vegetation burning is explained by the residual ash containing calcium, magnesium and potassium oxides at a rate of several hundred or thousands of kg/ha, according to data reported by OPDECAMP (1997, op. cit.). Aluminum would be "hydoxy-polymerized" in amorphous form (Al_{am}), then depolymerized again by the natural acidification that continues or even intensifies in the clearing via the **R15** reaction seen in point 3.

MOREAU (1993) also reports variations in pH after burning of a primary-structured old-growth forest, between 0-10, 10-20 and 20-30 cm. His system is located at the UNESCO Taï station (Côte d'Ivoire) for the MAB (Man And Biosphere) project, in two plots: Taï 1 (lower slope) and Taï 2 (mid-slope). His measurements, taken annually between 1978 and 1984, indicate a pH(H_2O) before slash-and-burn of between 4.8 and 5.0 for Taï 1 and between 5.1 and 5.2 for Taï 2 in the 3 layers considered. Such values indicate an aluminization index above 60% for Taï 1 and below 60% for Taï 2, which could be diagnostic of 2 different LH. Both plots were monitored for 6 years in relation to an uncleared control sub-plot. According to the author's fig. 3, for Taï 1, the increases in pH compared with the control are the greatest: from +0.5 to +1.5 on the surface. These positive changes remain significant throughout the 6-year period, down to a depth of 20 cm. For Taï 2, the differences in pH compared with the control are completely eliminated after 4 years.

The results of pH (H_2O) and soil aluminization rate (m%) measurements between 0 and 20 cm depth presented by ALONGO (op. cit.) are compared between old-growth (dense) forests and clearings (grassy fallows and edges). The pH values (H_2O) are all between 4.1 and 4.7 (p.169) on average, and aluminization rates between 59 and 80% (fig. 3.25 on page 138 and fig. 3.34 p.149). They thus confirm the absence of any lasting effect of slash-and-burn after land clearance, or even a probable absence of effect if forest regeneration stages are bypassed, as in the *zongisa* cultivation system mentioned for this Yangambi region. Unfortunately, ALONGO's study does not provide data on crop yields obtained under such conditions.

Effects of forest burning on crop yields

In the Yurimaguas experiment, the yields of several continuous cropping systems (CS), with or without "*annual complete mineral fertilization and episodic liming or limestone amendment*", were measured for 8 years after the young regeneration forest had been felled and slash-and-burned, of which two CS are presented by SANCHEZ et al. (1982 and 1983, op. cit.). One of these CS is a rice-corn-soya rotation, the other a rice-arachid-soya rotation. Rice is grown rainfed, without irrigation. There are therefore 4 cultivated species which will provide yield data per hectare for the duration of the experiment. Yields vary from year to year, depending in particular on rainfall distribution and plant health, which does not seem to be controlled. However, they are more stable and significantly higher when mineral fertilization and liming or limestone amendment are used. In each CS, the 3 species are planted in the same year, ensuring almost continuous soil coverage. The authors point out that in the absence of fertilization and amendment, yields become negligible after the third season, and therefore as early as the second year after slash-and-burn. Table 8 shows average yields for the 4 species under the two modalities.

Table 8. Average yields obtained in t/ha for the 4 species grown for "n" harvests during 8 years of slash-and-burn experimentation at Yurimaguas, from SANCHEZ et al. (1982, 1983, op. cit.).

Modality	**Rice (rainfed)** (n= 37)	**Corn** (n= 17)	**Soybeans** (n= 24)	**Peanut** (n= 10)
No fertilizers, liming or other amendments	0,99	0,21	0,24	0,69
Fertilization & Liming or limestone	2,71	2,81	2,30	3,46

Among the species cultivated, rainfed rice appears to be the most interesting without fertilizing, liming or amending, with an average of almost 1 t/ha over 8 years, which is in line with its phytobiological mechanisms of resistance to aluminum mentioned in point 4. The authors do not present a comparison between the 2 types of rotation, which should theoretically be diagnostic of two distinct LH. Results do not contain any observations on phytosanitary conditions, and in particular on weed invasion. Nevertheless, they make it essential to take into account the rate of soil aluminization when identifying Silva's LH.

Effects of forest burning on weeds

In a trial plot in a forest environment near Taï, in the "Pahi 3" field, DE ROUW (op. cit.) observed a drop in yield from 200 to 100 gr/m² (reduction from 2 to 1 t/ha) of dry paddy in rainfed rice (local cultivar "Demandé") when the degree of weed invasion doubled from 10 to 20% (cover rate). These results were observed during the first year of slash-and-burn cultivation of a 21-year-old forest, at a critical period of 90 days after sowing (fig. 5.7, p.113). This critical period for manual weeding is essential to detect because, says the author, the influence on rice yields of weed invasion at 25, 55 or 120 days after sowing is much less pronounced. In other words, weeding too early is practically useless, and weeding too late is of little use. This critical period corresponds to the end of the vegetative phase, when tillering is at its peak.
As for the results of soil surface pH (H_2O) measurements between 0 and 10 cm in this "Pahi 3" plot, they vary between 4.2 and 4.6 before burning and between 5.4 and 6.8 after the second year of cultivation (table 5.4, p.122-123). A LH with an aluminization rate of over 60% in the first 50 cm may be suspected, where slash-and-burn would have temporarily raised the pH and irregularly neutralized surface aluminum.
Based on observations and measurements carried out in another plot called "Pahi 1", rice performance is very different in the second year: even with double weeding, yield falls to around 0.45 t/ha, compared with 2 t/ha in the first year. From 0.45 t/ha it drops to 0.15 t/ha without weeding. The author points out that grass weeds are absent in the first year, which means that the weeds are essentially woody regrowth. As for the sharp drop in rice yields in the second year, she believes it is already attributable to a decline in LH fertility. This hypothesis seems to be confirmed by comparing 1st year yields in subplots of "Pahi 1" where "low" slash-and-burn is practiced. The paddy yield is then only 0.1 t/ha. The negative effect of weeds on yield could therefore be much less than that of a high rate of aluminization.

Agroforests

Remarkable studies of village dynamics and spatial organization in forest areas focus on peasant practices of slash-and-burn and the insertion of commercial plantations in regeneration stages. DOUNIAS (1996) describes three components of the agrosystem of the "Mvae", a forest-dwelling Bantu ethnic group in southern Cameroon. The first component is the residential area (pseudo-Urbs & Hortus), which includes a permanent agroforestry backyard. The second component is the "village bush", which constitutes the classic crop rotation in several stages of slash-and-burn agriculture described in table 6 above (clearing, invasion, young regeneration forest, etc.). Finally, a third component, called "anthropized forest" or "agroforest", defines Silva's older regeneration stages. Hunting and gathering (timber and firewood, fruit, medicinal plants, etc.) are practised here. At its heart is a line of LH marked by a cocoa plantation originally planted in a clearing. During the growing season, young cocoa trees grow in the shade of banana trees. Subsequently, new shade is provided by regenerating sun-loving trees or trees preserved during felling. Figure 6.11 shows a small corner of a cocoa agroforest formed in this way.
The cocoa tree can then provide income for the grubbers and thus constitute a cash crop alongside slash-and-burn subsistence crops. DOUNIAS (op. cit.) also cites oil palm (*Elaeis guineensis*) for oil extraction or for sap fermentation by bleeding to produce "palm wine". The author also draws attention to the presence of large bamboo groves, supplying building materials, in the sites of former abandoned villages.

Another example of an agroforest is presented in the study by MICHON et al. (1995) in South Sumatra with the damar gardens of Pesisir (Krui region). Some one hundred woody species of the Dipterocarpaceae family produce damar resin, which is also a source of income for the farmers who grow the trees. In Pesisir, resin production is dominated by a single species, *Shorea javanica*. From a village nursery, damar seedlings are transplanted into clearings after the first season of slash-and-burn rainfed rice, or into a young coffee or pepper plantation following rice. The associated growth of damar with these two other species limits competition with natural regenerating vegetation. When the coffee and/or pepper trees cease to be maintained, damar growth continues in the young forest. Damar comes into production at 25 years of age. The "garden" structure is acquired over time by the introduction of fruit trees,

palms, etc... It stabilizes after around 50 years, at the stage of old agroforestry where almost 50% of the original biodiversity has been recovered. The authors state that in 1994 these gardens covered more than 10,000 ha, but they do not provide specific records of other LH traits such as soil pH or aluminization rate. However, they also use the concepts of Silva and Ager to distinguish the forest from the cultivated domain. They place the gardens of Pesisir at the interface of the two.
RUF (2011) refers to the debate taking place in Indonesia on the future of agroforests versus pure plantations of damar, rubber or oil palm. In the introduction to his article, this author cites the possibility of replacing old agroforests with new ones, but the latter would now threaten protected forests. However, the author focuses on cocoa agroforests, which are already in decline in West Africa, in favor of cocoa plantations close to monocultures. It's not really a shade species. Its yields would even be tripled in "full sun" and under more intensive management (moderate use of fertilizers and pesticides). What's more, in West Africa, smallholdings are excluded from the legal timber market in favor of industrial production, which deprives them of a potential source of income via strictly forest species for commercial timber.

Figure 6.11: Close-up of a cocoa tree in an agroforest (Photo: Fotolia)

6.2.2. Traits of Silva's LH in eucalyptus plantations in Mexico

Within Silva's LF, timber harvesting is differentiated according to whether it is (pseudo-) "natural" forest timber or anthropogenic plantation timber. PIRARD et al. (2016) examine the possibility of substituting wood removed from large tracts of "natural" forest with wood produced in intensive production plots, with a view to obtaining a possible "natural" forest conservation benefit. Above all, these authors conclude that it is the evolution of the "conservation" values attributed by society that will be decisive. However, the function of nature conservation has grown with the ecologization of (Western) society to become a new structuring element of the territory and its planning, through a frenetic search for the natural (KALAORA, 2001).

Among commercial plantation timber species, PÉREZ-SANDOVAL et al. (2012) report that the *Eucalyptus* genus is by far the most widely exploited worldwide. In the absence of fertilization, its productivity can reach 33 m³/ha/year, and can exceed 60 m³/ha/year with fertilization and irrigation. Such values can be compared with the average productivity of 12 m³/ha/year quoted in point 2 (sub-paragraph 2 of 2.5.2) for Pinus pinaster in the Moors of Gascony.

Eucalyptus plantations have been planted in the south-east of Mexico, and the above-mentioned authors have researched the variables in the soil compartment that had an impact on the productivity of LH with two species: *E. urophylla* (Eu) and *E. grandis* (Eg). In this respect, it is worth recalling their phytobiological resistance to aluminium by complexation with malate at root level, as highlighted by SILVA et al. (op. cit.) and reported in section 4 (paragraph 4.2.3.). PÉREZ-SANDOVAL et al. (op. cit.) chose 21 sites in the municipality of "Huimangillo", in the state of Tabasco bordering the Gulf of Mexico. 56 plots of 500 m² were selected on the basis of productivity contrasts in 49 "Eu" plantations and 7 "Eg" plantations, with the largest sites comprising 2 to 3 plots. The plantations vary in age from 4 to 13 years and are established on former Saltus rangelands. Prior to planting, the herbaceous layer was removed, subsoiling was carried out to a depth of 60 cm and NPK 18-46-00 fertilization was applied. In each of the 56 plots, superficial composite soil samples 0-20 cm and 20-40 cm in 5 takes were sampled and the respective aluminization index (m%) were established, along with other routine laboratory analysis parameters. Annual productivities were calculated from measurements of tree wood volume and plantation age. Clay content in the superficial soil ranged from 9 to 45%, and in the subsurface soil from 15 to 64%. The corresponding aluminization index ranges from 12 to 88% and from 4 to 91% respectively. Average productivity from seed sowing is 49.3 m³/ha/yr for "Eu" and 35.7 m³/ha/yr for "Eg". An "IS" growth estimator is calculated for each plot by measuring the height of the 5 dominant trees and relating it to an equivalent age of 14 years. This estimator correlates well with annual productivity, as well as with 7 soil traits combined in a single empirical equation reproduced below, which explains 62% of the variation in the overall estimator, for the various LH:

$$IS_{global} = 22,5 - 7,6\ S_2 + 7,6\ Al_2 - 0,16\ m_1 + 0,38\ CEC_2 - 0,35\ FC_2 - 4,36\ Ca_1 + 0,30\ clay_1$$

where the variables of the soil compartment represent respectively:
- subsurface sand content "S_2",
- subsurface content of exchangeable aluminium "Al_2",
- surface aluminization index (%) "m_1"
- subsurface exchange capacity measured with ammonium acetate "CEC_2"
- subsurface water content at field capacity "FC_2",
- surface exchangeable calcium content "Ca_1" and,
- surface clay content "$clay_1$".

This equation accounts for a contradictory effect of aluminum on plantation productivity, sometimes favorable at depth (Al_2), sometimes unfavorable at surface (m_1). However, the authors observe an unfavorable effect of the surface aluminization rate (m_1) on the growth estimator in the 7 "Eg" plots. The limited range of "m_1", between 55 and 80%, should be noted. Their empirical field results are therefore not conclusive, but seem to be well in line with the ambiguous role of aluminization rate on the growth of *Eucalyptus sp*. sometimes stimulating, sometimes toxic, and characterized by relative phytobiological tolerance.
There are many other LH of Silva plantations, but the agropedological data available are rarely sufficient to establish and understand the landgenic influence of aluminization.

6.2.3. Saltus' LH Traits

Agro-pedological data for LH of Saltus are also rare. These share their past with those of Silva as a result of intertropical climatic pulsations. Their respective LH often occur in mosaics under an ecoclimatic regime compatible with both soil aluminization and the existence of forests, namely mainly that of uplands in humid and sub-humid regions (see paragraph 3.1.3). Drier climatic phases in the tropics lead to the regression of forests in favor of savannahs, and vice versa in wetter phases. In the northern hemisphere, these pulsations are marked by alternating colder and warmer temperatures.
Numerous typologies exist for herbaceous formations of varying degrees of anthropization, or for tree formations that can be assimilated to Saltus' LH. CÁMARA ARTIGAS (2009) proposes several for tropical and neo-tropical (American) savannas, but none explicitly refers to the degree of aluminization. For savannahs, MWORIA (2011, p.45) vaguely alludes to the fact that the greatest variation in their productivity is attributed to mineral nutrients in the soil.

Saltus' LH of altitude in Burundi

Burundi's altitude natural pastures with *Eragrostis olivacea* are aluminized at rates of over 60% in soil thicknesses of more than 50 cm, in areas covering huge areas, as reported by SOTTIAUX et al. (1988, p.100). Several natural regions, such as Kirimiro, Bututsi, Mugamba and Buyogoma, are involved, as are many LS (landgenic species). Figure 6.12 provides a photographic illustration of these pastures. They are subject to periodic anthropogenic fires as part of their use as rangelands for hardy Ankole pseudo-zebu cattle. On the basis of an average herd size of 4 to 5 and a fresh herbaceous biomass productivity of 15 to 20 t/ha/year, OPDECAMP et al. (1990) conclude that this type of very extensive farming is more profitable than more intensive Ager forage farming simulated with *Setaria splendida*, *Tripsacum laxum* or *Pennisetum purpureum*. The experiment leading to these conclusions is based on a trial to convert a Saltus LH into an Ager LH. The trial began in 1986 with the opening up of 56 ares of sweet potato pasture at Nyagatika, at a high altitude of 2,055 m, in a heavily aluminized LH at the Gisozi research station of ISABU (Institut des Sciences Agronomiques du Burundi), already mentioned in section 3.3.3.

Figure 6.12: Undulating agro-pastoral territory in the Bututsi highland natural region (±1,800 m) in Burundi. The Saltus consists of a natural, highly aluminized with Eragrostis Olivacea (Photo: Luc Opdecamp)

The main physico-chemical traits of the soil are shown in table 7. These traits are established on soil profile samples and show an aluminization rate of over 90% in the first 60 cm. They correspond to a single LH. The sweet potato (*Ipomea batatas*) used for opening is the local cultivar "Rusenya". It is planted with cords (cuttings) all over the site after ploughing and burning the grass in piles and spreading the ashes, but without liming or organic or mineral fertilizing. The yield obtained after 8 months is measured on 6 plots of 90 m². It varies between plots within a range of 0.6 to 3.0 t/ha. This opening yield is very low and would indicate the clearly unfavorable impact of the high aluminization rate of this LH. The surface effect of scattering of ashes between 0 and 15 cm is measured on the basis of the analytical results of a composite sample of 20 samples. The effect was insignificant, and even slightly negative, as the pH (H_2O) rose from 4.9 before to 4.4 after burning, and the aluminization index from 84% before burning to 90% after harvesting the sweet potato opening. The mineral mass of ash from natural grazing is obviously much lower than that released by a forest slash-and-burn operation, but has not been quantified. During the following three years of experimentation in the same original LH, from 1987 to 1989, food plots were installed and limed with 1.5 t/ha/year of magnesian limestone and NPK mineral fertilizer twice a year (season A and season B). A more marked evolution of pH and aluminization rate can be observed in the results, but remains limited to a depth of between 0 and 20 cm . Here, pH (H_2O) rises from 4.4 to 5.3 and aluminization index "m" falls from 90 to 13%. At a depth of 30 cm, however, the pH remains virtually unchanged, as does aluminization which remains at around 85%, according to the same authors (OPDECAMP et al., 1990, op. cit.). The effect of repeated annual liming therefore remains very superficial. However, a certain virtual economic profitability was finally diagnosed when wheat (2,038 kg/ha) and maize (2,691 kg/ha) were harvested in 1989. Such a conversion from Saltus to Ager by liming and mineral fertilization would, however, require financial resources to move away from a self-subsistence economy towards a market economy, which remains highly hypothetical given the small size of Burundi's domestic markets for food crops.

Table 7. Main soil characteristics at the opening of a pasture in the Nyagatika trial conducted at the ISABU station in Gisozi, according to Appendix 1 of OPDECAMP et al. (op. cit., 1990).

Depth (cm)	% C org.	% clay	pH (H_2O)	ECEC ($cmol_c/kg$)	m%
0-15	3,94	64,6	4,4	4,80	90
16-66	2,62	68,1	4,8	2,43	90
66-92	2,49	70,4	5,6	1,51	66
92-170	1,38	70,9	5,4	1,43	59

Saltus' LH in the lower French Pyrenees

POOZESH (op. cit.) reports on the results of fertilization and liming in a Saltus rangeland consisting of an association of several herbaceous species in the temperate Pyrenees at an altitude of 700 m (collinean stage) in the French commune of Massat (Ariège département). The trial is located on a fairly steep slope of 20% in a soil characterized superficially (0-20 cm) by a clay content of 30 to 40%, a pH (H_2O) <5.0 and a high aluminization rate "m">70%. Liming is carried out with $CaCO_3$ at a dose of 5 t/ha (200 $kmol_c/ha$) repeated every 2 years. Annual NPK fertilization is of the order of 150-70-175. Two features of this trial draw particular attention. The first involves the dry biomass produced, as follows:
- a small but significant effect of liming, i.e. an average increase over 3 years for the first cut of + 200 kg/ha/yr of DM compared with the control, the latter producing 800 to 900 kg/ha/yr;
- a highly significant effect of fertilizers, i.e. an average increase over 3 years for the same first cut of + 3 t/ha/yr DM compared with the same control.

The second striking fact relates to variations in the biodiversity of grasses (Poaceae):
- the control and the liming ($CaCO_3$) object have the highest number of grass species (6);
- objects with NPK fertilization and with fertilization combined with liming (NPK + $CaCO_3$) reduce the number of grass species (4 species on average).

There is a parallelism in this trial between the increase in dry biomass productivity and the reduction in the number of grass species. Moreover, grasses represent only 25% of species in the "NPK + $CaCO_3$" object, whereas they account for 50% in the other objects (control, NPK and $CaCO_3$).
It is possible to speculate on the interpretation of this small, one-off test. Firstly, there is a similarity in behavior between the control and liming alone. This would be consistent with a deficit in phosphorus uptake, sometimes due to aluminic toxicity in the control, sometimes due to a lack of assimilable Al-P complexes after liming. The latter would then turn out to be "over-liming". NPK fertilization would make up for both the phosphorus deficit in the "over-limed" object and the neutralization of aluminum by P in the "NPK" object. Secondly, the inverse effect of aluminization on biodiversity in Saltus compared with Silva could be due to the fact

that the primary interspecific competition factor is light. In Silva's aluminized LH, the growth of the various tree species is slow or stunted, but still pays off in the long run, compared with grasses progressively deprived of light. Selection pressure is secondary between woody species due to their low growth rates, whether or not induced by aluminum. On the other hand, in aluminized Saltus LH, grasses no longer compete as strongly for light, and adaptation to high aluminization rates becomes the primary selection factor. Their allogamous mode of reproduction and anemophilia (wind dispersal of pollen) argue in favor of the evolutionary adaptation of Poaceae.

6.2.4. LH Traits of Silva to Ager conversion

Conversion of estuarine mangrove swamps in Guinea into rice fields

In the coastal zone of Guinea-Conakry, SOW (2003) describes the traditional system of converting 380 Kha into rice paddies of 2 types of estuaries: potential FeS_2-poor *Avicennia* mangroves and FeS_2-rich *Rhizophora* mangrove. In the case of the latter, 140 Kha were converted into traditional rice paddy basins of around 30 ares each. However, 62 Kha have been abandoned, 35 Ka of which are considered sterilized. This failure is attributed to the following insufficiently controlled constraints: (1) salinization during high tides, which requires general diking, (2) abundant rainfall (P = 4,000 mm/year), 80% of which is concentrated from June to September and 50% from July to August, making it difficult to drain the basins, (3) rapid drying out when rainfall decreases, which triggers the acid sulfate process due to the high FeS_2 content and necessitates massive liming, (4) the rapid mineralization of the organic matter in the mudflats during dewatering, leading to a loss of nutrients and the need for additional mineral fertilization. SOW (op. cit) also mentions the development of iron and sulfur toxicity, but does not mention aluminum.
In an attempt to rehabilitate abandoned rice fields in estuaries, the author describes a redevelopment scheme being tested in a 14-hectare experimental polder. It is located in the village of Yangoyah, on a plain drained by a small inlet connected downstream to two estuaries, the Soumbouya and Morebaya, near Conakry. The re-admission of seawater in the dry season is an innovation that should prevent the oxidation of sulphide soils and their resulting acidification, enable their fertilization by the addition of fresh marine silt and promote weed control. This project is complemented by dikes and a freshwater reservoir upstream. The aim is to secure the availability of floodwater for the basins. A polder of 9.2 ha of rice paddies subdivided into 15 compartments and a 1.6 ha upstream freshwater reservoir has thus been created.
SOW and BARRY (2003) present the results obtained in comparison with those of traditional rice paddies. A campaign to measure soil pH at the start of the experimental polder's development revealed that it had risen to a weakly acidic level at the surface following the re-admission of seawater into the basins during the dry season. A second pH measurement ten months later, before rice transplanting, revealed a variation between 4.9 and 6.5 depending on the compartments, but the range was narrower at depth, between 4.3 and 5.3. In terms of salinity, electrical conductivity on saturated paste fell from 15-18 mS/cm at the start of the rains to 0.5-1 mS/cm at transplanting, indicating that salts had been leached out by the heavy rains of June and July. Yields tripled on average, from 462 kg/ha in traditional traps to 1,376 kg/ha in rehabilitated traps. In the latter, a maximum yield of 3,205 kg/ha is achieved, but the minimum is close to that of the traditional traps, at around 400 kg/ha. However, average yields in the experimental polder increased by 27% in the second year and by 75% in the third, while those in the traditional traps remained unchanged at around 500 kg/ha. Unfortunately, soil aluminization rates have never been measured. However, in view of the marked improvement in rice yields following the re-admission of saline seawater to the rice paddies during the rice-growing season, supplemented by freshwater irrigation from the reservoir, there is a likelihood that the aluminium has migrated downwards, carried along by the sulphates. This hypothesis needs to be verified.

Conversion of Silva into forage Ager in the Amazon

TOURRAND et al. (2006) describe the practice of artificially grazing Ager (sown grass) in the Amazon after one year of rice cultivation on forest slash-and-burn. But the pasture degrades quite rapidly in a few years, leading to a correction of "soil deficiencies" by liming and mineral fertilization. This operation pays for itself with a new crop of rice or maize followed by soya. New temporary grassland can then be reseeded. The durability of such cycles is not specified. However, these cycles are reminiscent of those of slash-and-burn shifting agriculture in fairly highly aluminized LH described in paragraph 6.2.1. The nature of the degradation of artificial pasture is characterized by the invasion of "weeds". The latter could be farmed more extensively as "natural" grazing Saltus, but this option is not considered on such ranches, which have to amortize the cost of reclaiming degraded pasture. The latter is estimated at 250-400 US$/ha, depending on the level of inputs used.

6.2.5. Comparative traits of Ager's LH for cassava and sweet potato

Comparison of yields according to the aluminization rate in Puerto Rico

ABRUNA-RODRIGUEZ et al. (1982) report on an experiment in Puerto Rico with yam (*Diascorea alata*), manioc (*Manihot esculenta*) and taro/colocase (*Xanthosoma sp.*) at 3 sites named "Corozal clay", "Corozal clay subsoil" and "Coto sandy clay". The experimental set-up consists of 30 4x4 m mini-plots at each site, except for the third, which has 40. These mini-plots have been limed with varying doses of limestone for several years. They were all surrounded by ditches to prevent runoff from one to the other. The relative yields obtained (% of maximum) with cassava on the plots at the 3 sites were found to be highly significantly correlated (**) with the surface aluminization rates of the plots between 0 and 15 cm. Maximum cassava yield was close to 30 t/ha. In fig. 2, the authors compare the parabolic regression also obtained at these sites for sweet potatoes (*Ipomea batatas*) by ABRUNA-RODRIGUEZ et al. (1979). Here are the two parabolic regression equations obtained, where "y" represents the relative yield and "x" the aluminization rate (m%) on the surface: $y = 93.74 + 0.27x - 0.006x^2$ for cassava and $y = 93.5 + 0.45x - 0.021x^2$ for sweet potato. Cancellation of the first derivatives enables us to calculate the aluminization rate corresponding to the maximum relative yield, i.e. m=22.5% for cassava and m=10.5% for sweet potato. The corresponding curves can also be plotted, as shown in figure 6.13.

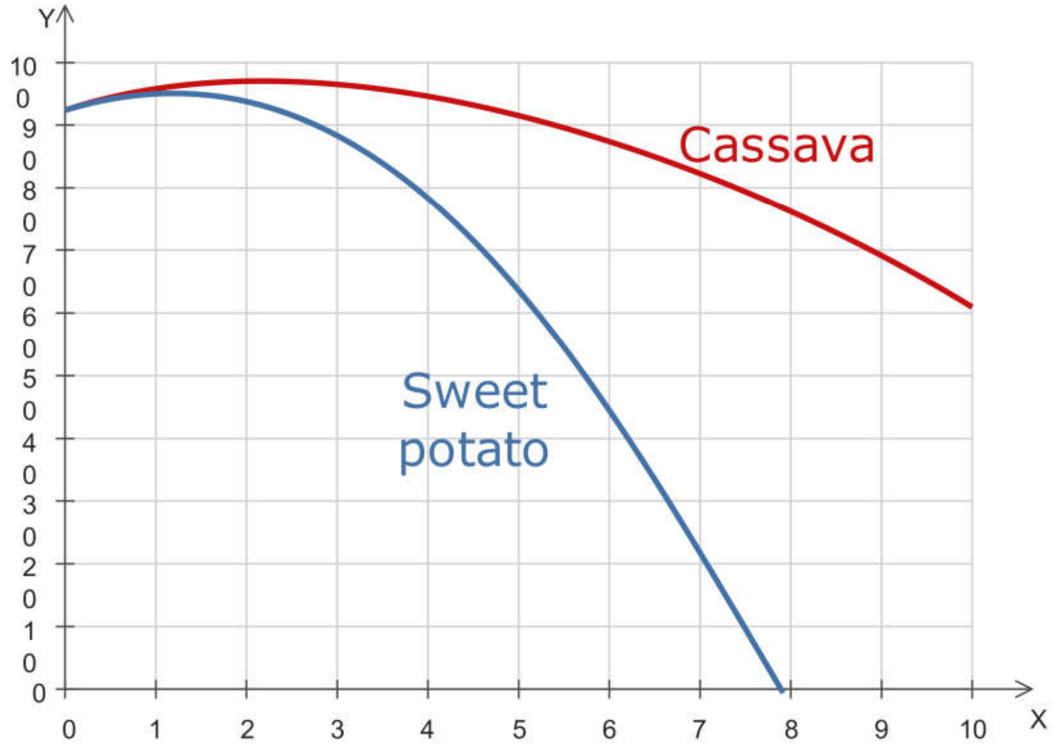


Figure 6.13: Comparative relative yield curves (%) for cassava and sweet potato as a function of surface aluminization rate m% (0-15 cm) based on experimental data from ABRUNA-RODRIGUEZ et al. (1982)

Cassava is clearly more tolerant than sweet potato. The latter suffers a relative yield reduction

to 50% when "m" reaches 57%, whereas for cassava the relative yield still reaches 60% of the maximum for a value of "m" virtually equal to 100%. Furthermore, it is remarkable to observe a stimulating effect on the yields of these two species for low values of "m", which is in agreement with the observations made in vegetation vases or in culture solution with several other Ager species in previous paragraphs 4.3.1. and 4.3.2.
Cassava's tolerance to high levels of aluminization explains its generally insignificant response to liming, as mentioned in the introduction by ABRUNA-RODRIGUEZ et al. (1982, op. cit.). These authors underline the vital importance of this crop in tropical regions, both in terms of total production and surface area. Although no liming was carried out during the above-mentioned experiments, the functions obtained and illustrated correspond to soils that had been limed in various ways in the past, and therefore represent the after-effects of liming increasing from right to left, rather than those of aluminization increasing from left to right.

Comparison of yields according to the aluminization rate in Burundi

Another comparison between cassava and sweet potato yields as a function of aluminization rate is reported by OPDECAMP et al. (1990, op. cit.), in multiple LH in the mid-altitude natural region of Kirimiro in Burundi. These LH belong to Ager LF but probably to several LI, as they are spread over nearly 20 distinct "hills". The latter are sub-communal administrative entities. As landgenic analysis had not yet been conceived or sketched out at the time, it is not possible to establish whether several true LI were represented, or whether they belonged to the same LS. Cassava and sweet potato are used in particular for the temporary cultivation of natural pasture. The comparison of yields is based on a network of 40 plots of 320 m² distributed in rural areas. Analytical soil characterization was carried out on composite samples of 9 samples taken between 0 and 15 cm and between 25 and 40 cm. The plots were set up in October/November 1985, monitored and harvested in April 1986 for sweet potatoes and in November 1987 for cassava by teams from the corresponding ISABU programs. Each plot is subdivided into two equal parts, one reserved for 4 cassava cultivars, each on 40 m², the other for 4 sweet potato cultivars, each also on 40 m². No fertilizers, amendments or phytosanitary treatments are applied, and the previous history is not considered. Table 8 shows the results obtained according to whether or not soil aluminization exceeded 60% in the first 40 cm of thickness. Average yields are fairly modest. However, they approach 20 t/ha for two cassava cultivars and 15 to 16 t/ha for two sweet potato cultivars. They are also affected by significant coefficients of variation, often exceeding 60% and even 100% for the local cassava cultivar. Absolute yields thus range from 0.5 to 33.4 t/ha for sweet potatoes and from 0.2 to 39.5 t/ha for cassava. Despite this, 3/4 of sweet potato cultivars and 1/4 of cassava cultivars have significantly lower yields in highly aluminized soils.

Table 8. Comparative average yields in Kirimiro, Burundi (Source: OPDECAMP et al., 1990, op. cit.)

Specis	**Cultivar and difference yes (*) or not significant (n.s.)**	**Average yields (t/ha)**	
		m<60% (0-40 cm)	**m>60% (0-40 cm)**
Sweet potato	TIS 2498DB (n.s.)	6,3	5,5
	NSASAGATEBO (*)	14,9	8,2
	RUSENYA (*)	16,1	8,6
	Local (*)	11,7	6,2
Cassava	CRIOLINA (*)	19,3	12,4
	MPAMBAYB (n.s.)	9,9	5,2
	ZAYIMETI (n.s.)	8,6	4,0
	Local (n.s.)	18,2	10,5

6.2.6. Ager's LH traits in perennial crops

Quantified agropedological data for a comparison of variously aluminized LH in perennial crops seem even rarer, at least for a highly aluminum-tolerant species such as tea. However, several tropical perennial crop plantations, such as rubber and certain palm species, are more or less known to have acceptable productivity levels in aluminized LH. These Ager LH are often derived from conversions of Silva LH, notably in Amazonia and South-East Asia, and it is well known that such humid tropical LH have a high probability of being more or less strongly aluminized.

Transitional stages of evolution into agroforests have already been mentioned (last sub-section 6.2.1). SCHROTH et al. (2016) recall the value of this for cocoa trees in the Amazon rainforest, because even if the plants are old, they still provide a small cash crop for small farmers. What's more, if they replant, they can use it as an argument to claim land rights. However, the aforementioned authors consider that to intensify cocoa production in order to satisfy growing world demand, eutrophic (non-aluminized) soils should be favored. On the other hand, still in the Brazilian Amazon, at an experimental station near Manaus, SCHROTH et al. (2000) report an apparent indifference to liming and fertilization of peach palm (*Bractis gasipaes*) heartwood production in a heavy soil with 80% clay, well drained and highly aluminized (m>70%) over more than 1 m in thickness. The authors explain this behavior by this little-known species' reputation for aluminum tolerance, which is confirmed by MORA-URPI et al. (1997, p.14).

Finally, throughout South-East Asia, MUTERT (1999) reports on the successful expansion of oil palm plantations on moderately or highly aluminized soils. In support of this assertion, this author reproduces in his table 1 the 0-30 cm characteristics of the eight main soils commonly found in the HP of these plantations in this vast territory. Their pH (H_2O) is all below 5.0 and aluminization rates are all significant. They are over 60% for 6 of the 8 soils selected, while the other two have "m" index of 27% and 47%. Palm nut yields in the range of 22 to 27 t/ha are reported by NELSON et al. (2011) at 4 acidic sites in Indonesia, with average pH (KCl) between 0 and 40 cm close to 4.0, which could correspond to pH (H2O) levels of around 5.0. These authors would thus confirm the satisfactory production capacity of oil palm in LH that should be significantly aluminized.

6.2.7. Discussion

An incompleteness of data on the agropedological traits of variously aluminized LH must be diagnosed, whereas the interest of aluminization from a phytobiological point of view is clearly marked by supported scientific documentation (point 4). The lack of agropedological data is similar to that of biotope characterization in the study of the ecological dynamics of aluminization carried out in point 5. It also appears that the characterization of LH soil compartment traits is often limited to pH. The latter is certainly an interesting index, but taken in isolation, it reduces the scope of studies to the more general process of soil acidification, without taking into account the particular double game of aluminum, sometimes stimulating, sometimes toxic. A double game in which each species plays its part in its own way, and which must be reflected in technical itineraries. The need for liming and the risk of over-liming are also directly associated with this, as is better management of phosphorus fertilization. In the case of tropical perennial crops, which are often established through agroforestry, it is necessary to verify, clarify or consolidate our knowledge of their tolerance or resistance to aluminization in multiple LH.

It's also very surprising that soil thickness is not standardized for the degree of aluminization. Data is generally limited to superficial soil, between 0 and 10 or 0 and 20 cm. For oil palm in South-East Asia, MUTERT (op. cit) reports data between 0 and 30 cm, whereas the same author points out that the roots of this perennial species are mostly between 0 and 60 cm deep. The technical classification of SANCHEZ et al. (2003, op. cit.) considers a soil thickness of 0 to 50 cm to assess soil aluminization, which seems to be the ad hoc standard. This thickness enables us to diagnose not only the degree of progress of aluminization from the surface, but also the possible need for aluminum neutralization in the sub-surface soil. The use of a gypsum-containing amendment in continental LH or the re-admission of seawater into the acid sulfate soils of coastal estuaries could be justified in line with prevailing ecoclimatic regimes.

In self-subsistence economies, the quest for food takes precedence over the quest for income. The latter is secondary, and yields must simply feed families and, if necessary, enable them to acquire a few secondary commodities on the market. Landgenic systems are based there on the pursuit of a varied range of products, with extensive use of inputs. The modest primary production of certain highly aluminized LH can therefore be considered interesting in spite of everything. The situation is quite different in market-economy of landgenic systems, where yields are crucial and must make the capital invested profitable. However, even in a subsistence economy, as demographic pressure continues to increase, labor profitability can become limiting in highly aluminized of low-productivity LH.

Agro-pedological field observations are made in complex systems exposed to the weather and climate conditions of the growing season, to possible parasitic attacks, to the effects of previous cropping history or communities of natural species, to the dynamics of nitrifying and symbiotic microflora (mycorrhizae and others), and so on. Significant variations can be observed from year to year, but they certainly also occur synchronously from one rural site to another in what would be identified as the same LH. Adopting a landgenic approach would broaden the agropedologist's point of view by contextualizing LH in their LF, LI and LS. This opening of angles would increase the variables considered, but could reduce the variability of data from a LH apprehended according to a greater number of dimensional axes (traits).

Another observation can also be made. This involves a reduction in biodiversity during aluminization in Saltus by fast-growing species, favored by fire. The latter annihilates woody species and species with lower colonization power (niche-R, or "realized"). This contrasts with the increase in biodiversity in Silva, where rapid growth is secondary to species dispersal.

The LH of Urbs, Hortus, Aqua and Desertum have not been explored, as they simply do not have the agropedological traits on which the focus adopted in this sub-point 6.2 is based. While agriculture and urban horticulture remain concerned by agropedological traits, the aluminization of their LH is not expected to play a significant role.

7. Conclusive synthesis

7.1. Interdisciplinary model

Landscape is one of these new objects that goes beyond the reductionism of the Enlightenment. It is an open, dynamic and complex thermodynamic system. It is open to its environment, such as climate and biodiversity, with which it evolves concomitantly. Given the number of its components, it requires a systemic approach. In terms of its local differentiation, it requires the contribution of the many parties involved from a social, economic and cultural point of view. Its functioning is in many ways empirical. As a result, many human and social scientific disciplines are involved in making it more rational. It's a truly interdisciplinary methodology that's at stake, to which an aesthetic dimension is sometimes added.

In the landgenic model proposed here, five levels of anthropic territorial organization are retained: the holon (LH), the facet (LF), the instantiation (LI), the species (LS) and finally the natural region. They are subject to mutation and change of destiny, so that a metaphor with biology is possible, allowing us to use the terms "phenotype" and "genotype" for a LI and its underlying levels. At the LS level, we could also validate the terms "phenome" and "genome".

The dimensions of landgenics are far more numerous than the landscape approach. In space, these are its three dimensions. The vertical axis includes not only the epigeous part, but also the hypogeous part of the soil and plant roots. What's more, landgenics calls on many more disciplines, such as human and physical geography, geomorphology, economics and sociology, urban planning, civil and agronomic engineering, and so on.
Seven LFs are distinguished, inspired by the ancient agrarian trilogy: Ager, Saltus and Silva, completed by Urbs and Hortus, as well as Aqua and Desertum. These LFs naturally transcend cadastral and administrative boundaries. The term "mutation" of the facets from one to the other and vice versa is particularly appropriate in the course of history, and even naturally before the appearance of man, via climatic pulsations.
Genotypic traits are expressed interactively at the LH level. Trait networks within these express the phenotypic traits of LFs. In the same way, several genes are involved in protein synthesis and regulation, in a mutual manner. Traits and landgenic characters interact in a similar intimate way, and require techniques and knowledge specific to scientific disciplines to identify them. Here too, LH evolution produces mutations, reinforcing the metaphor with evolutionary biology.

The phenomenon of self-organization normally characterizes all complex adaptive systems. This is how similar LH lead to the emergence of an LF. The same applies to LF for LI and LI for LS in the same natural region.

The example of the Moors of Gascogne illustrates this point. Its human occupation, around 2500 BCE, is marked by the coexistence of Silva, Saltus and Ager. In the Middle Ages, human occupation continued with pastoral mutation in the wet moorland, which was exploited as a true common, while the drier, mesophilic moorland showed facets of Ager and Silva in the form of pine forest. The latter was exploited for gemmage. The Urbs was then made up of airiaux grouped into districts and then into villages. At the end of the 19th century, Napoleon III enacted a final mutation to rehabilitate the moors (drainage) and convert them to intensive ager and maritime pine silva. This was a massive land grab by the communes, who then sold the land to the notables of Gironde and Landes.

Finally, neighboring LS whose territorial "biotopes" of LI are similar in several dominant characteristics form a single natural region. There is thus a spatial aggradation of natural and cultural characteristics through lateral affinities.

7.2. Aluminization and its systemic interactions with living organisms

An application of the model to the soil aluminization process takes the analysis a step further. The context focuses primarily on the interdisciplinarity between agriculture and pedology, unjustly separated by the history of science. Additional notes on the development of Urbs are developed to show the predominant influence of the non-aluminized Ager (and Hortus) on the development of cities throughout history.

7.2.1. Process

A description of the aluminization process involves natural or involuntarily provoked acidification (drainage of acid sulfate soils). This leads to the alteration of primary and secondary minerals in the soil parent material through root and microbial respiration, and the nitrification of nitrogen.

Certain details in the physico-chemical reactions are worth noting, as they probably play a part in the expression of traits based on certain agropedological features at field LH level. One example is the early appearance of amorphous organic or purely mineral forms of aluminum during acid hydrolysis of primary minerals, and their long-term persistence in highly weathered soils. Despite the scarcity of amorphous product assays in non-volcanic soils, it is assumed that non-crystallized aluminum hydroxy-polymers play an important buffering role, namely by depolymerization during acidification and by temporary repolymerization in the event of liming or biomass incineration ash inputs. What's more, in aluminized soils, these hydroxy-polymers show an affinity for phosphorus that seems to decrease from a maximum, sometimes through depolymerization and reduction of their surface area during acidification, sometimes through competition with hydroxyl groups during neutralization of soil acidity, for example during what should be considered over-liming.

7.2.2. Phytobiology

The toxic effects of aluminization on plant growth are well documented in phytobiology for many species, both natural and cultivated. Resistance-based adaptation mechanisms mainly involve root exudation of organic acids. Tolerance, on the other hand, is expressed by a capacity to accumulate aluminium via internal aluminium complexation in many species, of which tea is an emblematic example. Epigenetic regulation sometimes takes place very quickly after exposure, notably in rice and several other poaceae that make up the natural pastures of the Saltus.

Interactions with mineral nutrition, and phosphorus in particular, are often mentioned. For example, the stimulating effects of aluminization are observed in several species, both in culture solution and in vegetation vases with variously aluminized soil samples. A hypothesis is therefore put forward. It consists in attributing growth stimulation to the simultaneous absorption of aluminum and phosphorus in the form of Al-P complexes. It would be beneficial through the addition of phosphorus until an aluminum toxicity threshold is crossed during aluminization.

7.2.3. Écology

The vital processes causing soil acidification and aluminization drive the evolution and diversity of ecosystems not only in the relatively long Darwinian timeframe, but also, and above all, instantaneously in the highly heterogeneous environmental space of the ecosphere. It is in this space of varied geological materials, naturally drained by watercourses, and with a relief reshaped by wind and rain erosion, that species and their populations attempt to achieve their fundamental niche according to the natural obstacles and environmental stresses encountered. These spatial dynamics generate new ecotypes, which may be the precursors of new species. Some field evidence confirms this evolution, notably in the Rothamsted grassland park, with ryegrass, fescues and Agrostis. However, existing studies on these processes are rare or far too fragmentary and insufficiently documented in the field. They are also too superficial in the literal sense. We must therefore content ourselves with hypotheses in terms of coevolution between ecosystems and soil aluminization. It could be marked by a retrocession after a certain stage. Moreover, several observations point to an increase in biodiversity as aluminization progresses, at least as far as woody species are concerned. This seems to be confirmed worldwide, where forests are found in the most acidic soils.

7.2.4. Overall development of LF

Global evolution of landgenic facets is documented after human colonization in the Pleistocene. However, landgenics did not really begin until the Holocene, the period currently underway. It occurred with the domestication and spread of sexual reproduction, through the history of peoples and empires the world over. It is *Homo sapiens*, therefore, who considerably amplifies the R-niches of the plant and animal species under consideration.
The overall evolution of the landgenic facet of Ager (and Hortus) is well linked to the colonization of the world by the human population, and marks a remarkable inflection point with the industrial revolution. This is also reflected in the urban development of Urbs, a historical overview of which is provided. Today, however, Urbs occupies just 75 Mha, or 0.55% of the world's land surface. Ager and Saltus occupy around 2,500 Mha each, or almost 20% each. Silva is at 4,000 Mha, or 30%, and Desertum occupies the remainder. The overall evolution of the human population is marked by an exponential rate of increase from the 18th and 19th centuries onwards. This suggests an upcoming demographic transition and/or landscape innovations to meet the food challenge.

7.2.5. Interactions with agropedological LH

If we focus on the agropedological traits at the level of the more or less aluminized LH in the Silva, Saltus and Ager LFs, several experimental phytobiological facts are confirmed in the field. However, the available data are also often fragmentary.

In Silva (pseudo-) Naturale, a traditional technical itinerary based on slash-and-burn is still widely practiced today in tropical areas. A temporary food crop of 1 to 3 years followed by a long fallow period to regenerate the forest is adopted, as the neutralization of aluminum by incineration ash is temporary. Yields fall rapidly due to the ephemeral neutralization of aluminum and the return of its toxic effects. The long forest fallow that occurs afterwards replenishes the biomass extracted during incineration. This system requires large-scale forest rotation, resulting in shifting agriculture and a low human population density of less than 10 inhabitants/km².
Silva is also widely used in monospecific plantations with species of the Eucalyptus genus, whose resistance to aluminum and its stimulating effects on growth at low aluminization levels have been confirmed by the results of experiments carried out in Mexico.

In Saltus, it is in the natural highland pastures of Burundi that we find evidence of the selective action of aluminization on the Poaceae *Eragrostis olivacea*. The pastures dominated by this species form vast rangelands for very hardy livestock, while the population density is one of the densest in Africa, living in a self-subsistence economy on very small farms. The latter do not therefore seem able to colonize these highly aluminized Saltus soils, as shown by a field experiment. The predominance of Poaceae is also confirmed in the Saltus soils of the lower Pyrenees.
An important observation is that, while biodiversity is favored in Silva, the opposite is true in Saltus. Here, competition for light disappears, thanks to the periodic fires that impact woody species. It's the species most able to dominate in the R-niches (realized) that have a competitive advantage, namely the Poaceae.

In Ager, multiple HP trials in Burundi and Puerto Rico confirmed the sensitivity of cassava and sweet potato to high aluminization rates, as well as a better tolerance or resistance of cassava. In Puerto Rico, the stimulating effects of low aluminization rates were also confirmed.
In Amazonia, the success of Ager forage from soybeans and artificial pastures is maintained by liming and mineral fertilizers. However, this success would be threatened if subsidies or credit facilities were abolished. As a result, the impact of aluminization on Ager LH yields needs to be seen in the context of a market economy, with subsidies, or a self-subsistence economy.

The successful expansion of perennial plantations such as oil palm in South-East Asia in Ager's LHs provides further evidence of their relative tolerance or resistance to aluminization, but is only briefly documented.

7.3. Closing considerations

Finally, it is astonishing how little or incomplete data is available on the ecological and agropedological features of LHs in the major LF types, even though they account for around 70% of the land area (30% in Silva, 18 to 20% for Saltus and 13 to 18% for Ager).

The organization of knowledge and know-how into disciplinary silos appears to be the fundamental cause, inherited from the Enlightenment. It creates an epistemological deficit for the study and understanding of these complex, evolving systems. There is also an ethical problem, namely the more or less unconscious drift of science and applied science towards the greening of society, while the knowledge and skills deficit remains unfilled. The challenges of food security are therefore far from being properly assessed.

The proposed landgenics model aims to correct these shortcomings at the territorial level. It proposes outright the institution of transdisciplinary R&D. The latter must take into account the willingness, collaboration and participation of local populations, all too often neglected by top-down development policies. The local emergence of "potential commons" is thus of paramount importance in this landscape model.

Aesthetic and cultural data are also missing, but the proposed model is configured to incorporate them.

Many processes other than aluminization take place and animate landscapes. They can also be studied with such a model at local level: alkalinization or salinization of soils, but also industrialization, urbanization, greening or globalization. Highly pragmatic issues can even be addressed to reconfigure LI and LS: adopting innovations in value chains, adapting to certain markets, adjusting technical itineraries in forestry, crop or livestock systems, and so on.

The shaping and evolution of landscapes has been carried out mainly empirically by local populations, then amended or overturned by politics and advice from agronomists, urban planners and architects in a top-down approach. What is finally proposed here is a bottom-up approach and a rational interdisciplinary explanation of the interactions between its many components and stakeholders, with a view to promulgating a landscape humanism.

8. Glossary

Asterisks (*) refer to other terms in the glossary.

Actors: in the sense of those who perform acts, act in a territory, and therefore have interests and aspirations there. These are the social and economic players.

Aesthetics: philosophical branch dedicated to the sensitive understanding of natural and artistic objects, and to the sensations and emotions they can arouse. Aesthetics is not limited to the study of the beauty of things, but also to their strangeness, originality or the intensity of the reactions they produce.

Adsorbent (or soil exchange) complex: clay and/or humic micro-surfaces that are more or less intertwined with one another and have negative electrical charges, some of which are pH-dependent (e.g. carboxyl and hydroxyl groups on humic compounds). These charges constitute the cation exchange capacity (CEC) of a soil, and generally decrease with depth.

Agropedology: interdisciplinary approach to the relationships that exist in [landgenic holons (LH)]* between soil characteristics and properties, their [traits]*, and their agronomic exploitation, i.e. the [technical itineraries]* implemented in [forest systems]*, [grazing systems]* and [cropping systems]*.

Anthrobiota: this term is derived from biota in ecology, where it more broadly represents all living organisms in a particular habitat/biotope. The prefix "anthro" is used in landgenics to designate the decisive role played by humans in the composition of biota at the level of [landgenic facets]* and [landgenic holons]*.

Aluminization: progressive saturation of the [adsorbent complex]* in the soil compartment of a [landgenic holon (LH)]* at the expense of the [basic cations]*. The latter are displaced in solution and then subject to leaching by rainwater infiltration and drainage deep into the soil.

Basal area (forestry): indicator of tree density and volume. It corresponds to the cross-sectional area of a tree measured at 1.30 meters from the ground. Total basal area is expressed in m^2/ha. It corresponds to the surface area that would be occupied by all the tree trunks in a hectare if they were all grouped together in the same place.

Basic cations: these are the cations Ca^{2+}, Mg^{2+}, K^+ and Na^+ adsorbed on the soil's [adsorbent complex]*. The latter effectively develops negative charges. These cations contain a major (K^+) or minor (Ca^{2+}, Mg^{2+}) element in the plant's mineral diet. Their relative disproportion can lead to physiological deficiencies in plants, or instabilities in the aggregation of clays at nano- and micrometric scales, particularly in the case of sodication (Na^+). They are inherited primarily from the alteration of primary minerals in the parent rock, but can also be brought in by fertilization or amendment, whether mineral or organic, by irrigation water or by atmospheric deposition (dust, sea spray, etc.). Finally, they can be recycled through the decomposition of organic matter from litter, dead roots, animal droppings, etc.

Biome: biogeographical territory specific to the plant and animal species that predominate there and are adapted to its climate (temperature, precipitation). Biomes have essentially latitudinal and altitudinal boundaries. Examples of biomes: desert, scrubland, tundra, steppe, boreal forest, temperate forest, tropical rainforest, tropical savannah.

Catchment area: area specific to a watercourse in which the natural topography leads to the runoff of rainwater towards this watercourse, which thus serves as its outlet. This zone is delimited by a stormwater divide (ridge) with neighboring watersheds. The watershed of a river encompasses all the sub-watersheds of its tributaries.

Character ("phenotypic"): visible expression of one or more [traits (genotypic)]* shaping the morphology of each [landgenic facet (LF)]* making up a [landgenic instantiation (LI)]*. A morphological character of a place representative of an LF may relate to relief (topographic shape and position, altitude), to the appearance of the [anthrobiota]* such as the LF category, to hydrology (pond, river, torrent) or humidity (swamp, peat bog), to the stony, rocky or sandy aspect of the ground surface, to aesthetics, to human population density and its habitat type, and so on.

Common: a well-defined territory, delimited and shared by a community that governs and operates it, and benefits from its amenities and production values.

Cropping system: typical succession of crops, either pure or in association, for which the various [technical itineraries]* used are specified. This system therefore concerns a rotation determined in time or a crop rotation in space.

Cutting: part of a plant organ or organ fragment (root, stem, leaf) that can be planted to take root and develop an individual as a clone of the mother plant. It is therefore a vegetative, asexual mode of reproduction. In the case of sweet potatoes, for example, these are stem (rampant) cuttings. Sweet potato cuttings are sometimes called "cords".

Cuirass (laterite): layer of induration and cementation of rocky debris and laterite, by compounds rich in iron and aluminium. The individualization of ferric iron presupposes accumulation by migration of ferrous iron in a water-saturated environment, followed by oxidation to ferric iron by seasonal oscillation of the water table or by drying of the climate (climatic pulsations).

Cultivar: cultivated variety of a species that shares its genome. The genotype of a cultivar is specific and distinct from that of another cultivar. Seed reproduction of a cultivar requires conservation of its genotype.

Culture: in the broad sense used in this book, a culture is a body of knowledge and know-how, traditions, tastes, creations and works in all fields of the arts, sciences and techniques, as developed and practiced by a human population. Culture, then, is a human attribute. But we are also part of nature through our genome. Man shapes his culture by interacting with the natural world around him.

Design: the art of conceiving and configuring a thing so that it harmonizes with the needs and desires of the humans for whom it is intended. This applies to how landgenics organize territories.

Diaspore: element of dissemination of a species in space, such as seed, cutting, spore, etc., by wind, water, animals, man, etc.

Ecosphere: the lithosphere (earth's crust and upper mantle), the hydrosphere (ground and surface water), the biosphere (all living organisms) and the atmosphere (the gaseous envelope surrounding the planet).

Ecotype: variety or group of individuals of a species with a particular hereditary genotype adapted to specific environmental conditions. It is a kind of subspecies.

Ecozone: large ecological territory comparable to a [biome]*. The ecozone can be subdivided into ecoregions. Classifications are relative, as are the boundaries between ecozones, biomes and ecoregions.

Endoplasmic reticulum: vast folded membrane network connected to the cell nucleus. The rough end is the site of membrane protein synthesis, while the smooth end is involved in lipid synthesis and calcium storage.

Ethics (anthropocentric, biocentric or ecocentric): a branch of philosophy that aims to distinguish between right and wrong, beyond the Manichean prescriptions of morality, which only address fairly simple or elementary situations. Ethics contains morality, but is a matter of internal and collective debate, in complex situations where divergent opinions and points of view are expressed. There are several ethical approaches to man's relationship with nature. A strong anthropocentric stance places man as the absolute master and dominator of a nature-object. A more moderate anthropocentric stance sees man as the steward and improver of nature. In this managerial posture, man can perfect nature through technology. There is also an ecocentric posture, which preserves the integrity, stability and aesthetics of the biotic community into which man sees himself as simply inserted. Finally, a biocentric posture maintains that every living organism is an end in itself, that it has an inalienable intrinsic value, independent of human viewpoints. It's a kind of anti-speciesist posture.

Epistemology (constructivist): philosophical branch concerned with the study of the foundations and methods of human knowledge and know-how acquisition and development. Constructivist epistemology postulates that knowledge and know-how depend on culture. In other words, the way in which objects are studied and crafted depends on the subjects, i.e. their existing knowledge and skills, and the points of view and prejudices they adopt.

Forest system: a spatial unit organized into one or more stands of woody species, intended for the production of timber, firewood, pulp, charcoal or, much more incidentally, slash and burn in shifting agriculture. The concept of a forest system is based on a set of interactions between a forest stand and its reference site. Forest stations are representative of the various stands in a given massif. Each of them normally refers to a soil representative of the phytosociological association specific to a stand. The latter therefore constitutes a relatively homogeneous part of a forest. It should be identifiable by the spatio-temporal arrangement of its constituent trees. It also develops a structure characterized by the mix and dimensions of the dominant trees and by the vertical articulation of the constituent storeys and sub-storeys.

Genotype/genome: the genome corresponds to all the genes of a species, i.e. all its individuals. If we refer to a particular individual, we speak of its genotype, because not all the genes in the genome are expressed in the same way from one individual to another, leading to different phenotypes between individuals.

Geographic Information System (GIS): the various landgenic datasets are by definition multi-sourced. They can be collected and georeferenced in a database management system (DBMS). The latter may contain not only scientific data, but also artistic or aesthetic data (archaeological, heritage, architectural, urban planning, etc.). These multiple types of data then become interoperable via software that not only provides access to them, but also enables them to be updated, combined, cross-referenced and processed as required by a GIS-software tool.

Grazing system: spatial unit organized according to one or more specific and perennial plant communities, grassy and/or semi-shrubby, used for grazing by one or more domestic herds of cattle, sheep, goats or other ruminants. This system therefore has a triple constitution: soils, plants and livestock. Grazed fallow land and grazed grassland lasting more than 5 years are also included in the grazing system concept. On the other hand, mown meadows and temporary pastures lasting 5 years or less are included in the forage cropping system concept.

Landgenic facet (LF): territorial portion of a [landgenic instantiation (LI)]*, in a single or multiple locations, whose [characters (phenotypic)]* are diagnostic of one of the seven categories constituted by Ager, Saltus, Silva, Urbs, Hortus, Aqua and Desertum. An LF can be organized and managed as a [common]* by [actors]* who share the same interests. The [actors]* of the different LF of the LI can also organize and manage together and mutually the "composite common" that this LI then represents.

Landgenic holon (LH): territorial portion of a [landgenic facet (LF)]* characterized by a specific combination of [traits]* in relation to adjacent LHs. The [traits]* to be taken into consideration in diagnosing a LH are agreed upon by the various disciplines involved. They are measurable characteristics or properties that can be observed with more or less sophisticated equipment, devices or reference systems. Thus, sufficiently contrasting aluminization rates can be diagnostic of different LH. The same applies to different [technical itineraries]*.

Landgenic instantiation (LI): particular configuration of a [landgenic species (LS)]* corresponding to an arrangement of [landgenic facets (LF)]* to ensure the harmonization of the resources of its territory with the needs and aspirations of its human population.

Landgenic species (LS): set of [landgenic instantiations (LI)]* sharing networks of [traits (genotypic)*] expressing [characters (phenotypic)*] similar but not completely identical at the landgenic facet (LF) level. The latter have typical mutual relationships specific to the general design of the LS integrated with its [natural region]* of belonging.

Loci (quantitative trait): positions of a number of genes (genotypic traits, DNA segments) whose regulation determines the intensity of expression of a (phenotypic) character.

Natural region: community of [landscape species (LS)*] with [phenomes*] that converge because they share "significantly" similar natural characters, mainly in terms of geological structure, relief and climate.

Mesology: study of the environment as defined by BERQUE (1987).

Nucleus (cell): cellular structure containing the bulk of the cell's genetic material (DNA) in eukaryotic organisms (the major kingdoms of the living world, i.e. animals, fungi, plants and protists). It is therefore the seat of the genome, except in prokaryotes (bacteria), which have no cell nucleus.

Orogenesis: the process of relief formation linked to the dynamics of tectonic plates, which includes volcanism. It is particularly relevant to the formation of major mountain chains such as the Alps, the Pyrenees, the Himalayas, the Andes, etc.

P53 (genetic transcription protein): a protein that binds specifically to the regulatory regions of genes whose expression it controls. It is known as the "*guardian of the genome*".

Pedogenesis: the process by which soils evolve from their loose or indurated parent rock to their differentiated state at a given point in time. These processes include fracturing and loosening of rocks, primary and secondary alteration of minerals by dissolution, hydrolysis, degradation, aggradation, neoformation and claying (inheritance and formation of clays) of the parent material, incorporation of organic matter and humification, leaching of solubilized ions, clays and humic compounds, structuring of loose aggregates, etc.

Phenotype/phenome: just as a genotype and phenotype apply to an individual, a genome and phenome apply to the entire population of a [landgenic species*].

Physiocrat: 18th-century economist who saw the primary agricultural sector as the source of all wealth.

Plamodesm: membrane-bound channel through the cell wall, linking the [endoplasmic reticulum]* of adjacent cells.

Polderization: reclamation of coastal land, marshes, estuaries or lakes below sea level, lakes or nearby watercourses. Reclamation is achieved by diking and drainage.

Polymathic: relating to multiple skills and know-how, particularly in the arts and sciences.

Leonardo da Vinci was a typical polymath.

Profiling (gene): isolation and identification of specific DNA sequences for a given gene.

Rhizosphere: zone surrounding the roots for a few centimetres, marked by more intense microbiological activity, particularly from bacteria and fungi. This zone is directly influenced by root exudates, gaseous exchanges (O_2, N_2, CO_2) and mineral solutes (NO_3^-, NH_4^+, K^+, $H_2PO_4^-$, Ca^{2+}, Mg^{2+}, Al^{3+}, etc.), as well as by water uptake by plants.

Soil horizon: soil layer morphologically distinguishable on the vertical cross-section of a pit dug generally to a depth of over 100 cm. Distinction between horizons is based on variations in root density, color, organic matter content, clay content, structure, consistency, possible induration of the material, etc.

Soilscape: spatial distribution (3D) of [soil horizons]* developed in one or more parent materials of the soils of a given landscape. The soilscape develops under the action of a set of factors or dynamic variables associated with or derived from geomorphology, climate, vegetation and anthropogenic effects.

SOS (genetic correction/adaptation): a system for repairing mutations caused by cellular stress in bacteria. This system can be accompanied by adaptive mutations, leading to an increase in genetic variability.

SRM (genetic mismatch repair): during DNA replication, nucleotide base mismatches can occur, rendering the newly-reproduced DNA copy imperfect. The SRM system corrects these mismatches and is also responsible for the genetic barrier between species. This system is not infallible, however, and can allow mutations to pass through. Its effectiveness is progressively reduced as the individual aged.

Technical (agronomic) itinerary: defines the choice of species, their succession in time (rotation) and their arrangement in space (crop rotation), as well as all the phytotechnical methods adopted at the different stages of their development. These include soil preparation, choice of seeds or seedlings, use of organic and mineral fertilizers and soil improvers, use of irrigation water, phytosanitary monitoring, chemical, biological, manual or mechanical protection and maintenance, harvesting decisions and methods, and so on.

Tillering: production of multiple tufted stems at the corresponding stage of development of a poaceae (grass) seedling. Each stem can then produce an ear, multiplying cereal yields (except for maize, which has lost this tillering power).

Trait ("genotypic"): (measurable) characteristic or property identifiable with more or less sophisticated apparatus, devices or reference systems. For example, aluminization rates or [technical itineraries]* are agropedological traits, which when sufficiently contrasted can be diagnostic of different [landgenic holons (LH)]*.

Useful agricultural area (UAA): sum of the areas of the [landgenic facets (LF)]* of Ager and Saltus.

Xylem: plant tissue made up of dead cells, without a plasma membrane, surrounded by lignin and forming vessels for transporting water to the leaves (raw mineral sap). Xylem also plays a supporting role.

9. References

ABRUNA-RODRIGUEZ F., VINCENTE-CHANDLER J., RODRIGUEZ J. & SILVA S., 1979, "Crop response to soil acidity factors in Ultisols and Oxisols in Puerto Rico, V. Sweetpotato", *J. Agric. Univ. P.R.*, 63, 250-267

ABRUNA-RODRIGUEZ Fernando, VINCENTE-CHANDLER José, RIVERA Edmundo & RODRIGUEZ José, 1982, "Effect of soil acidy factors on yields and foliar composition of tropical root crops, *Soil sci. soc. Am. J.*, 46, 1004-1007

AFES (Association française pour l'étude du sol), 2009, *Référentiel pédologique 2008*, Versailles, Quæ.

AKITT J.W., GREENWOOD N.N, KHANDELWAL B.K. & LESTER G.D., 1972, "Al nuclear magnetic resonance studies of the hydrolysis and polymerization of the hexo-aquo-aluminium (III) cation", *Soil Sci. Soc. Am. J.*, 46, 1004-1007

ALEXANDRE-PYRE Sybille, 1971, *Le plateau des Biano (Katanga). Géologie et géomorphologie,* Ac. roy.belge Sc d'Outre-Mer, Mém., 151p

ALIA F.J., SHAMSHUDDIN J., FAUZIAH C.I., HUSNI M.H.A. & PANHWAR Q.A., 2015, "Effects of aluminum, iron and/or low pH on rice seedlings grown in solution culture", *Int. J. Agric. Biol.*, 17: 702–710, (RG[4])

ALONGO Sylvain, 2013, *Étude microclimatique et pédologique de l'effet de lisière en Cuvette centrale congolaise: impact écologique de la fragmentation des écosystèmes, cas des séries "Yangambi" et "Yakonde" à la région de Yangambi (R.D. Congo)*, Thèse de doctorat en Sciences agronomiques et ingénierie biologique, Université Libre de Bruxelles, Faculté des Sciences, Service d'Écologie du paysage et Systèmes de Production Végétale, 316 pp.

ATLAN Henri, 1972, L'organisation biologique et la théorie de l'information, Hermann, coll. "Actualités scientifiques et industrielles"

ATLAN Henri, 1995, "ADN: programme ou données", *Transversales sciences cultures*, 33

AUDOUZE Jean, CHAPOUTHIER Georges, LAMING Denis & OUDEYER Pierre-Yves, 2015, *Mondes mosaïques - Astres, villes, vivant et robots*, Paris, CNRS Éditions

BACHE B.W. & SHARP G.S., 1976, "Soluble polymeric hydroxy-aluminium ions in acid soil", *J. Soil Sci.*, 27: 167-174

BARNOSKY Anthony D., MATZKE Nicholas, TOMIYA Susumu, WOGAN Guinevere O. U., SWARTZ Brian, QUENTAL Tiago B., MARSHALL Charles, McGUIRE Jenny L., LINDSEY Emily L., MAGUIRE Kaitlin C., MERSEY Ben & FERRER Elizabeth A., 2011, "Has the Earth’s sixth mass extinction already arrived?", Nature 471, 51–57, (RG)

BENOIT Marc, RIZZO Davide, MARRACCINI Elisa, MOONEN Anna Camilla, GALLI Mariassunta, LARDON Sylvie, RAPEY Hélène, THENAIL Claudine & BONARI Enrico, 2012, "Landscape agronomy: a new field for addressing agricultural landscape dynamics", *Landscape ecology*, 10, 27: 1385-1394

BERGOEING Jean Pierre, 2004, "Impacts météoriques et changements climatiques", *Revista Geográfica*, 135, 79-94, (RG)

4 RG = available on ResearchGate

BERQUE Augustin, 1987, "Milieu et motivation paysagère", *Espace géographique*, tome 16, n°4, 241-250

BLANC Patrick, 1997, "La biodiversité tropicale : mémoire des changements passés", In: *Lettre n°6 du Programme International Géosphère Biosphère-Programme Mondial de Recherches sur le Climat,* CNRS, France

BLANC-PAMARD Chantal, 1986, "Dialoguer avec le paysage ou comment l'espace écologique est vu et pratiqué par les communautés rurales des hautes terres malgaches", in Chatelin Y., G. Riou (éd), *Milieux et paysages*, Paris, MASSON: 17-34.

BLOOM P.R., McBRIDE M.B. & WEAVER R.M., 1979, "Aluminium organic matter in acid soils: buffering and solution aluminium activity", *Soil Sci. Soc. Am. J.*, 43: 488-493

BLOOM P.R., 1981, "Phosphorus adsorption by an aluminium-peat complex", *Soil Sci. Soc. Am. J.*, 45, 267-272

BOJÓRQUEZ-QUINTAL Emanuel, ESCALANTE-MAGANA Camilo, ECHEVARRIA-MACHADO Ileana & MARTINEZ-ESTÉVEZ Manuel, 2017, "Aluminum, a friend or foe of higher plants in acid soils", *Frontiers in Plant Science*, vol. 8, art. 1767, (RG)

BOLLIER David, 2014, *La renaissance des communs. Pour une société de coopération et de partage*, Paris, Éditions Charles Léopold Mayer, traduit de l'américain par Olivier Petitjean

BOLT G.H. & BRUGGENWERT M.G.M., 1976, *Soil chemistry - A. Basic elements*, Elsevier.

BORGES Alberto V., DARCHAMBEAU François, TEODORU Cristian R., MARWICK Trent R., TAMOOH Fredrick, GEERAERT Naomi & al., 2015a, "Globally significant greenhouse-gas emissions from African inland waters", *NATURE GEOSCIENCE,* Published online, DOI: 10.1038/NGEO2486, (RG)

BORGES Alberto V., ABRIL Gwenaël, DARCHAMBEAU François, TEODORU Cristian R., DEBORDE Jonathan, VIDAL Luciana O. & al., 2015b, "Divergent biophysical controls of aquatic CO_2 and CH_4 in the World's two largest rivers", *Scientific reports*, Published online, DOI: 10.1038/srep15614, (RG)

BOTTOLLIER-DEPOIS, 2012, "Fiche de lecture: Gouvernance des biens communs, Elinor Ostrom,2010", Observatoire du Management Alternatif, Paris, HEC

BRETAGNOLLE Vincent & BAUDRY Jacques, 2015, "Vers une agro-écologie des territoires, pour une gestion durable des services écosystémiques: de l'observation à l'expérimentation", *Innovations Agronomiques* , 43,, 51-55

BRINKMANN, W.L.F., 1983, "Nutrient balance of a central amazonian rainforest: comparaison of natural and man-managed systems", *Assoc. Int. Hydrol. Sci. Publ.*, 140: 153-163
BROSSET C. BIEDERMANN G. & SILLEN L.G., 1954, "Studies on the hydrolysis of metal ions, XI, The aluminium ion, Al^{3+}", *Acta Chem. Scand.*, 8, 1917-1926

BRUNNER Ivano and SPERISEN Christoph; 2013: "Aluminium exclusion and aluminium in woody plants", *Frontiers in plant science*, vol 4, article 172

CALLAWAY Ewen, 2017, "Oldest *Homo sapiens* fossil claim rewrites our species' history", *Nature,* doi:10.1038/nature.2017.22114

CÁMARA ARTIGAS Rafael, 2009, "Concepts, approche bioclimatique et typologie des savanes. Application aux savanes américaines", *Les Cahiers d'Outre-Mer*, 246, 175-218

CASTELLA Jean-Christophe, 2005, "Une méthode d'analyse multi-échelle des transitions agraires, Application aux zones de montagne dans le Nord du Viêt-nam", *L'Espace géographique,* 2005/4, 34, 351-366

CHADWICK Oliver A. & CHOROVER Jon, 2001, "The chemistry of pedogenic thresholds", *Geoderma*, 100, 321–353

CHARLES-DOMINIQUE Pierre, 1997, "La forêt en Amazonie, une histoire Holocène très mouvementée", In: *Lettre n°6 du Programme International Géosphère Biosphère-Programme Mondial de Recherches sur le Climat,* CNRS, France

CHARMET Gilles et BALFOURIER François, 1994, "Influence of ecological factors on population differentiation in perennial ryegrass (Lolium perenne L.)", *Genetic Resources and Crop Evolution*, 41: 175–184

CHENERY E.M., 1948, "Aluminium in the plant world", *Kew Bull.*,3, 173-183

CHEVERRY Claude, 1969, "La genèse des sols salés à alcalis dans les polders des rives nord-est du lac Tchad", *Agrokemia es Talajtan (Agrochimie et Pédologie)*, 18, 238-242

CHOMARAT-RUIZ Catherine, 2014, *Précis de paysagétique*, Presses universitaires de Valenciennes, 229 pp.

CHOUQUER Gérard, 2002, "À propos d'un contresens partiel sur « Pays » et « Paysage » dans le Court Traité du Paysage d'Alain Roger", *Études rurales*, 161-162, 275-288

CHOUQUER Gérard, 2003, "Françoise Burel et Jacques Baudry, Écologie du paysage. Concepts, méthodes et applications", *Études rurales*, [En ligne], 167-168

CHUNG Sung-Yoon, KIM Young-Min, KIM Jin-Gyu & KIM Youn-Joong, 2009, "Multiphase transformation and Ostwald’s rule of stages during crystallization of a metal phosphate", *Nature Physics*, 5, 68-73, (RG)

CHURCHMAN Jock and LOWE David, 2012, "Alteration, formation, and occurrence of minerals in soils", In: Huang, P.M.; Li, Y; Sumner, M.E. (editors), *Handbook of Soil Sciences, 2nd edition, Vol. 1: Properties and Processes,* CRC Press (Taylor & Francis), Boca Raton, FL, pp. 20.1-20.72, (RG)

CoE - Conseil de l'Europe, 2000, *Convention européenne du paysage*

COLLINS J.P., KINZIG A., GRIMM N.B., FAGAN W.F., HOPE D., WU J. and BORER E.T., 2000, "A new urban ecology. Modeling human communities as integral parts of ecosystems poses special problems for the development and testing of ecological theory", *American Scientist*, 88: 416-425

COLWELL Robert K. & RANGEL Thiago F., 2009, "Hutchinson’s duality: the once and future niche", PNAS, 106: 19651–19658, (RG)

CRUDZEN Paul Josef, 2002, "Geology of mankind", *Nature*, 415, 23

DAVODEAU Hervé, 2009, "Les atlas de paysages français ou les difficultés de concilier l’approche sensible et l’approche scientifique", revue italienne de géographie *Rivista geografica italiana*, 2: 173-194

DEKOCK P. C. & MITCHELL R. L., 1957, "Uptake of chelated metals by plants", *Soil Science*, 84, 1: 55-62

DE ROUW Anneke, 1991, *Rice, weeds and shifting cultivation in a tropical rain forest, A study of vegetation dynamics*, Proefschrift ter verkrijging van de graad van doctor in de landbouw- en milieuwetenschappen, Landbouwuniversiteit te Wageningen, Nederland

DÉRY Steve, 1996, "Expansion agricole et déforestation: le modèle sud-est asiatique", *Cahiers de géographie du Québec*, 40,109, 29-48, DOI: 10.7202/022543ar
DEUFFIC Philippe, GINELLI Ludovic & Kevin PETIT, 2010, "Patrimoine foncier… et naturel ? Les propriétaires forestiers face à l'écologisation des Landes de Gascogne", *Sud-Ouest Européen*, 30, 109-124, (RG)

DIOT Marie-Françoise & TASTET Jean-Pierre, 1995, "Paléo-environnements holocènes et limites chrono-climatiques enregistrés dans un marais estuarien de la Gironde (France)", *Quaternaire*, 6, 2, 63-75

DOMMERGUES Yvon et MANGENOT François, 1970, *Écologie microbienne du sol*, Paris, Masson et C^ie^, 796 pp.

DOUNIAS Edmond, 1996, "Recrûs forestiers post-agricoles : perceptions et usages chez les Mvae du Sud-Cameroun", *Journal d'agriculture traditionnelle et de botanique appliquée*, 38, 1, 153-178

DRAAF (Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt - Aquitaine), 2013, "L'irrigation en Aquitaine: un facteur de production essentiel", *AGRESTE Aquitaine - Analyses et résultats,*70

DROEVEN Émilie, FELTZ Claude et KUMMERT Magali, 2004, *Les territoires paysagers de Wallonie*,Ministère de la région wallonne, Namur, Études et Documents, CPDT, 4

DUBREUILH Jacques, CAPDEVILLE Jean-Pierre, FARJANEL Geneviève, KARNAY Gabriel, PLATEL Jean-Pierre & SIMON-COINÇON Régine, 1995, "Dynamique d'un comblement continental néogène et quaternaire: l'exemple du bassin d'Aquitaine", *Géologie de la France*, 4, 3-26

DUFEY Joseph, 2002, "Solution du sol et garniture ionique des complexes d'échange: évolution suite à l'acidification et au chaulage", in: Association française pour l'étude du sol, *Programme et résumés du colloque acidification des sols, 4-5 avril 2001*, INRA Versailles, 5-6

ELISA A.A, NINOMIYA S., SHAMSHUDDIN & ROSLAN I., 2016, "Alleviating aluminum toxicity in an acid sulfate soil from Peninsular Malaysia by calcium silicate application", *Solid Earth*, 7, 367–374

ESPIAU P. et PEDRO G., 1983, "Etude du phénomène de ferrolyse par voie expérimentale. Production d'acidité d'échange et mise en évidence du rôle catalytique des minéraux argileux ", *Bulletin de l'association française pour l'étude du sol*, 3-4, 173-184

EVRARD, C., ROELS J., REMY P., TSHITENGE G. et H. POLLAK H., 1967, "Détection par activation neutronique d'accumulateurs d'aluminium dans la flore congolaise", *Atomic Energy Review*, 5(3), 119- 125.

FABER-LANGENDOEN Don & GENTRY Alwyn H., 1991, "Structure and diversity of rain forests at Bajo Calima, Choco region, western Colombia", *Biotropica*, 23, 2-11

FAO, 2016,. *Situation des forêts du monde 2016. Forêts et agriculture: défis et possibilités concernant l'utilisation des terres,* Rome

FAO, 2018, *Base de référence mondiale pour les ressources en sols 2014 - Système international de classification des sols pour nommer les sols et élaborer des légendes de cartes pédologiques - Mise à jour 2015*, Rome

FAURE Élodie & GALOP Didier, 2011, "La fin du paradigme du désert landais: histoire de la végétation et de l'anthropisation du désert landais à partir de l'étude palynologique de quelques lagunes de la Grande-Lande", in: *De la lagune à l'airial*, actes du colloque de Sabres (nov. 2008), Aquitania, Pessac, 43-59, (RG)

FEARNSIDE Philip, 1985, "Agriculture in Amazonia", in: G.T. Prance and T.E. Lovejoy (eds.), *Key Environments: Amazonia*, Pergamon Press, Oxford, U.K., 393-418

FITTKAU E.J., 1973, "Arten mannigfältigkeit amazonischer Lebensraüme aus ökologischer Sicht", *Amazoniana*, 4: 321-340

FRASER Dawn & KÆRN Mads, 2009, "A chance at survival: gene expression noise and phenotypic diversification strategies", *Molecular Microbiology*, 71(6), 1333–1340

FRINK Charles R*.,* 1973*,* "Aluminium chemistry in acid sulfate soils", in: H. DOST (ed), *Acid sulphate soils*, Int. Institute for land reclamation and improvement, Wageningen, The Netherlands, 131-168

FUJII Kazumichi, FUNAKAWA Shinya and KOSAKI Takashi; 2012: "Soil Acidification: Natural Processes and Human Impact", *Pedologist*, 415-425

FUSTEL DE COULANGES Numa Denis, 1885, *La Cité antique*, Paris, Hachette

GARCIA Jean-Louis & ROGER Pierre Armand, 2000, *Le cycle du souffre*, Laboratoire de microbiologie IRD, CESB-ESIL Marseille-Luminy

GARRITY D.P., SOEKARDI M., VAN NOORDWIJK M., DE LA CRUZ R., PATHAK P.S., GUNASENA H.P.M., VAN SO N. & HUIJUN G. MAJID N.M., 1997, "The Imperata grasslands of tropical Asia: area, distribution and typology", *Agroforestry Systems*, 36, 3-29

GASCUEL-ODOUX Chantal & MAGDA Danièle, 2015, "Gérer les paysages et les territoires pour la transition agroécologique", *Innovations Agronomiques*, 43, 95-106

GILLET Pauline, CODINA LLAVINA Elisabet, YAMBENE Henri et VERMEULEN Cédric, 2016: "Comment les villageois nomment-ils et s'approprient-ils leurs espaces ressources ? Description d'un socio-écosystème en pays Yambassa, Cameroun", *Cah. Agric.*, 25, 45006

GOLDEWIJK Kees Klein, BEUSEN Arthur, DOELMAN Jonathan & STEHFEST Elke, 2017, "Anthropogenic land use estimates for the Holocene – HYDE 3.2", *Earth Syst. Sci. Data*, 9, 927–953

GRUBA Piotr & SOCHA Jarosław, 2016, "Effect of parent material on soil acidity and carbon content in soils under silverfir(*Abies alba* Mill.) stands in Poland", *Catena*, 140, 90–95, (RG)

HAINZELIN Étienne & NOUAILLE Christine, 2013, "La diversité du vivant, moteur du fonctionnement écologique", in: *Cultiver la biodiversité pour transformer l'agriculture*, Versailles, éditions Quæ: 23-54

HARIDASAN Mundayatan, 1982, "Aluminium accumulation by some cerrado native species of central Brazil", *Plant and Soil*, 65, 265-273

HARIDASAN Mundayatan; 2008: "Nutritional adaptations of native plants of the cerrado biome in acid soils", *Braz. J. Plant Physiol.*, 20(3),183-195

HAYNES R.J. & SWIFT R.S., 1989, "The effects of pH and drying on adsorption of phosphate by aluminium-organic matter associations", *Journal of Soil Science*, 40, 773-781, (RG)

HUANG Lai-Ming, YANG Jin-Ling, THOMSON Aaron, ROSSITER David G., ZUO Shuang-Miao and ZHANG Gan-Lin; 2014: "Proton production from nitrogen transformation drives stream export of base cations in acid-sensitive forested watersheds", Ecological Indicators, 48, 348–357, (RG)

HUSTON Michael, 1980, "Soil nutrients and tree species richness in Costa Rican forests", *J. Biogeogr.*, 7: 147-157

HUTCHINSON George Evelyn, 1957, "Concluding remarks", *Cold Spring Harbor Symposia on Quantitative Biology*, 22, 2, 415–427

JAMONEAU Aurélien, 2010, *Relations entre les diversités α, β et γ de la flore vasculaire de fragments forestiers inclus dans des paysages agricoles contrastés*, Thèse de doctorat, Université de Picardie Jules Verne, Amiens, France, (RG)

JANIN Rémi, 2015, "Agriculture, la révolution urbaine", *Openfield*, numéro 4, https://www.revue-openfield.net/2014/11/26/agriculture-la-revolution-urbaine/

JANITZKY P & WHITTIG L D ,1964, "Mechanisms of formation of Na_2C0_3 in soils. II. Laboratory study of biogenesis", *Soil Sci.*, 15, 145-157

JOLIVET Claudy, AUGUSTO Laurent, TRICHET Pierre et ARROUAYS Dominique, 2007, "Les sols du massif forestier des Landes de Gascogne: formation, histoire, propriétés et variabilité spatiale", *Revue forestière française (RFF)*, 1, 7-30

JOUVE Philippe; 2016: *L'agronome et les systèmes. Approche systémique de l'exploitation agricole des zones tropicales et méditerranéennes*, St Ouen, Les éditions du net, 152 p.

JUSTE Christian, TAUZIN Jean, DUREAU Paulette, COURPRON Claude, 1982, "Exportation des éléments fertilisants par lessivage en sol sableux des Landes de Gascogne. Résultats de 8 années d'observations en cases lysimétriques", *Agronomie*, EDP Sciences, 2 (1), 91-98

KALAORA Bernard, 2001, "À la conquête de la pleine nature", *Ethnologie française*, vol. XXXI, no 4, 2001, 591-597

KAPLAN Jed O., KRUMHARDT Kristen M. & ZIMMERMANN Niklaus, 2009, "The prehistoric and preindustrial deforestation of Europe", *Quaternary Science Reviews*, 28, 3016–3034

KAMPRATH E.J., 1967, "Soil acidity and response to liming", *International soil testing series - rech. bull. 4*, North Carolina state univ. exp. sta. Raleigh

KAWANO Motoharu & TOMITA Katsutoshi, 1994, "Growth of smectite from leached layer during experimental alteration of Albite", *Clays and Clay Minerals*, 42, 1, 7-17.

KAWANO Motoharu & TOMITA Katsutoshi, 1996, "Amorphous Aluminium hydroxide formed at the earliest weathering stages of K-Feldspar", *Clays and Clay Minerals*, 44, 5, 672-676.

KOCHIAN Leon V., PINEROS Miguel A. & HOEKENGA Owen A., 2005, "The physiology, genetics and molecular biology of plant aluminum resistance and toxicity",*Plant and Soil*, 274, 175–195, (RG)

KOESTLER Arthur, 1969, "Beyond atomism and holism: the concept of the holon", in: Koestler A. et Smities J.R. (eds), *Beyond reductionism: new perspectives in the life sciences*, London, Hutchinson, 192-216

KONISHI Shigeki, MIYAMOTO Sobun and TAKI Takayuki, 1985, "Stimulatory effects of Aluminium on tea plants grown under low and high Phosphorus supply", Soil Scl. Plant Nutr., 31 (3), 361-368

KUPIEC Jean-Jacques et SONIGO Pierre, 2000, *Ni Dieu ni gène - Pour une autre théorie de l'hérédité -*, Pais, Seuil, 229 pp.

LACAZE Jean-Paul, 1990, Les méthodes de l'urbanisme, Paris, PUF, coll. "Que sais-je?", 127 pp.

LALIBERTÉ Étienne, GRACE James B., HUSTON Michael A., LAMBERS Hans, TESTE François P., TURNER Benjamin L. and WARDLE David A., 2013, "How does pedogenesis drive plant diversity?", *Trends in Ecology & Evolution*, 28, 6: 331-340, doi: 10.1016/j.tree.2013.02.008

LALLENSACK Rachael, 2018, "How warp-speed evolution is transforming ecology", *Nature,* 554, 19-21

LAMING Denis, 2015, "La ville", In: *Mondes mosaïques, astres, villes, vivant et robots*, Paris, CNRS Éditions, 59-127

LANSON B., FERRAGE E., HUBERT F., PRÊT D., MARESCHAL L., TURPAULT M-P. et RANGER J., 2015, "Experimental aluminization of vermiculite interlayers: an X-ray diffraction perspective on crystal chemistry and structural mechanisms", *Geoderma*, 249–250, 28–39, (RG)

LE MOIGNE Jean-Louis, 2006, *La théorie du système général. Théorie de la modélisation*, Coll. Les classiques du réseau intelligence de la complexité, Publication de l'édition de 1994, Nouvelle présentation 2006, 338 p.

LE ROY Étienne, 2016, "Des communs à double révolution", *Droit et Société*, 94, 603-624

LIU H., HECKMAN J.R. & MURPHY J.A., 1997, "Aluminium tolerance among genotypes of Agrostis species, *International Turfgrass Society Research Journal*, 8: 729–734

LOUSTAU Denis, BERT Didier et TRICHET Pierre, (1999), "Fonctionnement primaire et productivité de la forêt landaise: implications pour une gestion durable", R*evue forestière française*, vol. LI, 5, 571-591

LUNGU Obed and DYNOODT Ron, 2008, "Acidification from long-term use of urea and its effect on selected soil properties", *African journal of food agriculture nutrition and development*, 8, 1, 63-76

MALM Andreas & HORNBORG Alf, 2014, "The Geology of Mankind? A Critique of the Anthropocene Narrative", *The Anthropocene Review*, 1, 1, 62-69

MARCON Éric, 2015, *Mesures de la Biodiversité,* Master, UMR Écologie des forêts de Guyane, Kourou, France

MARQUES J.J., TEIXEIRA W.G., SCHULZE D.G. and CURI N., 2002, "Mineralogy of soils with unusually high exchangeable Al from the western Amazon Region", *Clay Minerals*, 37, 651–661

MARTELLOZO F., LANDRY J-S.,, PLOUFFE D., SEUFERT V., ROWHANI P.& RAMANKUTTY N., 2014, "Urban agriculture: a global analysis of the space constraint to meet urban vegetable demand", *Environmental Research Letters*, 9, 8 pp, doi:10.1088/1748-9326/9/6/064025, (RG)

MATIJEVIK E., MATHAI K.G., OTTERWILL R.H. & KERKER M., 1961, "Detection of metal ion hydrolysis by coagulation, III Aluminium", *J. Phys. Chem.*, 65: 826-830

MAYAUX Philippe, PEKEL Jean-François, DESCLÉE Baudouin, DONNAY François, LOUPI Andrea, ACHARD Frédéric, CLERICI Marco, BODART Catherine, BRINK Andreas, NASI Robert & BELLWARD Alan, 2013, "State and evolution of the African rainforests between 1990 and 2010", *Phil. Trans. R. Soc. B.*, 368: 20120300

MAZOYER Marcel & ROUDART Laurence, 2002, *Histoire des agricultures du monde*, Seuil (Points Histoire)

MERLIN Pierre, 1991, *L'urbanisme*, Paris, PUF, coll. "Que sais-je?", 125 pp.

MEYER, J.A. et DUPRIEZ G.L., 1959, "Quantité d'azote et d'autres éléments nutritifs apportés au sol par les eaux de pluie au Congo Belge et leur intérêt agronomique", *C.R. 3e conf. Interafricaine des sols*, CCTA.

MICHON Geneviève, DE FORESTA Hubert & LEVANG Patrice, 1995, "Stratégies agroforestières paysannes et développement durable: les agroforêts à Damar de Sumatra", *Natures, Sciences, Sociétés*, 3,3, 207-223

MORA Olivier, BANOS Vincent, CARNUS Jean-Michel & REGOLINI Margot (éditeurs), 2012, *Le massif des Landes de Gascogne à l'horizon 2050*, Rapport de l'étude prospective, Conseil régional d'Aquitaine-INRA, 290 p.

MORA-URPI Jorge, WEBER John C. & CLEMENT Charles R., 1997, *Peach palm. Bactris gasipaes Kunth,* Promoting the conservation and use of underutilized and neglected crops, 20, Institute of Plant Genetics and Crop Plant Research, Gatersleben/ International Plant Genetic Resources Institute, Rome, Italy, 83 pp.

MOREAU Roland, 1993, "Influence de la mise en culture et de la jachère forestière sur l'évolution des sols forestiers tropicaux", in: Éd. ORSTOM, Anonyme, *La Jachère en Afrique de l'Ouest*, 245-256

MORENO-ALVARADO Marcos, GARCIA-MORALES Soledad, TREJO-TÉLLEZ Libia Iris, HIDALGO-CONTRERAS Juan Valente & GOMEZ-MERINO Fernando Carlos, 2017, "Aluminum enhances growth and sugar concentration, alters macronutrient status and regulates the expression of NAC transcription factors in rice", *Frontiers in Plant Science*, vol. 8, article 73

MOSS Michael R., 2000, "Landscape ecology: the need for a discipline?", *Problemy Ekologii Krajobrazu*, 6: 174-187

MOUGENOT Bernard, ZANTE Patrick & MONTOROL Jean-Pierre, 1990, "Détection et évolution saisonnière des sols salés et acidifiés du domaine fluvio-marin de basse Casamance au Sénégal, par imagerie satellitaire", In : Lafrance P. (ed.), Dubois J.M. (ed.), *Apports de la télédétection à la lutte contre la sécheresse*, Montrouge, J. Libbey Eurotext: 173-179

MUGICA Julie, MALLET Cyril et HENNEQUIN Vincent, 2008, *Étude de l'évolution géomorphologique récente de la côte sableuse aquitaine*, Bureau de Recherches Géologiques et Minières (service géologique national français), BRGM/RP-56874-FR, 165 p.

MUTERT E.; 1999: "Suitability of Soils for Oil Palm in Southeast Asia", *Better Crops International*, 13, 1: 36-38

MWORIA John K., 2011, "Invasive Plant Species and Biomass Production", In: *Savannas, Biomass and Remote Sensing of Biomass*, Dr. Islam Atazadeh (Ed.), InTech, 35-56

NEKOLA Jeffrey C., ALLEN Craig D., BROWN James H., BURGER Joseph R., DAVIDSON Ana D., FRISTOE Trevor S., HAMILTON Marcus J., HAMMOND Sean T., KODRIC-BROWN Astrid, MERCADO-SILVA Norman & OKIE Jordan G., 2013, "The Malthusian–Darwinian dynamic and the trajectory of civilization", *Trends in Ecology & Evolution*, 28, 3: 127-130, (RG)

NELSON Paul, RHEBERGEN Tiemen, BERTHELSEN Suzanne, WEBB Michael, BANABAS Murom, OBERTHÜR Thomas, DONOUGH Chris, RAHMADSYAH, INDRASUARA Kooseni & LUBIS Ahmad, 2011, "Soil acidification under oil palm: rates and effects on yield", *Better crops*, 95, 4, 22-25

NICHOLAIDES J.J., BANDY D.E., SANCHEZ P.A., BENITES J.R., VILLACHICA J.H., COUTU A.J. & VALVERDE C.S., 1985, "Agricultural alternatives for the Amazon Basin", *BioScience*, 35, 279-285

OPDECAMP Luc, 1988a, *Étude de la toxicité alumino-manganique des sols d'altitude du Burundi*, Rapport scientifique final du contrat de recherche TSD-A-411- RU(MR) entre l'Institut des Sciences Agronomiques du Burundi (ISABU) et la Commission des Communautés Européennes (CCE), 123 pp.

OPDECAMP Luc, MUSONI Innocent & GOURDIN Jacques, 1988, "Effets stimulants et toxiques de l'aluminium sur la croissance des plantes cultivées dans les sols humifères acides du Burundi", *Publication ISABU*, n° 129, 1-26, (RG)

OPDECAMP Luc, GOURDIN Jacques & OTOUL Christian, 1990, "Exploitation vivrière et fourragère des sols alliques d'altitude du Burundi", *Publication ISABU*, n° 145, 1-42, (RG)

OPDECAMP Luc, 1997, *Discussion d'un modèle et de paramètres écologiques et économiques pour la gestion de l'écosphère tropicale humide*, Alterthèses asbl, 38 pp, (RG)

OPDECAMP Luc, 1998, *Discussion thermodynamique des relations entre la pédogenèse acide, la biodiversité et les systèmes agraires dans l'écosphère tropicale humide*, Alterthèses asbl, 30 pp, (RG)

OPDECAMP Luc, 2015, Les agropédosystèmes dans l'agropédopaysage, 11 pp, (RG)

OSAKI Mitsuru, WATANABE Toshihiro & TADANO Toshiaki, 1997, "Beneficial effect of aluminum on growth of plants adapted to low pH soils", *Soil Science and Plant Nutrition*, 43:3, 551-563, (RG)

OSWALD W., 1897, "Studien über die Bildung und Umwandlung fester Körper, *Z. Phys. Chem.*, 22, 289–330

OXMAN Neri, 2016, "Age of entanglement, an inaugural essay for the Journal of Design of Science, *JoDS, en ligne,* <http://jods.mitpress.mit.edu/pub/AgeOfEntanglement>

PAPY Louis, 1977: "Les Landes de Gascogne: la maîtrise de l'eau dans la lande humide", in: Norois, n° 95 ter, Novembre 1977, Géographie rurale. pp. 199-210

PAVAN Marcos A., BINGHAM F.T. & PRATT P.F., 1982, "Toxicity of aluminium to coffee in ultisols and oxisols amended with $CaCO_3$, $MgCO_3$ and $CaSO_4.2H_2O$", *Soil Sci. Soc. Am. J.*, 46, 1201-1207

PELTZER Duane A., WARDLE David A., ALLISON Victoria J., BAISDEN W. Troy, BARDGETT Richard D., CHADWICK Oliver A. et al., 2010, "Understanding ecosystem retrogression", *Ecological Monographs*, 80,4, 509-529, (RG)

PÉREZ-SANDOVAL Reyna, GOMEZ-GUERRERO Armando, FIERROS-GONZALEZ Aurelio & HORWATH William R., 2012, "Site productivity of clone and seed raised plantations of Eucalyptus urophylla and Eucalyptus grandis in Southeast Mexico", *Open Journal of Forestry*, 2, 4, 225-231

PIRARD Romain, DAL SECCO Lise & WARMAN Russell, 2016, "Do timber plantations contribute to forest conservation?", *Environmental Science & Policy*, 57, 122–130

POOZESH Vahid, 2007, *Réponse des graminées des prairies permanentes à l'acidité, à l'aluminium et à la fertilisation (N, P): relations avec les traits fonctionnels*, Thèse de Doctorat à l'Institut national polytechnique de Toulouse, 138 pp., (RG)

POTTIER Aude, 2010, "Les ambiguïtés du paysage forestier des Landes de Gascogne", *Projets de Paysages* [En ligne]

POUX Xavier., NARCY J.-B. et RAMAIN Blandine, 2009a, "Le saltus: un concept historique pour mieux penser aujourd'hui les relations entre agriculture et diversité", *Courrier de l'environnement de l'INRA*, n° 57, 23-34.

POUX Xavier., NARCY J.-B. et RAMAIN Blandine, 2009b, "Réinvestir le saltus dans la pensée agronomique moderne: vers un nouveau front eco-politique?", *L'Espace Politique*, Revue en ligne de géographie politique et de géopolitique, 9,3

PREISER Rika, PEREIRA Laura M. & BIGGS Reinette (Oonise), 2017, "Navigating alternative framings of human-environment interactions: variations on the theme of 'Finding Nemo'", *Anthropocene*, 20, 83–87

PROCTOR J., ANDERSON J.M., CHAI P. & H.W. VALLACK, 1983, "Ecological studies in four contrasting rain forests in Gunung Mulu National Park, Sarawak. I. Forest environment: structure and floristics", *J. Ecol.*,71: 237-260

RAYMOND Richard, LUGINBÜHL Yves, SEGUIN Jean-François, CEDELLE Quentin et GRARE Hélène, 2015, *Les atlas du paysage. Méthode pour l'identification, la caractérisation et la qualification des paysages*, République française, Ministère de l'écologie, du développement durable et de l'énergie

REINECKE J., WULF M., BAETEN L., BRUNET J., DECOCQ G., DE FRENNE P., DIEKMANN M., GRAAE B.J., HEINKEN T., HERMY M., JAMONEAU A., LENOIR J., PLUE J., ORCZEWSKA A., VAN CALSTER H., VERHEYEN K. & NAAF T., 2016, "Acido-and neutrophilic temperate forest plants display distinct shifts in ecological pH niche across north-western Europe", Ecography, 39 (12): 1164-1175, (RG)

RICHARDS, P.W., 1996, *The tropical rain forest*, second edition, Cambridge university press, 575 p.

RICHARDSON Sarah J., PELTZER Duane A., ALLEN Robert B., McGLONE Matt S. & PARFITT Roger L., 2004, "Rapid development of phosphorus limitation in temperate rainforest along the Franz Josef soil chronosequence", *Oecologia*, 139, 267–276

RICHBURG J.S. & ADAMS F., 1970, "Solubility and hydrolysis of aluminium in soil solutions and saturated paste extracts", *Soil Sci. Soc. Am. J.*, 34, 728-734

RIZZO Davide, MARRACCINI Elisa, LARDON Sylvie, DEBOLINI Marta, BENOIT Marc & THENAIL Claudine, 2013, "Farming systems designing landscapes: land management units at the interface between agronomy and geography", *Geografisk Tidsskrift-Danish Journal of Geography*, 113, 2: 71-86

ROBARGE W.P. & COREY R.B., 1979, "Adsorption of phosphate hydroxy-aluminium species on a cation exchange resin", *Soil Sci. Soc. Am. J.*, 43, 481-487

ROBERTS Patrick, HUNT Chris, ARROYO-KALIN Manuel, EVANS Damian & BOIVIN Nicole, 2017, "The deep human prehistory of global tropical forests and its relevance for modern conservation", *Nature plants*, 3, art. 17093, (RG)

ROGER Alain, 1997, *Court traité du paysage*, Gallimard, essais folio, 249 pp.

ROSSI Georges, 2000, *L'ingérence écologique. Environnement et développement rural du Nord et du Sud*, Paris, CNRS éditions

RUF François, 2011, "The myth of complex cocoa agroforests: the case of Ghana", *Human Ecology*, 39, 373–388, (RG)

SALJNIKOV Elmire & CAKMAK Dragman, 2011, "Phosphorus: Chemism and Interactions", in: *Principles, application and assessment in soil science*, Dr. Burcu E. Ozkaraova Gungor (Ed.), InTech

SAMPOUX JP., 2006,. *Étude des déterminants environnementaux de la structuration spatiale de la diversité spontanée inter et intra spécifique des fétuques à feuilles fines*, 6ème Colloque National des Ressources Génétiques, La Rochelle (2006)

SANCHEZ Pedro A., BANDY D.E., VILLACHICA J.H. & NICHOLAIDES J.J., 1982, "Amazon Basin soils: Management for continuous crop production", *Science*, 216, 821-827

SANCHEZ Pedro A., VILLACHICA J.H. & BANDY D.E., 1983, "Soil fertility dynamics after clearing a tropical rainforest in Peru", *Soil Sci. Soc. Am. J.*, 47, 1171-1178

SANCHEZ Pedro A., PALM Cheryl A. and BUOL Stanley W., 2003; "Fertility capability soil classification: a tool to help assess soil quality in the tropics", *Geoderma*, 114, 157–185

SASAKI T., YAMAMOTO Y., EZAKI B., KATSUHARA M., AHN S. J., RYAN P. R. et al., 2004, "A wheat gene encoding an aluminum-activated malate transporter", *Plant J.*, 37, 645–653. doi: 10.1111/j.1365-313X.2003.01991.x

SCHNEIDER A., FRIEDL M. A., MCIVER D. K. & WOODCOCK C. E., 2003, "Mapping urban areas by fusing multiple sources of coarse resolution remotely sensed data, *Photogrammetric Engineering and Remote Sensing*, 69, 1377−1386

SCHNEIDER Annemarie, FRIEDL Mark A. & POTERE David, 2010, "Mapping global urban areas using MODIS 500-m data: new methods and datasets based on urban ecoregions", *Remote Sensing of Environment*, 114, 1733–1746

SCHWARTZ Dominique, 1997, "Forêts et savanes d'Afrique centrale: une histoire holocène mouvementée", *Lettre n°6 du Programme International Géosphère Biosphère-Programme Mondial de Recherches sur le Climat*, CNRS, France, 14-22

SCHROTH Götz, SEIXAS Rosangela, DA SILVA L.F., TEIXEIRA W.G. & ZECH W., 2000, "Nutrient concentrations and acidity in ferralitic soil under perennial cropping, fallow and primary forest in central Amazonia", *European Journal of Soil Science*, 51(2), 219-231, (RG)

SCHROTH Götz, GARCIA Edenise, GRISCOM Bronson Winthrop, TEIXEIRA Wenceslau Geraldes and BARROS Lucyana Pereira, 2016; "Commodity production as restoration driver in the Brazilian Amazon? Pasture re-agro-forestation with cocoa (*Theobroma cacao*) in southern Para", *Sustain Sci*, 11:277–293, doi 10.1007/s11625-015-0330-8

SCHWARTZ Dominique, 1997, "Forêts et savanes d'Afrique centrale : une histoire holocène mouvementée", In: *Lettre n°6 du Programme International Géosphère Biosphère-Programme Mondial de Recherches sur le Climat,* CNRS, France

SHAMSHUDDIN Jusop, PARAMANANTHAN S. & MOKHTAR Nik, 1986, "Mineralogy and surface charge properties of two acid sulfate soils from peninsular Malaysia", *Pertanika*, 9(2),167-176, (RG)

SHAMSHUDDIN Jusop, MUHRIZAL Sarwani, FAUZIAH Ishak & VAN RANST Eric, 2004, "A laboratory study of pyrite oxidation in acid sulfate soils", *Communications in Soil Science and Plant Analysis*, 35 (1 & 2), 117-129, (RG)

SILVA I.R., NOVAIS R.F., JHAM G. N., BARROS N. F., GEBRIM F. O., NUNES F. N., NEVES J. C. L. & LEITE F. P., 2004, "Responses of eucalypt species to aluminum: the possible involvement of low molecular weight organic acids in the Al tolerance mechanism", *Tree Physiology*, 24, 1267–1277

SILVERTOWN Jonathan, POULTON Paul, JOHNSTON Edward, EDWARDS Grant, HEARD Matthew & BISS Pamela M, 2006, "The Park Grass Experiment 1856–2006: its contribution to ecology", *Journal of Ecology*, 94, 801–814

SINGH J.S. and GUPTA S.R.;,1977, "Plant decomposition and soil respiration in terrestrial ecosystems", *The botanical review*, 43, 4, 449-528.

SIVASUBRAMANIAM S. & TALIBUDEEN O.; 1971: "Effect of aluminium on growth of tea (Camelia sinensis) and its uptake of potassium and phosphorus", *Tea Q*., 43, 4-13

SMIT Jac, NASR Joe & RATTA Annu, 2001, "Urban agriculture yesterday and today",In: *Urban agriculture: food jobs and sustainable cities*, The urban agriculture network (second edition wtih permission of UNDP)

SNAYDON R.W., 1970, "Rapid population differentiation in a mosaic environment. I Response of Anthoxanthum odoratum L. to soils", *Evolution,* 24, 257-269

SOIL SURVEY STAFF, 2014, Keys to soil taxonomy, Twelfth edition, United States Department of Agriculture, National Resources Conservation Service

SOTTIAUX Guy, OPDECAMP Luc, BIGURA Célestin et FRANKART Raymond, 1998, *Carte des sols du Burundi - échelle 1/250.000^e^ - Notice explicative*, AGCD (Administration générale de la coopération au développement), Publication du service agricole n° 9, 142 p.

SOW Mamadou, 2003, "Innovations en aménagement des sols de mangrove pour la riziculture: Partie 1 - Cas du périmètre de Yangoyah (Guinée)", *Étude et Gestion des Sols*, 10, 2, 95-106,

SOW Mamadou et BARRY M.B., 2003, "Innovations en aménagement des sols de mangrove pour la riziculture, Partie 2 - Résultats agronomiques", Étude et Gestion des Sols, 10, 2, 107-119

SUING Guillaume, 2016, *ÉVOLUTION: La preuve par MARX - Dépasser la légende noire de Lyssenko*, Paris, Éditions Delga

TANG VAN HAI, TRUONG THI NA & LAUDELOUT Henri, 1989, "Effect of aluminium on the mineral nutrition of rice", *Plant and Soil*, 114 (2), 173-185

THIERRON V. and LAUDELOUT H., 1996, "Contribution of root respiration to total CO_2 efflux from the soil of a deciduous forest", *Can. J. For. Res.,* 26,: 1142-1148

TOLRA Roser, VOGEL-MIKUS Katarina,HAJIBOLAND Roghieh,KUMP Peter, PONGRAC Paula, KAULICH Burkhard, GIANONCELLI Alessandra, BABIN Vladimir, BARCELO Juan, REGVAR Marjana & POSCHENRIEDER Charlotte, 2011, "Localization of aluminium in tea (*Camellia sinensis*) leaves using low energy X-ray fluorescence spectro-microscopy", *Journal of Plant Research*, 124, 1, 165–172, (RG)

TOURRAND J.F., VEIGA J.B., BURLAMAQUI A.B., POCCARD-CHAPUIS R., PIKETTY M.G., 2006, "L'Amazonie pâturée", *Renc. Rech. Ruminants*, 13, 345-348

TSAYEM DEMAZE Moïse, 2008, "Quand le développement prime sur l'environnement: la déforestation en Amazonie brésilienne", *Mondes en développement*, 143, 97-116, DOI 10.3917/med.143.0097

TSUJI Masaki, KUBOI Toru & KONISHI Shigeki, 1994, "Stimulatory effects of aluminum on the growth of cultured roots of tea", *Soil Science and Plant Nutrition*, 40,3: 471-476, DOI: 10.1080/00380768.1994.10413324

TURNER Benjamin L. & LALIBERTÉ Etienne, 2015, "Soil development and nutrient availability along a 2 million-year coastal dune chronosequence under species-rich mediterranean shrubland in southwestern Australia", *Ecosystems*, 18, 287–309

VANDERPOOTEN Michel, 2012, *3000 ans de révolution agricole. Techniques et pratiques agricoles de l'Antiquité à la fin du XIX^{e} siècle,* Paris, L'Harmattan

VAN BREEMEN N., MULDER J. and DRISCOLL C.T., 1983, "Acidification and alkalinization of soils", *Plant and Soil*, 75, 283-308

VAN MIEGROET Helga. and COLE D. W.; 1985: "Acidification sources in Red Alder and Douglas-fir soils -- Importance of nitrification", *Soil Science Society of America Journal*, 49, 1274-1279

VIDAL Roland, 2011, "Construire des territoires partagés entre la ville et l'agriculture", in: Conseil Régional de Bretagne (Rennes), *Entre ville et campagne, un paysage à inventer*, Coll. "Ateliers techniques du paysage", 13-36.

VIDAL Roland, 2014, *L'Agriurbanisme - En 40 pages*, Format Kindle, UPPR éditions

VIENNET Jean-Christophe, 2015, *Minéraux argileux aluminisés des sols : caractérisation structurale par modélisation des diffractogrammes de rayons X et détermination des mécanismes de formation par approche expérimentale*,Thèse de doctorat, Sciences de l'environnement, Université de Poitiers, France, 189 p.

WANG Jianwu, LUO Shiming & FENG Yuanjiao, 2000, "Aluminum forms in acid sulfate soils", *Chinese Journal of Applied Ecology, 11(5), 735-40, (Abstract), (RG)*

WARDLE David A. , WALKER Lawrence R. & BARDGETT Richard D., 2004, "Ecosystem properties and forest decline in contrasting long-term chronosequences", *Science*, 305, 509-513

WARDLE David A., BARDGETT Richard D., WALKER Lawrence R., PELTZER Duane A. and LAGERSTRÖM Anna; 2008: "The response of plant diversity to ecosystem retrogression: evidence from contrasting long-term chronosequences", *Oikos*, 117, 93-103, doi: 10.1111/j.2007.0030-1299.16130.x

WATANABE Toshihiro, JANSEN Steven & OSAKI Mitsuru, 2005, "The beneficial effect of aluminium and the role of citrate in Al accumulation in *Melastoma malabathricum*", *New Phytologist*, 165, 773–780

WATANABE Toshihiro, JANSEN Steven & OSAKI Mitsuru, 2006, "Al–Fe interactions and growth enhancement in Melastoma malabathricum and Miscanthus sinensis dominating acid sulphate soils", *Plant, Cell and Environment*, 29, 2124–2132, (RG)

WATSON James E. M. & VENTER Oscar, 2017, "A global plan for nature conservation", Nature, 550, 48-49

WEINSTEIN Steven & PAVLIC Theodore P., 2017, "Noise and function", in: S.I Walker, P.C.W. Davies and G.F.R. Ellis (ed), *From matter to life, information and causality*, Camnbridge university press, 174-198

WICKE Birka, SIKKEMA Richard, DORNBURG Veronika and FAAIJ André; 2011, "Exploring land use changes and the role of palm oil production in Indonesia and Malaysia", Land Use Policy, 28, 193–206.

WYNS Robert, CORNU Sophie et PROGNON Caroline, 2014, "Régolithe et sol: l'interface entre lithosphère et atmosphère", *Geosciences,* BRGM, 8-15

ZEMUNIK Graham, TURNER Benjamin L., LAMBERS Hans and LALIBERTÉ Etienne; 2016, "Increasing plant species diversity and extreme species turnover accompany declining soil fertility along a long-term chronosequence in a biodiversity hotspot", *Journal of Ecology*, doi: 10.1111/1365-2745.12546