LAVAL UNIVERSITY

FACULTY OF FORESTRY AND GEOMATICS

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«Fundamentals of Forest Ecosystem Pedogenetics: An Approach to Metastability Through Tellurian Biology»

by

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Fundamentals of Forest Ecosystem Pedogenetics: An Approach to Metastability Through Tellurian Biology

1-Introduction

The following rationales and conclusions must be seen and assessed in the context of our twenty year "adventure." Continual scepticism and frequent resistance towards our research made funding virtually impossible at every level: the forest sector would direct us to the agricultural sector and vice versa. On the other hand, this allowed us greater freedom in our experimentation and now freedom of speech.

It further allowed us to evaluate the degradation of scientific thinking in the biological field, particularly the forestry and agricultural sectors. It quickly became apparent that the quest for data had supplanted the quest for ideas: science in conflict with technique ruled by technology.

Numerous other discoveries were surprising as well, such as the origin and definition of the terminology, which stand in the way of basic knowledge development. For example, although pedogenetic mechanisms have their origins in forestry, they are either part of the agricultural vocabulary or are ignored by it. Whereas forestry specific techniques should have been developed long ago, the tendency has been to borrow or plagiarize agricultural data and customs. Similarly, our concept and knowledge of agricultural soils are based solely on references to chemistry and pathology, never to the forest. In both cases, pedology seemed to us to be approached on a descriptive level only, or worse yet, solely from the perspective of chemical and physical properties. Yet, in reality, pedology is much more than just chemistry and physics.

We therefore hope that readers will be able to appreciate the agro-forestry history of soil and will give some thought to both its importance and the related lack of knowledge, if only from a descriptive standpoint.

2- SOIL : OF FUNDAMENTAL VALUE TO HUMANS.

The past two decades have surreptitiously contributed data which, in hindsight, have led to an anthropogenic view and understanding of ecosystems which have rarely been challenged until now. Being more concerned about finding food in order to live, man has paid little attention to the source of that food and the link to all other life forms: soil. The term humus has existed for barely a century and, although it is most likely of anthropocentric origin, it holds only a veiled connotation of life.

In order to survive, man gradually gained control over the forest, felling trees and working the land to domesticate and cultivate plants for food. Over the centuries, we have thus come to consider agricultural soil as the source of all life. However, this notion fades the farther away from the tropics and the closer to the poles one moves. Similarly, societies that depend on and live in tune with nature and its constraints do not hold the same view as those that live off the fruits of nature while controlling its constraints such as industrial societies.

2.1- A new experience with agricultural origins

In order to untangle the maze of thoughts and hypotheses contained in this document, we must go back to the 1970s, when three researchers[1] got the idea of exploiting thousands of tons of residue from the steam distillation of branches in the production of essential oils. These industrial residues were composed exclusively of hogged evergreen branches *(Abies balsamea* and *Thuja occidentalis)* which were considered to be without use and hence waste. The researchers came

[1] **Edgar Guay,** Deputy minister, Ministry of Forest, Québec
Lionel Lachance, Head of Plant Production Dept, Ministry of Agriculture, Québec, Agronomist.
R. Alban Lapointe, Forest Engineer, Ministry of Forest, Québec.

up with the idea of using these residues as a mulch for growing potatoes, wheat, oat, strawberries, etc. First, though, they sent the material to the lab for analysis and discovered that it had a valuable chemical and biochemical content[2]. Further testing showed that hogged evergreen or hardwood branches incorporated into topsoil had different effects over a number of years.

The technique proposed by these authors is a combination of the sheet composting technique used in the United States and brush composting used by the French. Branches less than 7 cm in diameter were hogged into chips no more than a few centimeters long and then spread on the ground at a rate of $200m^3$/ha, or 2 cm thick, and incorporated into the top 10 cm of soil. Varied results were obtained over a period of several years.

When they asked me to explain these differences in yield, Guay, Lachance and Lapointe issued a challenge that I could not back away from. To my great surprise, I was unable to find even one article on what, to my mind, was a major source of plant production: at the time, I estimated the world production of branches at a few billion tons/year. In my first major publication, in 1985, I proposed the term "Bois Raméal"[3],which I described in detail a year later[4] .

The agricultural results obtained from adding chipped twigs to topsoil, e.g. enhancement of soil substructure and texture, positive changes in the C/N ratio and pH, and the modification of weed, insect and disease behaviour, proved that we were looking at a very important phenomenon that had been ignored by the scientific literature.

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[2]**Guay, E., Lachance, L. & Lapointe R.A. (1982)** « Emploi des bois raméaux fragmentés et des lisiers en agriculture» Ministry of Energy and Resources, 74 pages, Québec

[3]**Lemieux, G. Lapointe, R.A.(1985)** «Essais d'induction de la végétation forestière vasculaire par le bois raméal fragmenté» Université Laval, Faculté de Foresterie, 109 pages.

[4]**Lemieux, G. (1986)** «Le bois raméal et les mécanismes de fertilité du sol» Université Laval, Faculté de Foresterie 17 pages, ISBN 2-550-21338-1.
Chipped twigs from branches less than 7 cm in diameter.

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In early 1990, we came across two significant publications that put us on a promising trail. The first was by **Leisola and Garcia (1989)**[5], who describe and promote the role of basidiomycetes in lignin degradation by a manganese dependent enzyme called lignoperoxidase, producing humic and fulvic fractions while retaining the larger molecule on the mycelium, preventing repolymerization and producing aliphatic compounds.

The second paper, by **Perry et al. (1989)**[21], dealt with the relationship between soil (hypogeous ecosystem) and vegetation (epigeous ecosystem). Their research was aimed at understanding and describing the relationships between the various trophic levels at which mychorrhizae play a vital role.

2.2- Forest experimentation

Although the agricultural experimentation gave us food for thought and pointed us in the right research direction, we were far from understanding the basic mechanisms causing the observed changes. If chipped branches were responsible for various soil modifications, such as nutrient content, changes in pH, crop yields (quality and quantity), it was not clear why. We postulated that these mechanisms had some kind of forest origin, without being able to find any clues in the existing literature. In the spring of 1983, we established our first research site, followed by others in 1984, 1985, 1988, 1990 and 1992, with each site having a different background.

With assistance from D[r]. Marcel Goulet, we selected a one hectare site known to have been sterile for the past 50 years but completely surrounded by forest, thereby ensuring the availability of seeds for natural regeneration. Small plots from 2 to 4 m^2 in size were established and a 1.5 to 2.0 cm thick layer of RCW spread as litter or incorporated into the top few centimetres of soil, with a control plot established above each row.

[5]Lignin degradation mechanisms in «Enzyme systems for lignocellulose degradation» Workshop on organic matter degradation, p. 89-99 Galway Ireland,

The agricultural testing had shown an alteration in several tellurian parameters during a period of over a year, always with an upgrade in physical, physicochemical and chemical characteristics. We concluded that we were looking at a series of biological phenomena that significantly affected all factors at once. Based on this hypothesis, it was decided that all plots had to be subject to the same conditions and constraints, which meant establishing small plots one meter apart in order to better evaluate discrepancies in post RCW development.

2.3- Assessment criteria

Whereas the assessment criteria used in agriculture are well established, i.e. profitability, productivity, crop health, etc. in relation to situ nutrient availability, the same cannot be said for forestry. So as not to waste time, we immediately decided to conduct our observations over a minimum of five years by measuring regeneration and growth of native and non native plant species in local stands. Regeneration was measured by counting the number of new plants in each plot every year for five years. Regeneration of control plots was measured every two years. During the final two years, we also collected topsoil samples to try and assess RCW metabolization in comparison to the control plots.

The report of our work published in 1989[6] is far too long and complex to try and summarize here; however, we will refer to it often for relevant data.

2.4- Effect of pH on nutrient accessibility.

For example, if we look at the changes in pH compared with the control plots from the fourth to seventh year following RCW application to determine whether there has been complete metabolization (Table 1), we can see that the 1990 values are almost identical to those of 1983, the first year of testing.

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[6]**Lemieux, G. & Lapointe R.A. (1989)** «La régénération forestière et les bois raméaux fragmentés: observations et hypothèses» Département des Sciences Forestières, Université Laval, Québec, Canada, 223 pages ISBN 2-550-21342-4.

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We have chosen this physicochemical parameter because it shows H^+ and OH^- ion balance, which is in turn responsible for the availability of certain nutrients or the diminished availability of others, such as phosphorus.

The remaining parameters were chosen because they are directly linked to biological results. After all, the aim of the testing was to find a way of assessing the recolonization of forest ecosystems. The temporal and spatial measurement of regeneration using an actual forest site seemed to us to be the only alternative to chemical nutrient quantitative analysis, which we have always considered dubious.

Stemwood production is a function of photosynthesis in the crown. From this perspective, wood can be seen as the result of overproduction and not of production itself since, as underlined by several authors, 80% of a tree's energy production is transported directly to the hypogeous ecosystem[7].

We subsequently postulated that during metabolization RCW generates tellurian characteristics that foster new levels of plant succession, creating a new forest ecosystem. We then confined our work to counting and identifying seedlings in plots, distinguishing between trees, shrubs (conifers and hardwood), herbaceous plants and non native plants.

2.5-The case of *Picea glauca*

Table 2 shows the results obtained after six years for *Picea glauca* , including germination and growth success.

2.6- Some comments on Picea glauca behaviour in control plots

In 1984, not a single *Picea glauca* seedling was observed in any of the control plots (Column 1, Table 2), indicating that this

[7]Fogel, R, & Hunt G, [1983]), Meyer, J.R. & Linderman, R.G. [1986], Rambelli, A. [1973]), Reid, C.P.P., & Mexal, J.G. [1977], Vogt, K.A., Grier, C.C., & Meir, C.E. [1982], Whipps, J.M. & Lynch, J.M. [1986]

particular forest environment was not conducive to germination, even though there as an abundance of seeds each year. *Picea glauca* seedlings were observed in 1990, but by 1995 there were none left and the plots were the same as in 1983.

Of the 25 RCW species, only 10 control plots supported *Picea glauca* seedlings. The seedlings had all disappeared by the 1995 count, whereas those in the RCW treated plots were not only growing in number, they were thriving. This unpredictable seedling behaviour is indicative of constant biological instability and demonstrates that germination and survival do not go hand in hand. We have not given data for 1984 and 1995, since no seedlings were counted. And even though germination was observed in 1990, no seedlings were left in 1995.

Comparative changes in pH four years after RCW application

RCWs	chek plots	'87	'88	'89	'90
Conifers					
Larix laricina	4,0	5,3	5,1	5,0	4,7
Pinus resinosa	5,1	5,5	5,6	5,2	4,7
Pinus strobus	5,1	5,8	5.7	5,6	5,5
Thuja occidentalis	5,1	6,0	6,5	6,0	5,3
Transition hardwoods					
Acer rubrum	5,1	5,3	5,2	5,2	4,9
Acer spicatum	5,0	5,5	5,4	5,1	4,8
Alnus rugosa	5,0	5,5	5,3	5,1	4,6
Amelanchier bartramiana	4,9	5,8	6,1	5,3	5,4
Betula populifolia	5,1	5,8	5,7	5,4	5,1
Cornus rugosa	5,1	5,5	5,4	5,3	5,0
Populus balsamifera	5,3	5,7	5,9	5,6	5,2
Populus grandidentata	4,9	6,1	6,5	5,7	5,6
Populus tremuloides	5,0	5,9	6,2	5,4	5,3
Prunus pensylvnica	4,9	5,5	5,5	5,2	5,1
Salix bebbiana	5,0	5,7	5,6	5,3	5,1
Salix lucida	5,1	5,2	5,5	5,1	4,9
Sambucus pubens	5,0	5,2	5,6	5,0	4,9
Climax hradwoods					
Betula alleghaniensis	5,0	5,1	5,1	5,0	4,8
Carpinus caroliniana	5,0	6,0	5,7	5,3	5,2
Fraxinus americana	4,9	5.5	5.7	5,0	4,9
Juglans cinerea	4,8	5,7	5,7	5,7	5,5

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Prunus serotina	5,1	5,6	5,2	5,2	5,1
Quercus rubra	5,0	5,6	5,4	5,1	4,8
Tilia americana	5,0	5,0	5,8	5,4	5,0
Ulmus americana	5,0	5,6	6,1	5,2	5,2

Table n° 1

From Guay, E., Lachance, L., Lapointe, R.A. & Lemieux, G. (1991)[9]

In contrast to *Picea glauca*, *Abies balsamea* seedlings were unable to take root, even though seeds from nearby stands are abundant almost each year.

Distribution of Picea glauca seedlings
in RCW treated plots, 17/19 species, 1984 to1990

RCWs	84	85	86	87	88	90
Conifers (2/4)						
Larix laricina				1	4	8
Pinus resinosa					1	1
Transition hardwoods (9/13)						
Acer rubrum					2	2
Acer spicatum				2	3	3
Alnus rugosa				3	10	15
Betula populifolia				4	7	6
Cornus rugosa			1	2	4	5
Populus grandidentata					1	0
Prunus pensylvanica					1	1
Salix lucida					1	2
Sambucus pubens					2	1
Climax harrwoods (6/8)						
Carpinus caroliniana				8	21	28
Fraxinus americana				2	2	3
Juglans cinerea					3	4
Prunus serotina					1	2
Quercus rubra			1	4	4	5
Tilia americana				4	7	13

Table n° 2

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From Guay, E., Lachance, L., Lapointe, R.A. & Lemieux, G. (1991)[9]

After seven years, none of the conifer plots supported balsam fir: the seedlings would die as soon as they germinated. This same phenomenon was recorded every year, with *Abies balsamea* from surrounding stands ensuring an abundance of seeds. This instability can be seen in Table 4, which shows that even successful for plot seedlings *(Alnus rugosa, Carpinus caroliniana, Quercus rubra)* had dropped in number by 1990. This led us to draw our first conclusion: **The biology and biochemistry of RCW treated soil are not suited to fir for reasons that warrant further study .**

Distribution of Picea glauca seedlings in control plots, 1990

RCWs	
Conifers(2/4)	
Larix laricina	8
Pinus resinosa	1
Transition hardwoods (5/13)	
Acer rubrum	2
Acer spicatum	3
Cornus rugosa	2
Populus grandidentata	2
Salix lucida	2
Climax hardwood(3/8)	
Fraxinus americana	3
Quercus rubra	4
Tilia americana	1

Table nº 3

From Guay, E., Lachance, L., Lapointe, R.A. & Lemieux, G. (1991)[9]

2.7- Abies balsamea : irregular seedling survival and relatively unfavorable plots

If balsam fir was virtually unable to take root in new soils, how did hardwoodsbehave under the same conditions (Table 5)? Just like with balsam fir, the conifer plotswere totally unfavorable for the germination and growth of hardwoods, even transition hardwoods. However, the transition hardwood plots were more favourable to the germination and growth of hardwood seedlings (Table 5), all transition (Table 6): no climax hardwoods were ever observed on these plots. It is interesting to note that plots composed of dominant climax species had a greater number of seedlings of different species. This led to our second conclusion: Plots treated with hardwood RCW were more favorable than those treated with softwood RCW, although they showed a certain instability in individual and stand growth. As well, plots treated with dominant climax hardwood RCW showed greater tolerance to hardwood germination and growth.

Plot distribution of *Abies balsamea* seedlings, 1984 to 1990

RCWs	84	85	86	87	88	90
Conifers (0/4)						
	-	-	-	-	-	-
Transution hardwoods (2/13)						
Alnus rugosa				1	1	0
Cornus rugosa			2	1	1	2
Climax hardwoods (4/8)						
Betula alleghaniensis				1	1	1
Carpinus caroliniana			1	1	1	0
Quercus rubra			2	1	1	1
Tilia americana				2	2	4

Table n° 4

From Guay, E., Lachance, L., Lapointe, R.A. & Lemieux, G. (1991)[9]

It is fairly clear from Table 6 that, after 7 years, softwood plots were unfavourable for hardwood germination, with the sole exception of white pine *(Pinus strobus),* a species frequently found in climax hardwood forests. Transition hardwood plots were more conducive to

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the establishment of both conifers and hardwoods, but to a lesser extent than climax species. Conclusion: Larch *(Larix laricina)* stands are more suited to conifer seedlings, whereas transition hardwood stands are more suitable to both conifers and hardwoods, while nevertheless showing a certain degree of instability. Dominant species from climax forests are also conducive to conifers and hardwoods, although no climax species were ever noted in our plots.

3- INITIAL CONCLUSIONS AND COMMENTS

As with the first agricultural experiments using RCW has showed a clear improvement in yield, modification of soil structure, decrease or change in adventitious plants, and a decrease in fungal diseases and parasites, we concluded that we were dealing with a biological, rather than chemical or physical, phenomenon. The results obtained with the forest regeneration testing increase our conviction. We concluded that the mechanisms involving pedogenesis were of biological origins dating back millions of years.

Distribution of hardwood seedlings from 1984 to 1990

RCWs	84	85	86	87	88	90
Conifers(1/4)						
Pinus strobus	-	1	1	1	1	1
Transition hardwoods (8/13)						
Acer rubrum			1	0	0	0
Acer spicatum				1	1	1
Alnus rugosa		2	2	7	7	6
Amelanchier bartramiana				3	2	1
Betula populifolia	1	1	1	1	2	2
Cornus rugosa			21	22	20	15
Populus tremuloides	1	0	3	1	1	2
Sambucus pubens		1	0	0	0	0
Clmax hardwoods (6/8)						
Betula alleghaniensis				1	1	1
Carpinus americana	1	0	4	7	6	3
Fraxinus americana		1	2	2	2	3
Quercus rubra	3	2	21	9	17	9
Tilia americana		1	4	0	1	3
Ulmus americana		1	3	3	3	6

Table nº 5

From Guay, E., Lachance, L., Lapointe, R.A. & Lemieux, G. (1991)[9]

From numerous scientific literature reviews further convinced that we were entering in a new field of science and technology so far relatively ignored, even though it wasdealing with the root of all life on Earth as known today. It was clearly understood that we were dealing with a natural phenomenon which was for several decades, under research from the standpoint of degrading, i.e. reduced productivity, diversity and biological activity, rather than upgrading the soil. Our opinion was that this was a forest oriented upgrading process that would eventually allow for the reintroduction and maintenance of fertility control mechanisms.

Distribution of seedlings on RCW plots from 1984 to1990

RCWs	*conifers*	*fransition hardwoods*	*climax hardwoods*
Conifers			
Larix laricina	8	-	-
Pinus resinosa	1	-	-
Pinus strobus	-	1	-
Thuja occidentalis	-	-	-
Transition hardwoods			
Acer rubrum	2	2	-
Acer spicatum	3	2	-
Alnus rugosa	15	8	-
Amelanchier bartramiana	2	-	-
Betula populifolia	6	3	-
Cornus rugosa	7	18	-
Populus balsamifera	4	1	-

Populus grandidentata	-	-	-
Populus tremuloides	3	2	-
Prunus pensylvanica	1	2	-
Salix bebbiana	1	1	-
Salix lucida	5	-	-
Sambucus pubens	1	2	-
Climax hardwoods			
Betula alleghaniensis	1	1	-
Carpinus caroliniana	28	8	-
Fraxinus americana	3	3	-
Juglans cinerea	4	-	-
Prunus serotina	2	1	-
Quercus rubra	7	15	-
Tilia americana	17	5	-
Ulmus americana	1	6	-

Table nº 6
From Guay, E., Lachance, L., Lapointe, R.A. & Lemieux, G. (1991)[9]

However, we were still far from understanding the ins and outs of the matter, especially since the literature was virtually silent on both ramial chipped wood and the biological mechanisms controlling fertility. We had to explain what we were observing. The question was disturbing because these mechanisms were still present and even increased in magnitude over time. It took more than six years of intensive research before we could focus on the biological, biochemical and chemical mechanisms underlying the pedogenesis, process being the result of biofeedback between hypogeous and epigeous ecosystems.

3.1- Intellectual prisoners of productivisim

More than once we have found that nearly all the agricultural and forestry literature was dealing with the mean to increase yield while minimizing losses through an accounting approach if there ever was one!

The terminology under scruteny showed that agricultural principles and even technology are applied to forestry as well. Organic matter, fertilizers, pesticides, fungicides, viral, bacterial or fungal diseases, pests, infestations, harvesting, seed collection, nursery, plantations all words with an agricultural connotation. It is important to understand that this anthropocentric approach explains why there has been so little study of the mechanisms controlling forest ecosystems, except in terms of chemistry, physics, physical chemistry and related fields such as physiology, genetics, botany, mycology, entomology, etc. Pedogenesis: universal mechanisms rooted in forestry.

If we were able to increase productivity and alter soil structure and biochemical properties without the use of fertilizers, we had to start thinking in terms of universal mechanisms. We postulated that while humans might see agriculture as being the economic source of life, historically this is not so, since agriculture relied on biological mechanisms of fertilization before replacing them with solely chemical mechanisms. Production became the goal, and agriculture went from controlled genics to the genetic modification of plants.

It is thus obvious that the techniques developed by agriculture and copied by forestry are production oriented techniques that have nothing to do with the fundamental mechanisms; in fact, it is quite the opposite, they are short cut methods designed to procure immediate profit. Both agriculture and forestry foster growing instability rather than the maintenance and enhancement of metastability[8], the goal in all ecosystems. This enables us to envisage the eventual use of RCW as an upgrading agent, not just by adding chemical nutrients but, more importantly, by increasing the stability of tellurian ecosystems. Thus we enter the debate over modern physics and, in particular, Prigogine's[9] for contributions to nonequilibrium thermodynamics. From the world of chemistry and productivism, we find ourselves in the midst of one of the most important debates of the 20th century, implying physics and philosophy which gave rise to the chaos and "big bang" theories.

3.2- Universality of pedogenesis takes us to the Tropics

[8] **Godron, M. & Lemieux G. (1996)** «Les cycles de la "matière organique forestière"» in Lemieux «Rapport des missions internationales de 1996...» pp 166 à 185. ISBN 2-921728-22-2.

[9] **Ilya Prigogine,** winner of the Nobel prize of chemistry.

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Base on the recent plot results and the previous years' findings, we decided to pursue some tests under tropical conditions, where the expected yields and efficiency of mechanisms would not be affected by either water or heat. The first trials were conducted in 1992[10] in Sénégal, Africa, in and then in 1994 in the Dominican Republic[11]. The preliminary agricultural results were the same as obtained in Québec. For the forestry experiments, the only institution interested in conducting them was Falconbridge Dominicana, which failed to respect certain part of the techniques and than failed to obtain significant results.

A recent literature review added to the results obtained allow us to put forward some arguments and hypotheses. They form the background of pedogenesis and support our deep conviction that all pedogenetic mechanisms are of the tropical forests origin. At the beginning of the experimentation, **Guay et al. (1982)**[2] had noted that when the proportion of conifer RCW exceeds 20%, fertility decreases, and with 100% conifer RCW yields were very low. Than a question arose: **"What was the difference between conifers and hardwoods, in terms of interaction in the soil since chemical analyses had shown only negligible differences between the two?"**

3.3- Organic composition of wood and its contribution to metastability through pedogenesis

Before coming into more complex we need to look at the traditional perception of wood. It has long been known that sawdust, bark and other "waste" wood have a negative effect on soil, even in forests, where they do not generate fertility. For the forest industry these residues has only negative value and the faster they disappear the better it is. There a difference between stemwood[12] and ramial

[10]**Lemieux, G (1993)** «Rapport de mission au Sénégal du 5 au 15 décembre 1992 pour le compte de l'Agence Canadienne de Développement International» Université Laval, 25 pages.

[11]**Lemieux, G. & Marcano, J. (1994)** «Informe sobre la mision realizada en la República Dominicana del 24 abril al 8 mayo 1994» Université Laval ISBN 2-921728-06-0 -1994.

[12]The stem-wood relates to the stem wich is considered as timber, where lignin is highly polymerized and bark containing polyphenols, tanins, resins and a high rate of manganese, often toxic for various microbiologic levels. It has a C/N ratio ranging from 400 to 700/1.

wood[13], and there is also a significant difference between the type of soil developped under conifers and hardwoods.

All plants are generally made up of cellulose, hemicellulose and lignin, the result of glucose synthesis. In trees, photosynthesis produces these same three compounds associated in continuum and stores them for energy. One of the physical consequences is the gradual hardening of stems and its growth in diameter. As stemwood contains very few nutrients except those from cambium, its role is to offert a physical support for branches as well as an access to nutrients, rather than playing some a biological and dynamic roles.

Lignin is the only basic constituent of wood with significantly in structure. This is one of the most complex and least understood natural macromolecules because it has always been perceived as a worthless by-product of the pulp and paper industry and largely responsible for water pollution. However, we know that Gymnosperms (conifers) Dicotyledons and Monocotyledons contain different types of lignin. In Dicotyledons, lignin is under the form of symmetrical aromatic rings with two methoxyl groups (OCH_3), or syringuyl lignin, whereas in conifers lignin is characterized by asymmetrical rings with only one methoxyl group, or guayacil lignin. Monocotyledons contain both types, along with a third characterized by aromatic rings with no methoxyl groups.

3.4- The first link with soil genesis

Dicotyledons (hardwoods) produce complex and stable brown soil based on aggregates, with a large biodiversity of microfauna and microflora in hypogeous ecosystems and of macroflora in epigeous ecosystems. In contrast, in coniferous forests the podsol soils refered to ferrous precipitation in the lower horizons and a buildup of plant tissue on the surface, underlying the problems of proper nutrient cycling. There is less soil biodiversity, particularly in

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[13]Neologism currently known and written as **RCWs** (Ramial Chipped Wood) because it relates to the biological nutrient cycling technique. Its definition from the tree is arbitrary to some extent because all banches ove a diameter of 7 cm are used as for firewood in all conrtries, These RCWS are containing almost the entire chemical and bochemical nutrients of a tree with a C/N ratio ranging from 30 to 150/1. Moreover the have a higher rate of little polymerized lignin than the stem-wood.

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the epigeous ecosystem, where species diversity is limited. Therefore ecosystems are under by two basic mechanisms: "megabiodiversity" and "oligobiodiversity," or large diversity and minimum diversity.

Under Monocotyledons soil are normally made of dark aggregates, often unstable in water. This type of soil occurs only in regions with little precipitation (e.g. pampa, steppes, prairies). There is greater buildup of plant residue than what can be handled by enzymatic combustion due to the lack of water. Although fertile, this type of soil is fragile and easily depleted by intensive farming, supporting only small human populations.

3.5-Estimated RCW production: billions of tons/year

As previously stated, the scientific literature failed to provide an accurate description or name for the extremely important part of trees and shrubs which are the branches. Branches are the site of photosynthesis and, therefore, where plant tissue is built from glucose molecules. The world branch production can be estimated by billions of tons annually. In Québec only, it is likely around 100 000 000 tons (green) based on figures for the ENFOR program, and not including non commercial species such as brush.

In 1986, we suggest the new term of **"ramial wood"** for this biological material which up to now had been treated as industrial waste and nuisance. As well as cellulose, hemicellulose and lignin, ramial wood contains numerous proteins, all amino acids, most sugars and starches, and derived polysaccharides. This is in addition to countless enzyme systems, hormones, polyphenols, essential oils, terpenes, tannins, etc., all associated to at varying degrees, with the basic nutrients required for synthesis and regulation of living organisms.

Many of these compounds, such as enzymes, amino acids and several proteins, are extremely fragile. Others, such as sugars, cellulose and hemicellulose, are immediate sources of energy. Lignin, a three dimensional molecule, is one of nature's most complex molecules and an important source of energy, although not easily available since it is found in aromatic rings that are not easily broken down by living organisms: protozoa, bacteria and, most significantly, basidiomycetes. We concluded that the major difference is found in the structure of lignin, and consequently in the way depolymerization occurs.

3.6- Lignin derivatives: polyphenols, aliphatic acids, terpenes.... the basis of soil formation and dynamics.

The first hypotheses dealing with the major role played by lignin in pedogenesis were formulated nearly a century ago. The research works of recent decades have shown lignin as a pollutant in order to accelerate its decomposition. In the last ten years, numerous authors have reported comments and conclusions regarding the structure and development patterns of this molecule; among them, **Erickson et al. (1990)**[14], **Rayner & Boddy (1988)**[15]. Basidiomycetes play a vital role in the transformation process, as do bacteria, although the latter generally contribute solely to decomposition.

From glucose coniferyl alcohol is formed, which results in a monomeric lignin that becomes increasingly polymerized. Aromatic rings, the most important in terms of structure and energy content, will become the principal elements of stable soil structure.

Obviously, this highly polymerized molecular structure can be altered to produce polyphenols, aliphatic acids, essential oils, terpenes, tannins, etc., all these can affect plant metabolism and the various trophic levels of the food chain.

For example tannins combined with proteins are responsible for leaves to turn brown, and prevent the decomposition of leaves as well as the loss of valuable nutrients. However, only few bacteria, most often associated with soil microfauna or macrofauna, have the enzyme

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[14] **Erikson, K. E. L., Blanchette, R. A. & Ander, P.** (1990) «Microbial and enzymatic degradation of wood and wood components». Spingler-Verlag, Berlin, 407 pp.

[15] **Rayner, A. D. M & Boddy, Lynne** (1988) «Fungal Decomposition of Wood». John Wiley & Sons. 597 p.

systems needed to break down tannins and release proteins and their chemical nutrients. The tendency is therefore to approach nutrient cycling from the perspective of lignin derivatives, even though we remain strongly convinced that we must first understand and improve nutrition. **We therefore need to understand soil nutrition and identify the components responsible for energy and nutrient distribution**.

3.7- Knowledge of lignin and pedogenesis obtained from studying decomposition and degradation

Nearly all the scientific literature published up to now deals solely with lignin and cellulose development from the perspective of wood degradation. This approach seriously hampered our attempts to understand pedogenetic mechanisms, and consequently we could understand the previously unexplicable of tests conducted between 1978 and 1986. We could comment our observations and data, as reported in numerous publications: **Guay et al. (1982)**[2], **Lemieux & Lapointe (1985)**[3]**, Lemieux & Lapointe (1989)**[7], **Lemieux & Lapointe (1990)**[16], **Lemieux & Toutain (1992)**[17]**.**

4- "ORGANIC MATTER": TERM WITHOUT CONTENT

4.1- First references to humification

A few years later and in front of continuous alterations in soil and colour, we concluded that we were touching the pedogenetic mechanisms, since traditional soil amendments had no scientific basis

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[16] **Lemieux, G. & Lapointe, R. A.** (1990) «Le bois raméal et la pédogénèse: une influence agricole et forestière directe». Département des Sciences Forestières, Université Laval et Ministère de l'Énergie et des Ressources (Forêts) Québec. 35 pages. ©ISBN 2-550-21267-3.

[17] **Lemieux, G. & Toutain, F.** (1992) «Quelques observations et hypothèses sur la diversification: l'aggradation des sols par l'apport de bois raméal fragmenté». Université Laval, 13 pages ISBN 2-550-26541-6.

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apart from **mineralization**[18] a term largely inspired by agriculture and used to describe the process that transforms plant and animal matter into chemical products used to fertilize crops. We had reached the basic principles of **humification**[19]. a process that provides the soil with its physical and biological structure and develops into "humus." Therefore forest ecosystem pedogenesis and its reactions on the production oriented agriculture: the productivism.

We gradually realized that we were penetrating the mysterious biological world of soil formation. In the long term, ramial chipped wood will provide an understanding of hypogeous ecosystem function and the biological dynamics which, combined with geology and the laws of physics, chemistry and biochemistry, govern this unknown world except from chemical aspects.

4.2- Development of current knowledge

Because we do not fully understand soil mechanisms we consistently comment from the chemical side through fertilization, soil amendment, and so forth. Looking at this reasoning a step further, we see soil the soil as a mere physical support, and eventually in favour of liquid fertilizers and hydroponicmethod for growing crops.

4.3- Decomposition and degradation: a negative interpretation

Measuring plant tissue in soil as a transition towards chemical fertilizers release for plant growth, had been taken long ago. "Organic matter" is associated with chemical uptake while maintaining certain

[18]Term from agricultural origin by which processus are evaluated as pure chemical contents of animal or plant substances as «fertilizers» for the crop to come.

[19]Mechanisms as a whole allowing the soil build its own physical and biological structure and then giving what we call *«humus»*

physical parameters, such as soil air control and elimination of gases from biological activity, which is always associated with decomposition. Only fertilizer and, particularly, nitrogen are recognized notions.

4.4- RCW: a new door to knowledge on pedogenesis

Subsequently we postulated that RCW could be a perfect way to study and understand soil formation and the related dynamics, primarily assessed in terms of a chemical nutrient distribution system for plant growth. After years we began to understand the ins and outs of the established mechanisms, their evolution and even their disintegration. Even though the previous decade had witnessed many important publications on biological mechanisms related to nutrient dynamics. The first comprehensive work had been published by **Perry et al., [1989]**[20]**.** from experiments conducted at Oregon State University in Corvallis, focused on the behaviour and effects of various biological organisms, including mychorrhizae.

4.5- Biological and chemical nutrient control

The research works conducted by the Corvallis team was essentially aimed at explaining the significance of a single level, i.e. life, in a spirit of competitiveness and complementarity, which at the time was the only possible way to apprehend our world. The concept of RCW enabled us to pay more attention to both forestry and agriculture, because we were convinced that this complex world was at the center of our economy wich is the soil. Soil is responsible for controling nutrients, but also for an astonishing number of life forms with countless niches, including all forms of life, from viruses to the most highly evolved mammals. Soil is also the "bank," "manager" and "driving force" for all life on Earth. All chemical and biochemical nutrients resulting from the synthesis or retrosynthesis of polyphenolic compounds, are generally derived from lignin and, as far as we know, are the main elements of humus in humic and fulvic fractions.

[20]**Perry, D. A., Amaranthus. M.P., Borchers, J.G., Borchers, S.L. & Brainerd, R.E.** (1989) «Bootstrapping in Ecosystems» BioScience **39 (4)**: 230-237

4.6- Logical reasoning

The explanations for the above observations and measures must be of various kind: so many results and implications involved must reveal some homogeneity in fundamental parameters, whether physical, chemical or biological. Paradoxically, when a coherent entity is found there must be an outer face showing some incoherence; otherwise, we would have a rigid system consistently producing the same results. In order to formulate sound hypothesis, the issue must be considered from all sides.

Numerous meetings and discussions in several countries and a complete literature shown us that we were exploring a new field of knowledge dealing with forest pedogenesis. Moreover, field tests showed that the application of RCW has significant effects on ecosystem behaviour, particularly plant germination and competition.

4.7- Chipping

For a long time, researchers were convinced that leaves and branches were beneficial to soil, but without being able to measure the exact effects. In fact few people care, and hope only to gett rid of twigs and other logging waste considered as "nuisance." For example the removal of branches from the forest floor during logging, is made for greater profitability **(Freedman, [1990] in Lemieux [1991])** [21] At the start, chipping was seen as a necessity and a simple technique for soil preparation, handling and spreading of fertilizers. As we gain a understanding of the mechanisms at work, however, the ramial wood chipping proved to be important. It can be compared to chewing for animals, because the attacks by enzymes are more efficient.

5- NUTRIENTS + ENERGY = FOOD

5.1- Pedogenesis and composting: the fundamental differences

[21]**Lemieux, G. (1991)** «La perte de nutriments par la récolte des grumes: une absurdité» *traduction et commentaires de B. Freedman:«Nutrient Removals during Forest Harvesting: Implications for Site Fertility» traduction en* langue française et commentaires, publication nº 20 ISBN 2-550--22280-6.

The notion of food implies a combination of two things: the energy needed for a living organism to function, and the chemical compounds (fertilizers) as well as their biochemical intermediates (proteins, amino acids, sugars, cellulose, etc.). Rapidly, we had to forget about traditional concepts leading directly to mineralization, i.e. the dissociation of energy and nutrients. The best way for recycling organic plant or animal matter was considered to be through composting, whereby energy nutrient dissociation is carried out by bacterial and fungal thermophilic fermentation, with thermal energy loss and the recovery of nutrients and some organic residue, mainly degraded lignins and polyphenolic compounds. Although the process involves enzymatic combustion, it in many respects resembles fire combustion **(Kirk & Farrell, [1987])**[22]. Pedogenesis, which is the opposite extreme of compost, gives organic or organo-mineral structure to soil by favouring trophic level biodiversity.

5.2- Principles underlying RCW

Nevertheless the beneficial effects of RCW became increasingly obvious, the basic principles underlying its transformation in the soil was under scruteny. In1989 we began to understand the mechanisms which enabled energy release while preserving the high energy content aromatic rings of lignin.

In the early 1980s, many authors from North America, Asia and Europe published major works on lignin, its structure and enzymatic degradation **(Kirk & Fenn, [1982]**[23]**,Tien & Kirk [1983]**[24] , **Lewis, N. G, Razal, R.A & Yamamoto E. [1987]**[25], **Leisola & Waldner, [1988]**[26] **Leisola and Garcia, [1989]**[27], **Leatham & Kirk, [1982]**[28]

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[22]**Kirk, T. K. & Farrell, R. L. (1987)** «Enzymatic combustion: The microbial degradation of lignin». Ann. Rev. Microbiol. **41**: 465-505.

[23]**Kirk, T. K. & Fenn, P. (1982)** «Formation and action of ligninolytic system in Basidiomycetes». in: *Decomposer Basidiomycetes: their Biology and Ecology* (Franklin, J.C., Hegger, J.N. & Swift, M.J. edit.) p. 67-90, Cambridge Univ. Press.

[24]**Tien, M., & Kirk, T. K.** (1983) «Lignin-degrading enzyme from Hymenomycete *Phanerochœte chrysosporium*» Burds. Science **221**: 661-663.

[25]**Lewis, N. G., Razal, R.A. & Yamamoto, E. (1987)** «Lignin degradation by peroxidase in organic media: a reassessement». Proc. Nat. Acad. Sci. USA, 7925-7927.

[26]**Leisola, M., & Waldner, R. (1988).** «Production, characterization and mechanism of lignin peroxidases». In: Zadrazil, F., Reiniger, P. éditeurs., *Treatment of lignocellulosics with white rot fungi*. Elsevier Appl. Sci. Pub, New York. p. 37-42

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However all these research works focused on the use, degradation and final disposal of lignin as one of the major pollutants generated by the pulp and paper industry. Admittedly, this "negative" approach to lignin was not without value and was totally understandable for industries that use generated capital to spur their own growth, forsaking anything that may get in the way of profit.

5.3- Production of fulvic and humic fractions

The main contribution for a real understanding was provided by **Leisola and Garcia (1989)**[28], who explained the enzymatic mechanism responsible for lignin depolymerization into two macromolecules, one of low molecular weight (1000 to 300 000 daltons) assimilated with fulvic acid, and the other of much higher weight, identified as humic acid. More interesting the same authors have shown under the action of a manganese dependent enzyme called lignoperoxidase the heavier molecule stick to the mycelium of basidiomycetes *(Chrysosporium phanerochaete),* preventing fulvic fraction recombinations. This can results in stable polyphenolic compounds with antibiotic or other properties. The fixation of these heavy macromolecules to the mycelium gives the soil a dark brown appearance characteristic of brown soils. A similar change in in soil colour was consistently observed following the application of RCW to cultivated soils.

Numerous research works have dealt with the behaviour of different enzyme systems that play a fundamental role in lignin degradation : **Dordick et al., [1986]**[29], **Garcia, & al. [1987]**[30], **Rayner & Boddy [1984]**[16], **Jones & O'Carroll [1989]**[31].

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[27]**Leisola, M. S. A & Garcia, S. (1989)** «The mechanism of lignin degradation» in *Enzyme systems for lignocellulose degradation.*- Atelier tenu à Galway, Irlande dans le cadresde la Communauté économique européenne. Publié par Elsevier Applied Science pp.89-99.

[28]**Leatham, G. F. & Kirk, T.K. (1982)** «Regulation of lignolytic activity by nutrient nitrogen in white-rot basidiomycetes». FEMS Microbiol. Lett **16**: 65-67.

[29]**Dordick, J. S., Marletta, M. A. et Kilbanov, A. M. (1986)** «Peroxidases depolymerise lignin in organic media but not water». Proc. Natl. Acad. Sci. USA, **83**: 6255-6257.

[30]**Garcia, S., Latge, J. P., Prévost, M. C. & Leisola, M. S. A. (1987)** «Wood degradation by white-rot fungi: cytochemical studies using lignin peroxidase-immunoglobulin-gold-complex», Appl. Environ. Microbiol. **53** : 2384-2387.

[31]**Jones, A. & O'Carroll L.** (1989) «Biotechnological modification of lignin». Alberta Research Council, Technical Report, Edmonton, Canada, 18 pages polycopiées

All these scientific publications brought their support to the fact that Basidiomycetes are present on forest floor and totaly absent in agricultural soils. Many authors refer to basidiomycetes as "white rot fungi," again a negative term refering to the decomposing function of these fungi. The role of Basidiomycetes in ectomychorrhizal formation was under discussion by **Amaranthus & Perry [1987]**[32], **Amaranthus et al. [1987]**[33], **Hintikka, V. [1982]**[34], **Tate, R.L. [1987]**[35] and **Vaughan & Ord [1985]**[36].

5.4- "Organic matter" for agricultural fertility with no forestry significance

All of the already mentioned authors taught us a great deal about wood degradation in forest ecosystems. The more we delve into the logic of "organic matter" and its agricultural benefits, the further away we get from the lignin fertility linkage and the more we see annual fertility in terms of yield, all other parameters being subsidiary. The notion of organic matter clearly derives from agriculture and was adopted by the forest sector without any questions, a hurdle we had to overcome in order to interpret our observations.

We had to look into the relationship between the various life forms, particularly microfauna, and their effects as reported by different authors. We were reaching the heart of the issue, and it became clear that fungi, even so important its role was, did not explain the dynamics of either soil formation or nutrient cycling. Other forms of life had to be involved to form the trophic levels where all organisms interact in the vital process that controls nutrient availability

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[32]**Amaranthus, M. P. and D. A. Perry (1987)** «The effect of soil transfers on ectomycorrhizal formation and the survival and growth of conifer seedlings on old, none reforested clear-cuts». *Can. Jour. For. Res.* **17:** 944-950.

[33]**Amaranthus, M. P., Li, C.Y. and Perry D. A. (1987)** «Nitrogen fixation within mycorrhizae of Douglas-fir seedlings». Page 79 in D.M. Sylvia, L.L. Hung and J.H. Graham eds. *Mychorrhizae in the Next Decade: Practical Applications and Research Priorities.* University of Florida, Gainesville.

[34]**Hintikka, V., (1982)** «The colonisation of litter and wood by basidiomycetes in Finnish forest». In: (Frankland, J.C., Hedger, J.N. & Swift, M.J. éditeurs), *Decomposer basidiomycetes, their biology and ecology.* Cambridge University Press, Cambridge, pp. 227-239.

[35]**Tate, R.L.** (1987). «Soil organic matter: biological and ecological effects». 291pp. Wiley-Interscience Pub. New York. USA

[36]**Vaughan, D. & Ord, B. G. (1985)**. «Soil organic matter : a perspective on its nature, extraction, turnover and role in soil fertility». In: (Vaughan, D & Malcolm R.E., éditeurs) *"Soil Organic Matter and Biological Activity"*. pp. 469. Martinus Nijhoff & W. De Junk Pub., Dortrecht, Hollande.

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from chemical, mineral or biochemical sources through energy storage and release.

5.5- Nutrient transfer: an unequivocal approach

We learned a great deal about nutrient transfer from **Anderson [1988]**[37], **Anderson et al. [1981]**[38], **Bachelier, G. [1978]**[39]. **Bouché M.B. [1981]**[40], **Larochelle [1993]**[41], **Larochelle, Pagé, Beauchamp & Lemieux [1993]**[42] . **Parkinson, D. [1988]**[43]. **Sauvesty, Pagé & Giroux [1993]**[44] . **Seastedt, T.R. [1984]**[45] . **Swift, M. J. [1976]**[46] **Swift, Heal & Anderson [1979]**[47] . **Toutain, F. [1993]**[48] . However, for all of them the question arise from the perspective of dynamics, predation and energy transfers from one level to another, with the general effects on nutrient transfer. None of them discussed or questioned the mechanics of energy transfers other than the commonly known conversion of triphosphate adenosin into diphosphateadenosin with the release of one kilocalorie, where glucose is the primary energy source.

5.6- Lignins and polyphenols

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[37]**Anderson, J. M.** (1988) «Spatio-temporal effects of invertebrates on soil processes» Biol. Fertil. Soils. **6** : 216-227.

[38]**Anderson, R. V., Coleman, D. C. & Cole, C.V.** (1981) «Effects of saprotrophic grazing on net mineralization» In Clark F.E. & Rosswall T. edit. Terestrial nitrogen cycles. Ecol. Bull. **33** : 210-216.

[39]**Bachelier, G.** (1978) «La faune des sols, son écologie et son action». Document technique n˚ 38. Office de la Recherche Scientifique et Technique Outremer (ORSTOM), route d'Aulnay, 93140 Bondy, France, 391 pages.

[40]**Bouché, M.B. (1981)** «Contribution des Lombriciens aux migrations d'éléments dans les sols tempérés» *In Migrations organo-minérales dans les sols tempérés, Colloques Internationaux du CNRS nº 303* Nancy 24-28 septembre 1979 Éditions CNRS Paris pp. 145-154

[41]**Larochelle, L. (1993)** «L'influence de la qualité des bois raméaux fragmentés (BRF) appliqués au sol: effets sur la dynamique de leur transformation». In "Les actes du quatrième colloque international sur les bois raméaux fragmentés" édité par le Groupe de Coordination sur les Bois Raméaux Département des Sciences forestières, Université Laval, Québec.(Canada) 187 pages, ISBN 2-550-28792-4 p. 77-84.

[42]**Larochelle, L., Pagé, F., Beauchamp, C., & Lemieux, G. (1993)** «La mésofaune comme indicateur de la dynamique de la transformation de la matière ligneuse appliquée au sol». AGROSOL **6** (2): 36-43.

[43]**Parkinson, D.** (1988). «Linkage between resource availability, microorganisms and soil invertebrates». *Agriculture, Ecosystems and Environnement*. **24**: 21-32.

[44]**Sauvesty, A., Pagé, F. & Giroux, M. (1993)** «Impact des milieux pédologiques en bosses et creux sur les teneurs en composés phénoliques et en éléments minéraux dans les feuilles d'érable à sucre en dépérissement au Québec» Can. Jour. For. Res. **23**: 190-198.

[45]**Seastedt, T.R. (1984)** «The role of microarthropods in decomposition and mineralization processes» Ann. Rev. Entomol. **29**: 25-46

[46]**Swift, M. J. (1976)** «Species diversity and structure of microbial communities» in (J.M. Anderson & A. MacFaden, éditeurs) - *Decomposition processes*- Blackwell Scientific Publications, Oxford, p. 185-222.

[47]**Swift, M. J., Heal, O. W., & Anderson, J.M. (1979)** «The influence of resource quality on processes». in *Studies in Ecology, vol. 5. •Decomposition in Terrestrial Ecosystems.* Univ. of California Press Berkeley, p 118-167.

[48]**Toutain, F.** (**1993)** «Biodégradation et humification des résidus végétaux dans le sol: évolution des bois raméaux (étude préliminaire)» In "Les actes du quatrième colloque international sur les bois raméaux fragmentés" édité par le Groupe de Coordination sur les Bois Raméaux Département des Sciences forestières, Université Laval, Québec.(Canada) ISBN 2-550-28792-4 p. 103-110.

As previously mentioned, since branches or ramial wood had never been described or considered as useful matter, monomeric lignins had obviously never been approached from the energy angle as such. However, numerous authors do make reference to the complexity of this macromolecule and suggest it plays an important role in humus formation and the production of "undesirable" polyphenols : **Erikson et al., [1990]**[15], **Rayner & Boddy, [1988]**[16], **Kirk & Farrell, [1987]**[23] **Lewis, et al. [1987]**[26], **Leisola & Garcia, [1989]**[28], **Leatham & Kirk, [1982]**[29], **Kirk & Fenn, [1982]**[24], **Leisola & Waldner [1988]**[27], **Dordick et al, [1986]**[30], **Garcia et al. [1987]**[31], **Jones & O'Carroll, [1989]**[32], **Glenn & [1985]**[49], **Stott et al. [1993]**[50], **Vaughan & Ord (1985)**[51]. **Vicuna, R [1988]**[52].

Using different approaches, the above authors discuss the structure of lignin and the importance of methoxyl groups based on the origin, "fragility" and "digestibility" of slightly polymerized lignin and its ability to be depolymerized. We then realized the importance of this young lignin as an energy source, not only following cellulose conversion, but also through the substantial energy contained in the benzene rings, some of which are reserved for humus formation. It would seem that lignin could play a twofold role as both energy provider and soil builder, where soil controls and regulates living organisms and nutrients through the cycling process.

5.7- Polyphenolic controls and biological regulation

Polyphenols apparently could cause a decrease in fertility, even if all nutrients needed for proper plant growth in hypogeous ecosystems are present. Our goal is not to look at the various pathways followed by nutrients to reach plants in "proper order". However, some

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[49]**Glenn, J. K. & Gold, M. H. (1985)** «Purification and characterization of an extracellular Mn (II) -dependent peroxidase from the lignin-degrading by the Basidiomycete *Phanerochaete chrysosporium* ». Arch. Biochem Biophys. **242**: 329-341

[50]**Stott, D. E., G. Kassim, M. Jarrell, J. P. Martin & Haider, K. (1993)** «Stabilisation and incorporation into biomass of specific plant carbons during biodegradation in soil». Plant and Soil **70:**15-26.

[51]**Vaughan, D. & Ord, B. G.** (1985). «Soil organic matter : a perspective on its nature, extraction, turnover and role in soil fertility». In: (Vaughan, D & Malcolm R.E., éditeurs) *"Soil Organic Matter and Biological Activity"*. pp. 469. Martinus Nijhoff & W. De Junk Pub., Dortrecht, Holland.

[52]**Vicuna, R. (1988)** «Bacterial degradation of lignin». Enzyme Microb. Technol. **10** : 646-655.

examples can be cited, such as earthworms which use the large colonies of bacteria in their food tube to destroy the brown pigment of leaves. This brown pigment comes from the association of a polyphenol (tannin) with proteins, thereby preventing nutrient degradation **(Toutain, [1993]**[53]**)**. Similarly, during nutrient cycling, basidiomysetes and several species of Acaridae and Collembola breakdown finer particles by chewing, enabling enzymatic and bacterial attacks, **(Swift, M. J. [1977]**[54], **Larochelle & al. [1993]**[43]**).**

5.8- Definition of nutrients

Nutrients traditionally have been promoted according to their role in crop production. The main elements, are nitrogen, phosphorous and potassium, but they can be combined with numerous other elements, including iron and silicium, and the various "trace elements." This way of classification is showing our "industrial" view of agricultural productivity which, over the years, has spread to forestry as well.

The idea of using mineral compounds to qualify and assess plant growth is somewhat odd. This production oriented approach has shown its limitations in various ways: soil erosion, ever growing number of parasites, constantly evolving fungal, viral and bacterial diseases. The huge investments by industrial nations to control these epidemics are beyond comprehension.

For several authors, particularly **Amaranthus & Perry (1987),**[33] **Bormann & Likens (1979),**[56] **Amaranthus & Perry (1988),**[57], **Flaig (1972),**[72] **Gosz & Fischer (1984),**[59] **Gosz et al. (1978),**[55] and **Martin et al. (1986)**[56] it is possible to alter ecosystem behaviour by modifying

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[53]**Toutain, F. (1993)** «Biodégradation et humification des résidus végétaux dans le sol: évolution des bois raméaux (étude préliminaire)» In "Les actes du quatrième colloque international sur les bois raméaux fragmentés" édité par le Groupe de Coordination sur les Bois Raméaux Département des Sciences forestières, Université Laval, Québec.(Canada) ISBN 2-550-28792-4 p. 103-110.

[54]**Swift, M. J. (1977)** «The role of fungi and animals in the immobilisation and release of nutrient elements from decomposing branch-wood». In *Soil Organisms as Components of Ecosystems* (Lohm, U. & Persson, T. éditeurs) p. 193-203. *Ecol. Bull.* ***25*** Swedish Natural Science Research Council, Stockholm.

[55]**Gosz, J. R., Holmes, R. T., Likens, G.E. & Bormann F. H.** (1978) "Le flux d'énergie dans un écosystème forestier". in *Pour la Science,* juin 1987 pp. 101-110.

[56]**Martin, W. C., Pierce, R. S., Likens, G. E. & Bormann F. H. (1986)** «Clearcutting Affects Stream Chemistry in the White Mountains of New Hampshire». USDA Northeastern Forest Experiment Station Research Paper NE-579.

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biological factors which could have a major impact on nutrients, that is, their form, which will in turn have far-reaching physicochemical effects.

We may conclude that there is a direct relationship between biological parameters and nutrient availability. While the chemical/physical relationship is well documented, much less is known about either the chemical/biochemical relationship or energy transfers.

5.9- Microbiological organisms in tropical rainforests: from soil to forest canopy

Taking into account the impressive findings regarding rainforest canopies which are always associated with relatively poor soil, my reaction was to pay a closer look to tropical ecosystems. These findings increasingly suggest, as one might think, that ecosystem life is structured solely around mechanisms that depend on the forest and, to a lesser extent, to the trees. This could explain the situation in Africa after removing the trees, where only poor soils were left, growing low food production unsufficent to ensure a decent and stable standard of living.

5.10- Water

Everyone knows that water is essential to life. Under tropical conditions, the availability of water is vital to all life-forms and it is reflected in the structure of forest ecosystems and their ability to withstand drought. In temperate, forest ecosystems climates have to deal with a surplus of water, which affects fertility by interrupting the biological soil development, thereby leading to a build-up of plant residue, of which peat bogs are the end results. Hypothesis: *hypogeous ecosystems, i.e. living soil, have succeeded in overcoming all climate-related*

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problems by creating a system of multiple life-forms in which nutrient uptake by plants is not affected by the chemical cycles favoured and developed by agriculture in temperate climates. This is of prime importance when it comes to water management, where water acts as a nutrient, immune to osmotic pressure caused by high soil salt concentrations.

However, it obvious that the biological and chemical turnover in temperate forests, particularly climax hardwood forests, is linked to lignin depolymerization, which cannot occur in water **(Dordick et al., [1986])**[30] as cannot the responsible fungi.

5.11- Nitrogen

5.11.1-Non-symbiotic fixation: N_2

From day one, we assumed that the nitrogen found in soil was the direct result of protein degradation from the microbial biomass. However, since there was no sign of nitrogen deficiency in vegetation after three years, we started looking why it was that way. Like many authors, we concluded that the process started within the forest soil and was essentially related to the non-symbiotic fixation of nitrogen by rhizosphere bacteria **(Rouquerol et al. (1975),**[57] **Thomas-Bauzon et al. (1990),**[58] **Thomas-Bauzon et al. (1995)**[59]**, Parkinson (1988),**[44] **Stott et al. (1993)**[51], **Swift (1976),**[47] **Tate (1987)**[36] **,Vaughan & Ord (1985)**[37].

5.11.2- Nitrogen availability

Nitrogen fixation is generally carried out by a group of bacteria through a special enzyme containing primarily of iron, as seen with hemoglobin. Far from the nitrogen-fixing *Rhizobium* on the leguminous plant roots, this could explain the high amount of nitrogen in forest litter as well as in the RCW-treated soils. At this point, then,

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[57]**Rouquerol, T., Bauzon, D, & Dommergues, Y.** (1975) «Les ectomycorhizes et la nutrition azotée et phosphatée des arbres» Congrès DGRST, mai 1975.

[58]**Thomas-Bauzon, Kiffer, E., Pizelle, G. & Petitdemange, E.** (1990) «Fixation d'azote et cellulolyse: activités de la nitrogénase et/ou de la cellulase d'organismes fixateurs d'azote et/ou cellulolytiques. Presses de l'Université de Nancy, 89 pages.

[59]**homas-Bauzon, E. Kiffer, G. Janin & F. Toutain** (1995). "Méthodologie de recherche des bactéries cellulolytiques diastrophes appliquée à *Sphaerotermes sphaerotorax"*. Science de la Vie/Life Science 318:699-707.

we think that *nitrogen cycling is primarily triggered by N_2 fixation through a microbiological process and, secondarily, through fungi and mychorrhizae in RCW-treated soil.*

5.12- Phosphorus and phosphatases

Phosphorus availability has always been a problem in plant nutrition mainly due to its immobilization by iron in acidic soil and by calcium in alkaline soil and consequently it is in short supply in soil solutions. However, phosphorus deficiencies are happening only in agricultural soils but no deficiencies were recorded in forested ecosystems. The enzyme known as alkaline phosphatase is able to reach phosphorus during energy transfers and "release" it for plant growth. It is also known that proper mychorrhization increases phosphorus availability **(Rouquerol et al., [1975]**[62]**)**.

Seck & Lemieux (1996)[60] found that alkaline phosphatase enzyme presentin the microbial biomass tend to increase in RCW-treated agricultural soil. Another study for detecting RCW some enzyme availability shows a significant concentration of both alkaline and acid phosphatases in red oak twigs **(Toutain, [1996]**[61], one of the most promising sources of RCW in temperate climate. It is too soon to draw conclusions on different enzymes, such as lipase. However, we hope to publish some new data in the near future, and bring new pieces of evidence in the field of pedogenesis,wich could be added to the findings made by **Flaig [1972]**[58], **Ratnayake et al. [1978]**[62], **Swift et al. [1979]**[48], and **Vaughan & Ord [1985]**[52] Hypothesis: *RCW not only adds nutrients to soil, but it also supports thee mechanisms that build soil while allowing enzymatic activity that supplies epigeous vegetation with phosphorus.* The studies published by **Lalande et al. [1997]**[63] and **Seck**

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[60]**Seck, M.A. & Lemieux G. (1996)** «Fertilisation organique par l'utilissation des Bois Raméaux Fragmentés (BRF) de filao *(Casuarina equisetifolia)* dans les cuvettes maraîchères des Niayes (Sénégal)» Conférence de l'IFOAM, Copenhague, Danemark août 1996 Université Cheikh Anta Diop Dakar, 19 pages. Publication nº 69 GCBR Université Laval, Québec, Canada

[61]**Toutain, F (1996)** «Les entretiens de Nancy» in Rapport des missions internationales de 1996 Lemieux, G. edt. Université Laval, Québec, Canada p186-191 ISBN 2-921728-22-2, 284 pages.

[62]**Ratnayake, M. R.T. Leonard & J. A. Menge** (1978). "Root exudation in relation to supply of phosphorus and its possible relevance to mycorrhizal formation". New Phytol. **81**: 543-552.

[63]**Lalande, R.L., V. Furlan & D.A. Angers (1997)**. "Changes in microbial population and biological activity following addition of Ramial Chipped Wood on a sandy loam soil," submitted for publication to the American Journal of Alternative Agriculture.

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& Lemieux [1996][65], have shown some biological changes following the addition of RCWs.

6- TELLURIAN BIOLOGY: ADAPTATION CONSTRAINTS

From the agricultural and forestry trials conducted for exploring the effects of RCWs on nutrient supplies, it was clearly shown that qualitative or quantitative analyses were not conclusive. All preliminary results were of limited value when compared to the current literature. The more recent publications in the field of RCW are: **Beauchamp [1993]**[64], **Guay et al. [1982]**[2], **Larochelle et al. [1993]**[43], **Lemieux & Lapointe [1985]**[3], **Lemieux & Lapointe [1989]**[6], **Lemieux & Toutain [1992]**[65], **Michaud [1993]**[66], **Sauvesty [1993]**[45] **Seck (1993)**[67]**,** **Seck [1994]**[68]**,** **Toutain [1993]**[54] and **Tremblay (1985)**[69]**.** These documents, published over a period of ten years, have raised only few questions generally focused on empirical farming techniques used to retrieve nutrients from crop residue.

6.1- Shedding some light on the dynamics of tellurian biology

It was obvious that there was no scientific interest for our logical approach but in many respects confusing, taking into account the actual economic and technical context. The linkage between these biological mechanisms, for which enzymatic mechanisms are partially

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[64]**Beauchamp, C. (1993)**. "La caractérisation et la valorisation agricole des BRF et leurs impacts sur le sol et les cultures" in *Les actes du quatrième colloque international sur les bois raméaux fragmentés*" ed. Groupe de Coordination sur les Bois Raméaux), Département des Sciences forestières, Université Laval, Québec, Canada. 187 pages, ISBN 2-550-28792-4, page 42-49.

[65]**Lemieux, G. & F. Toutain (1992)**. "Quelques observations et hypothèses sur la diversification: l'aggradation des sols par l'apport de bois raméal fragmenté", Université Laval, Groupe de Coordination sur les Bois Raméaux publication no. 23, ISBN 2-550-26540-8, 13 pages.

[66]**Michaud, M. (1993)**. "Les bois raméaux fragmentés: un amendement organique pour les sols en production horticole" in *Les actes du quatrième colloque international sur les bois raméaux fragmentés*, (ed. Groupe de Coordination sur les Bois Raméaux), Département des Sciences forestières, Université Laval, Québec, Canada, 187 pages, ISBN 2-550-28792-4, page 49 to 55

[67]**Seck, M.A. (1994)**. "Appui au développement pour les maraîchers des Niayes (Sénégal)" in Lemieux, G. *Rapport de mission africaine au Sénégal du 2 au 13 décembre 1994*, page 1-12, Groupe de Coordination sur les Bois Raméaux ed., and Canadian International Development Agency, ISBN 2-921728-08-7, 48 pages.

[68]**Seck, M.A. (1994)** «Appui au développement pour les maraîchers des Niayes (Sénégal) in Lemieux, G, «*Rapport de mission africaine au Sénégal du 2 au 13 décembre 1994*» , page 1 to 12, Groupe de Coordination sur les Bois Raméaux, éditeur, et Agence Canadienne de Développement International ISBN 2-921728-08-7, 48 pages.

[69]**Tremblay, Y (1985)** «Essais comparatifs de l'utilisation de la biomasse forestière et du lisier de porc dans la culture des pommes de terre par le compostage de surface avec apports variables d'engrais de synthèse» Rapport interne, Minitère de l'Agriculture du Québec ,8 pages.

responsible, must not be apart from the importance of chemical and biochemical nutrients. Whereas we were relying on chemical and physical data to understand soil dynamics, we can now propose a number of biological explanations that shed some light on forest ecosystems.

Before going further, we should look more closely at the modern views on universe, as proposed by some physicists namely **(Prigogine & Stenger [1988]**[70] **Prigogine [1988]**[71]**).** We come to the quest for equilibrium generated by forest ecosystems and how RCW in that process Thus, we move from a production oriented world and unbalance to another world carachterized by balance and diversity. We need to seek metastability, that is, a world in which ecosystems are at once stable and fragile. This is the essence of hypogeous forest ecosystems, characterized by complex soil molecules resulting from lignin degradation and the various trophic levels that regulate all life and all chemical, physical or temporal exchanges. This is the world everyone seems to be seeking, judging by the cries of alarm from all circles over the past half-century.

6.2- Forest ecosystems and differential soil generation

The more we understand about life and fertility processes, the more clearly we can define the various roles. In soil biology chemical and biochemical balances are the key element for all the forest ecosystems, both in terms of time and space. The reference to the forest origins of soils in this document implies that the soil formation mechanisms are millions of years old. Moreover, we have arguments for considering soils developped in hardwood and conifer forests as different not on the basis of climatic differences, but on the origins of their structure and their evolution.

It is interesting to underline the evolution of these two forest ecosystems through the centuries. Conifer forests were so hardy that

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[70] **Prigogine, I. & I. Stenger (1988)**. "Entre le temps et l'éternité". ed. Fayard, Paris.

[71] **Prigogine I. (1996)**. "La fin des certitudes", ed. Odile Jacob, Paris, ISBN2-7381-0330-8, 223 pages.

they still occupy a large percentage of land whose climate is close to what it was on the past. It is nevertheless surprising to see such a large number of archaic species in these forests (Gymnosperms, Equisetum, Bryophytes, ferns, mosses, lichens) and to find Gymnosperms as the dominant species.

These dominants species inherited shapes and behaviours from lower autarkic species which are far less dependent on their environment. However, like saurians, amphibians and reptiles, they can count on a variety of "chemical" defences to ensure them a place under the sun. Conifers have developed their own survival techniques, including eliminating the competition. These techniques are the most effective because they do not allow the plants to groweven the germination of competing vegetation. As we will see further on, surplus production of polyphenols, such as terpenes, and a special function of guacyl lignin during depolymerization, are clearly age-old means of survival that rely not on adapting to new environments, but on making the entire ecosystem adapt to the one's own behaviour. Based on behaviour it is difficult to fully understand the ecosystem management and evolution. The following authors, although focussing comparative description of dynamics without any experimentation, can provide significant information: **Dommergue & Mangenot [1970]**[72]**, Duchaufour [1974]**[73]**, Duchaufour [1980]**[74]**,Duchaufour [1991]**[75]**, Duchaufour & Jacquin [1975]**[76]**, Duchaufour & Toutain [1990]**[77]**,Toutain [1981]**[78]**, Ranger & Bonneau [1984]**[79] **, Frontier & Pichot-Viale [1993]**[80]**.**

6.3- Theoretical focus on energy rather than nutrients

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[72]**Dommergue, S. Y. & F. Mangenot (1970)**. "Écologie microbienne du sol", Masson ed. Paris, 796.

[73]**Duchaufour, P. (1974)**. "Le climax du sol forestier" in *Écologie Forestière*, P. Pesson ed., Gauthier-Villars, Paris, p. 129-134.

[74]**Duchaufour, P. (1980)**. "Écologie de l'humification et pédogénèse des sols forestiers", *L'Actualité d'Écologie Forestière*, P. Pesson ed. Gauthier-Villars, Paris p. 177-201.

[75]**Duchaufour, P. (1991)**. "Pédologie: sol, végétation, environnement", Masson ed., Paris 3ième édtition, 189 pages.

[76]**Duchaufour, P. & F. Jacquin (1975)**. "Comparaison des processus d'humification dans les principaux types d'humus forestiers", Science du Sol **1**: 29-36.

[77]**Duchaufour, P. & F. Toutain (1985)**. "Apport de la pédologie à l'étude des écosystèmes", Bull. Écol. **17**(1) p. 1-9.

[78]**Toutain, F. (1981)**. "Les humus forestiers, structures et modes de fonctionnement" Rev. For. Fr. **6**: 449-464.

[79]**79Ranger, J. & M. Bonneau (1984)**. "Effets prévisibles de l'intensification de la production et des récoltes sur la fertilité des sols de la forêt. I- Le cycle biologique en forêt", Rev. For. Fr. **2**: 93-112

[80]**Frontier, S, & D. Pichot-Viale (1993)**. "Écosystèmes: structure fonctionnement, évolution", Masson ed. Paris 2ième édition, 447 p.

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Although the following description refers to all forest ecosystems, the tropical ones is the most dependant and advanced on account of the high temperatures and extended periods without heat or water fluctuations. Tropical forests have a more elaborate biological basis than boreal forests, with more "success stories" and, consequently, a greater variety of balances. Energy seems to be central to all of them. This energy is under the form of nutrients, namely, exogenous energy that can be infused into vital cycles and associated with biochemical nutrients (sugars, waxes, oils), which themselves produce endogenous energy. However, it seems clear that all fertile and productive tellurian systems hinge on regular and direct energy uptake from the epigeous ecosystem to the hypogeous ecosystem.

6.4- Eighty percent of energy in the form of photosynthates is transfered directly into the soil

Between 70 and 80 percent of the endogenous energy produced by trees is transfered directly to the soil, leaving only between 20 and 30 percent of the total energy production for tissue growth **(Fogel & Hunt [1983]**[81], **Meyer & Linderman [1986]**[82],**Rambelli [1973]**[83], **Reid & Mexal [1977])**[84],**Vogt et al. [1982]**[85], **Whipps & Lynch [1986]**[86]**).** In grasses (monocotyledons), only between 10 and 40 percent of produced energy is directed to the hypogeous ecosystem, which can affect soil stability.

6.5- Energy contribution from the epigeous ecosystem: the basis of terrestrial life

[81]**Fogel, R. and G. Hunt (1983)**. "Contribution of mycorrhizae and soil fungi to nutrient cycling in a Douglas-fir ecosystem", Can. Journ. For. Res. **13:** 219-232.

[82]**82Meyer, J. R. and R. G. Linderman** (**1986)**. "Selective influence on population of rhizosphere or rhizoplane bacteria and actynomycetes by mycorrhizas formed by *Glomus fasciculatum"*, Soil Biol. Biochem. 18: 191-196.

[83]**Rambelli, A.** (**1973)**. "The rhizosphere of mycorrhizae" in A.C. Marks and T.T. Kozlowski eds. *Ectomycorrhizae: Their Ecology and Physiology.* Academic Press London. pg. 229-249.

[84]**Reid, C. P. P. and J. G. Mexal (1977)**. "Water stress effects on root exudation by lodgepole pine". *Soil Biol. Biochem.* **9:** 417-422.

[85]**85Vogt, K. A., C.C. Grier and C.E. Meier (1982)**. "Mycorrhizal role in net primary products and nutrient cycling in *Abies amabilis* ecosystems in western Washington". Ecology **63:**370-380.

[86]**Whipps, J. M. and J.M. Lynch (1986).** "The influence of the rhizosphere on crop productivity". Adv. Microb. Ecol. 9:187-244.

Endogenous energy is thus transported to the hypogeous ecosystem through the root system, where mychorrhizae play a major role by carrying nutrients from the soil to the plant and the necessary energy from the plant back to the soil, while at the same time benefiting from it. Fungi, particularly basidiomycetes, are largely responsible for plant nutrition and plant/soil exchanges **(Allen & Starr, [1982]**[87], **Amaranthus & Perry, [1987)**[34] **Amaranthus & Perry, 1987;**[35] **Anderson et al. 1[985]**[88] **,Borchers & Perry, [1987]**[89], **Clarholm [1985]**[90], **Coleman, [1985]**[91], **Fogel & Hunt [1983]**[86] **Ingham et al., [1985]**[92], **Janos [1988]**[93], **Lynch & Bragg [1985]**[94], **Malloch et al., [1980]**[95], **Olsen et al., [1981]**[96], **Perry et al., [1987]**[97] **Trappe, [1962]**[98] **Vogt et al., [1982]**[90]**)**.

6.6- Sources of lignin with minimum polymerization: roots and twigs

Numerous times throughout this document we have mentioned the importance of lignin in soil formation and nutrient control at the different trophic levels. In conifer and hardwood forests, there are two regular sources of slightly polymerized lignin, namely, the lignin-rich tissue constantly shed from the canopy in the form of leaves, fruit, and small twigs of all kinds, and the tiny roots and

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[87]**Allen, T. F. H. and T.B. Starr (1982)**. "Hierarchy: Perspectives for Ecological Complexity", University of Chicago Press, Chicago.

[88]**Anderson, J. M., S. A. Huish, P. Ineson, M. A. Leonard and P. R. Splatt (1985)**. "Interactions of invertebrates, microorganisms and tree roots in nitrogen and mineral element fluxes in deciduous woodland soils" in A.H. Fitter, D. Atkinson, D.J. Read and M.B. Ushers eds. *Ecological Interactions in Soil.* Blackwell Scientific Publications, Oxford UK, pg. 377-392.

[89]**Borchers, S. and D. A. Perry (1987)**. "Early successional hardwoods as refugia for ectomycorrhizal fungi in clearcut Douglas-fir forests of southwest Oregon" in D.M. Sylvia, L.L. Hung and J.H. Graham eds, *Mycorrhizae in the Next Decade: Practical applications and Research Priorities.* University of Florida Gaineville, p. 84.

[90]**Clarholm, M. (1985)**. "Possible roles for roots, bacteria, protozoa and fungi in supplying nitrogen to plants" in A.H. Fitter, D. Atkinson, D.J. Read and M.B. Usher eds, *Ecological Interactions in Soil.* Blackwell Scientific Publications, Oxford UK, pg. 355-365.

[91]**Coleman, D.C. (1985)** «Through a ped darkly: an ecological assessment of root-soil-microbial-faunal interactions» Page 1-21 in A.H. Fitter, D. Atkinson, D.J. Read and M.B. Usher eds. Ecological Intercations in Soil, Blackwell Scientific Publications, Oxford, UK.

[92]**ngham, R. E., J.A. Trofymow, E. R. Ingham and D. C. Coleman (1985)**. "Interactions of bacteria, fungi, and their nematode grazers; effects on nutrient cycling and plant growth". Ecol. Monogr. **55:** 119-140.

[93]**Janos, D. P. (1988)**. "Mycorrhiza applications in tropical forestry: are temperate-zone approches appropriate?" in S.P. Ng ed. *Trees and Mycorrhiza.* Forest Research Institute, Kuala Lumpur, Malaysia, pp. 133-188**.**

[94]**Lynch, J. M. & E. Bragg (1985)**. "Microorganisms and soil aggregate stability". Adv. Soil. Sci. **2**: 133-171.

[95] **Malloch, D. W., K. A. Pirozynski and P. H. Raven (l980)**. "Ecological and evolutionary significance of mycorrhizal symbioses in vascular plants". *Proc. Natl. Acad. Sci.* **77:** 2112-2118.

[96]**Olsen, R. A., R. B. Clark and J. H. Bennet (1981)**. "The enhancement of soil fertility by plant roots". *Am. Sci.* **69:** 378-384.

[97]**Perry, D.A., R. Molina, & M.P. Amaranthus (1987)**. "Mycorrhizae, mycorrhizpohere, and reforestation: current knowledge and research needs". Can. Journ. For. Res. **17**: 929-940.

[98]**Trappe, J. M. (1962)**. "Fungus associates of ectotrophic mycorrhizae". *Bot. Rev.* **28:** 538-602.

rootlets metabolized by microfauna. Extremely rich in slightly polymerized lignin, these tiny roots and rootlets are sapid to microfauna. In a sugar maple stand, annual production is estimated at 2-3 tonnes/ha **(Sauvesty et al, [1993][43])**. This production is greater in deciduous dicotyledon forests than in evergreen forests composed of Gymnosperms or Angiosperms.

7- SOME CLUES TO UNDERSTANDING TESTING RESULTS

All results obtained in both forest and agricultural environments were later substantiated: **Aman et al. [1996]**[99],**Beauchamp [1993]**[69], **Guay et al. [1982]**[2], **Lemieux [1985]**[3], **Lemieux & Lapointe [1986]**[100] **Lemieux & Lapointe [1988]**[101], **Lemieux & Lapointe [1989]**[102], **Lemieux & Lapointe [1990]**[103], **Lemieux & Tétreault [1993]**[104],**Lemieux & Toutain [1992]**[18], **Lemieux [1995]**[105], **Seck [1993]**[73]**.** In most cases, the results, which can be reproduced with certain variations due to annual fluctuations in climatic and environmental conditions, were positive. Where verifications were unsuccessful, we found what went wrong and the explanations to confirm basic principles. Thus, an excess of water prevents lignin depolymerization by washing away the responsible basidiomycetes. However, it is also possible that these basidiomycetes may not be present in the ecosystem on account of the type of RCW used.

At this stage in our research, we can safety put forward the following hypothesis: *Ramial wood that is invaded by basidiomycetes can*

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[99]**Aman, S., S. Depatie, V. Furlan & G. Lemieux (1997)**. "Effects of chopped twig wood (CTW) on maize growth and yields in the forest-savanna transition zone of Côte d'Ivoire" (in press).

[100]**Lemieux, G. & Lapointe, R. A.** (**1986)** "Le bois raméal et les mécanismes de fertilité du sol". Département des Sciences Forestières Université Laval, Québec17 pages. ©ISBN 2-550-21338-1.

[101]**Lemieux, G. & Lapointe, R. A. (1988)** "L'importance du bois raméal dans la "synthèse" de l'humus". Département des Sciences Forestières, Université Laval, Québec, 29 pages. ISBN 2-550-21341-6.

[102]**Lemieux, G. & Lapointe, R. A. (1989)** "La régénération forestière et les bois raméaux fragmentés: observations et hypothèses". Département des Sciences Forestières de l'Université Laval, Québec, 223 pages. ISBN2-550-21342-4.

[103]**Lemieux, G. & Lapointe, R. A. (1990)** "Le bois raméal et la pédogénèse: une influence agricole et forestière directe". Département des Sciences Forestières, Université Laval et Ministère de l'Énergie et des Ressources (Forêts) Québec. 35 pages. ISBN 2-550-21267-3.

[104]**Lemieux, G. & Tétreault, J.-P. (1993)** "Les actes du quatrième colloque international sur les bois raméaux fragmentés". Édité par le Groupe de Coordination sur les Bois Raméaux, Université Laval, Québec, Canada, 187 pages. ISBN 2-550-28792-4,

[105]**Lemieux, G. (1995)** "La dynamique de l'humus et la méthode expérimentale: l'apport de la forêt à l'agriculture par le bois raméal fragmenté**".** Texte présenté à la conférence constitutive du Réseau Africain du Compost, Dakar, 26 avril. Université Laval, Québec, 13 pages, ISBN 2-921728-12-5.

*replace all biological functions requiring chemical or biochemical nutrients. However, the dominant presence of bacteria capable of depolymerizing lignin will not have the same positive effects***.**

7.1- The shape of trees: a brief evolutionary history

Many of our observations and thoughts on energy in relation to soil life were neither supported nor discussed in the scientific literature, and one of our publications on this topic was ignored by the scientific community **(Lemieux [1995]**[106]**).** We were constantly struck in the tropics and the level of soil degradation by the low productivity, **(Lemieux [1995]**[107]**)** whereas in northern climates plant tissues are abundant but neither transformed nor productive in terms of annual biomass.

The rapid transformation of RCW under tropical conditions and the stagnation of organic debris under arctic conditions are the direct result of an inversion of exogenous energy distribution or availability from the sun. **Godron & Lemieux (1996)**[12] have shown the strategic importance of branches in the evolution of tree shape for more efficient capture of shortwave photons, a theory to which we subscribe. We are mystified by the fact that the most ancient trees, namely, conifers, bear such little resemblance to hardwoods with regard to photon capture.

Dicotyledon trees with a trunk and broad top are able to filter light and capture "high-performance" photons, thereby becoming the most productive and dominant species. Consequently, they are able to produce more energy and hence store surplus energy in the form of wood in the trunk, while accelerating the plant tissue cycling process, improving the quality of the hypogeous ecosystem. As a result, hardwood climax forests can tolerate "all" vegetative competition at nearly every level and make it benefit the entire ecosystem. This leads

[106]**Lemieux, G. (1995)** "Passer de l'enthalpie à l'entropie"**.** *Ecodecision*, winter 1995, pp. 72-73, Royal Society of Canada, Université Laval, Québec.

[107]**Lemieux, G. (1995)** "Rapport de mission en Afrique (Sénégal)". CIDA and Université Laval, December 1994, 48 pages, ISBN 2-921728-08-7.

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to maximum biodiversity with maximum **metastability.** All elements converge to create stability with maximum complexity where all living organisms can replace one another. Natural selection of species and individuals will occur, but with no known effects on the distribution of roles in ecosystem stability.

Generally speaking, conifers (gymnosperms) have the opposite shape of hardwoods (dicotyledons). Since conifers appeared before hardwoods, we submit that their genetic development reflected environmental conditions which no longer exist. As the quality of the atmosphere filtering sunlight changed, so the quality of the light reaching the treetops changed. Since the top branches are short rather than long and wide as in hardwoods, it would seem to indicate that conifers did not have the same need to dominate the ground. As a whole, this means that conifers are suited to environmental conditions which no longer exist except in a few remaining places such as boreal forests and high altitude environments. Conifers are, to a certain extent, directly associated with paleoclimates. It is possible that the quality of light at a given altitude has changed and that the proportion of shortwave photons is substantially different.

7.2- Pedogenesis Under Conifers

Conifer forests most likely developed restrictive systems by eliminating competitive vegetation based largely on the inhibiting effects of polyphenols. Their lignin has an asymetrical structure with aromatic rings composed of a single methoxyl group, giving rise to numerous polyphenols, fatty acids, resins, terpenes, etc. and inhibiting the action of certain lipases, when present. Many species from the Umbelliferae and Labiatae families have inherited this characteristic from gymnosperms, as have Australian eucalytus, which eliminate vegetative competition, destroying agricultural crops in the process.

These two methods of managing competition, one "old" (conifers) and one "modern" (hardwoods), suggest that **the structure and evolution of lignin among pedogenetic mechanisms as a whole**

are directly responsible for the type of competition existing in ecosystems, through both the changes it undergoes in soil and its effects on chemical and biochemical nutrient availability.

8 - SOME THOUGHTS ON RAMIAL WOOD

The increased productivity enabled by harmonious mechanisms led us to see RCW as a basic "nutritional" approach to agriculture within the framework of pedogenetic causes and factors. If RCW influences both agricultural and forest soils, we concluded that it might be the basis of a whole new field of knowledge which, if the scientific literature published during this century is any indication, has never been approached from this perspective.

The ability of RCW to reestablish the various life cycles and exchanges clearly indicates that metastability is the culmination of a series of vital processes the importance of which is demonstrated through the new discoveries being made every day in the field of physics. We have begun looking more closely at the biological aspects of soil, an approach that has faced resistance, but which is slowly gaining acceptance.

8.1- Fertility: A Definition

In short, we must seek diversity in order to allow nature to build a bridge between the geological world and living organisms using familiar chemical and biochemical mechanisms whose interdependence is nowhere as close as in soil. This should force us to define soil solely in these terms, rather than in terms of chemical criteria for the sole purpose of classification in order to define and induce fertility, as is currently the case. **Fertility can be defined as the well-ordered and balanced flow of chemical and biochemical nutrients, as well as of water and energy transfers in keeping with demand, itself controlled by climate changes.**

8.2- The Impact of Biotechnology

For ages, the tendency has been to manipulate genetic capital in order to correct biological deficiencies and increase productivity. Although these new biotechnologies seem to provide infinite possibilities and results, it cannot be stressed enough that the current genetic system and metastability took millions of years to build. We should therefore be looking only to correct mishaps without challenging the logic of established balances. These "accidents" are almost always imprinted in individual genetic heritage and, by extension, the environmental heritage of a given population. They must be identified before taking action.

Producing more with less and producing better quality, particularly in increasingly degraded soil, seems to be warranting an awful lot of investment in a spirit of greed. We must protect ourselves against this kind of action through proper knowledge rather than through new technologies, no matter how attractive they may seem.

9- MODERN FORESTRY PRACTICES

9.1- Forestry Versus Agricultural Logic

As seen earlier, forestry is marked by agricultural vocabulary, techniques and concepts within an industrial context of production and economic yield measured in terms of cash receipts. It is perfectly logical, then, that forestry be expected to operate the same as agriculture, with the same constraints. We would like to propose a **forestry logic**, rather than the agricultural logic we have so scrupulously followed since the beginning of time.

As in traditional agriculture, where expected yields were low due to primitive techniques, the forests in eastern North America have

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not been overly disturbed given that logging was largely carried out during winter, with only small volumes being harvested. Increased logging after the Second World War and greater mechanization of operations, particularly since the 1960s, have led to significant changes.

This trend has continued to gain momentum with the globalization of markets, but without any promise of reprieve in trade disputes, since competition now rules the marketplace, and constant innovation is a must. How can we impose this kind of logic on a metastable ecosystem, the very essence of terrestrial life since the dawn of time and bound by the laws of physics? We have spent years of hard work and reflection trying to answer this very question.

I have just gone over the conclusions arrived at through a review of the scientific literature and our forest and agricultural testing both in Québec and in the Tropics, while blaming our "agricultural perception" of the forest when the logical approach would have been the exact opposite. Since we cannot change the course of human history, we can only state the facts and then attempt to change our perception in order to adopt a "silvo-forest" approach, i.e. the forest seen its own right.

9.2- Back to Silvicultural Techniques

Unlike agriculture, forest productivity is based on a stable ecosystem. Where the ecosystem is not stable, forest "enemies" either completely destroy the site or bring it to its knees, sometimes for thousands of years, as is the case in the Mediterranean basin. Traditionally, and even today, we have only been interested in tree stems. Even though the nutrient capital is not exported, we end up depleting the entire biological system. Since the only nutrient export occurs through leaching, where does this belief come from that ecosystems cannot return to their natural state before being logged? Ironically, it is only when the linkages responsible for the ecosystem's metastability are broken that ecosystems cannot recolonize (**Perry et al., [1990]**[21]).

The more complex the "megabiological" system, the more it depends on the linkages between the constituent elements. The agricultural logic disregards these constraints and imposes its own rules provided that mankind invest the capital and labour needed to maintain ecological balances and short-term crop rotations. And that is the weakness: forestry has become an industry that is trying to ensure its sustainability by submitting to agricultural constraints and borrowing its techniques.

The surprising thing is that, while claiming that "logging debris" is beneficial to soil and that its decomposition "enhances the station" the same as manure does farmland, logging companies fell entire trees and remove all debris from the logging site in the name of profitability. When this debris accumulates and becomes problematic, controlled burning is carried out to facilitate artificial regeneration.

Freedman in Lemieux [1990][22] demonstrates just how detrimental removing logging debris can be for total nutrient balance. Once again, this is an agricultural perspective based on the reasoning that chemical nutrients are the only basis of assessment.

9.3 - A Necessary Distinction Between Stemwood and Ramial Wood

As previously demonstrated, foresters make no distinction between types of debris: it is generally lumped together as "homogeneous material" of no worth. However, the analyses conducted by **Guay et al. (1982)**[3] clearly indicate that branches are rich in nutrients, with a C/N ratio far greater than that of trunks or bark.

In keeping with the tradition of perceiving forestry from an agricultural perspective, no distinction is made between trunks and branches, both being considered logging waste. We propose that such a distinction form the basis of a new approach to forest management whereby branches, which are rich in available energy and biochemical and chemical nutrients, are allowed to become part of the life cycle through the vital process of pedogenesis.

Thus, branches and leaves, considered the greatest hindrance and the most dangerous logging waste in terms of fire hazard, should be chipped or hogged immediately after felling and left on the forest floor. Soil basidiomycetes will immediately invade this organic matter to retrieve the best nutrients, including many proteins and enzymes. With the tree-soil cycle thus being completed, all other pedogenetic mechanisms will immediately fall into place.

9.4 - The Role of Basidiomycetes

It is of utmost importance that basidiomycetes be the first to colonize this matter; otherwise, the other biological levels will be able to consume a large portion of this "feast" without forming proper or efficient trophic chains. If, on top of this, there is surplus water, there is a greater chance the humus will develop into peat.

9.5 - The Carbon Cycle

I would like to point out that none of the discussions regarding carbon in any of its forms allows us to predict fertility, since this is a purely biochemical assessment of forms from CO_2 to diamonds or sugars to coal which precludes any understanding of pedogenetic mechanisms. In my opinion, this carbon-based assessment of our planet is pure folly; instead, we should be looking at ecosystem metastability for an understanding of how these mechanisms function. Seen from this perspective, carbon will take the form of its biological evolution, where aromatic rings play a role whose importance we have not even begun to suspect. This is the direction we must take if we want to understand the evolution of life on Earth. Carbon will become the basic structural element responsible for energy conservation, although it can also be used for other functions under the action of enzyme systems.

9.6 - Perception of Logging Debris

Currently, logging debris is seen in a negative light and the attempts in Europe to reclaim this so-called waste by reintroducing it into forest soil have all failed. The perception is therefore that of worthless material or a "nuisance" whose only effect is to cause extremely costly and destructive forest fires. Efforts therefore focus on how to get rid of it. It decomposes through the action of numerous fungi, or burns up in smoke during forest fires, not only doing nothing to upgrade the ecosystem, but depleting it further through the loss of nutrients and diversity.

Most foresters argue (without substantiation) that logging waste is transformed into a kind of fertilizer that conditions the soil and promotes regeneration. Nothing could be further from the truth, however. The fungal and microbial degradation of this debris emits carbon dioxide and nitrogen into the atmosphere, releasing precious energy from the aromatic ring for nothing, while chemical components leach onto the soil when it rains and run into lakes, streams and rivers. In drier climates or during droughts, this debris is blown away by the wind. Consequently, what has taken decades if not centuries to become an integral component of productive ecosystems is lost forever in a matter of seasons.

9.7 - Safeguarding a Hard-Gained Heritage

In contrast, chipping branches and spreading the RCW on the forest floor helps protect the "chemical heritage" as well as the

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valuable, high-energy-content aromatic ring, in addition to building soil. Rather than leading to soil depletion and desertification, RCW initiates an upgrading process, fosters regeneration and re-creates the chemical heritage lost through the use of current silvicultural techniques, techniques which have been handed down through the generations without ever being questioned other than in agricultural terms.

9.8 - The Role of Mychorrhizae

The mychorrizal mania witnessed in recent decades and the positive effects of mychorrhizae on agricultural production have often been assessed only in terms of increasing productivity, particularly through greater phosphorus uptake. In our opinion, mychorrhizae play an even greater role by storing phosphorus in mycelium tissues thanks to greater phosphatase activity. Another role, more important still, is the transport of nutrients unhindered by the chemical constraints of soil, particularly poor soil. This fertility aspect is made possible by the fact that basidiomycetes' mycelia have no septa and act like a "pipeline", protecting and transporting nutrients from one point to another, as well as from the plant to the soil and vice versa.

This basidiomycetes "transportation system," composed primarily of mychorrhizae, represents the basic living instrument of forested ecosystems. Accordingly, energy is needed for this living system to exist and function. And where else does this energy come from, if not from the transformation of existing organic matter: sugars are the first to be converted and the benzene rings the last. This is the first cycle whereby soil aggregates undergo constant change in fertile soils, being used as both food and a nest by numerous microorganisms, including bacteria and fungus spores.

9.9 - What to do with Stemwood?

Apart from leaves and branches, logging debris includes low-grade trunks and large crown branches that cannot be treated as branches and are not of the same quality. Stemwood left on the forest floor is left precisely because it is rotted or has been attacked by bacteria. Because of the highly polymerized lignin and the presence of numerous polyphenols and high levels of manganese, this wood is not likely to benefit pedogenesis. The lignin is depolymerized by other enzymes such as bacterial laccases. This type of polymerization produces fractions that recombine as different polyphenols, such as fatty acids, rather than producing only humic and fulvic fractions. These black, poorly structured substances are relatively poor in nutrients and relatively immobile with a tendency to form peat in the right water conditions.

9.10 - Lignin and Manganese

We suspect this process to be the basic means of controlling vegetative competition in conifer forests where manganese is abundant. Several of our analyses, as yet unpublished, show that the metabolism of hardwoods which compete successfully with conifers, either directly or in transition stages, is not affected by high manganese concentrations.

Recent discussions with European pulp and paper engineers indicate that even a trace of manganese hinders lignin transformation in the new bleaching techniques. We are inclined to see the role of manganese as being similar in soil, a theory that requires major conceptual research. For the moment, we see it as being one of the main factors controlling forested ecosystems and pedogenesis, a hypothesis which obviously needs to be proven.

9.11- Chipping Methods and Time

Clearly, trunks and branches must be treated differently. While it is crucial that branches be chipped and spread on the ground immediately after felling, the same is not necessary for trunks, although it is important that they be in contact with the ground in order to enable microbiological exchanges and provide valuable nests for small mammals.

9.12 - Potential of Conifer and Hardwood RCW

Most scientists would agree that conifers are capable of cycling nutrients without relying on soil. This is one of the main reasons why conifers, especially pine, are planted all over the world. However, conifers are not apt to upgrade forested ecosystems into which they are introduced. Although they have no long-term positive effects, their hardiness enables them to survive by eliminating vegetative competition or tolerate species which succeed in adapting to their conditions.

By comparison, hardwood plantations are less productive in terms of growth, although they are much more productive in terms of volume. The climax hardwoods of eastern North America have to recycle their nutrients through soil, a primary condition for soil calcium metabolism, where the calcium is isolated and concentrated from dead leaves by basidiomycetes **(Toutain (1993)**[49]**).** This fundamental role of the hypogeous ecosystem contributes greatly to fertility and biodiversity, since the soil is able to transform the various biological inputs and make their constituent nutrients available for uptake by plants in the epigeous ecosystem.

9.13 - Energy Stored in Hardwood Forest Soils

This would largely explain why **Gosz et al. (1978)**[59] observed such large amounts of energy stored in soils under the forest canopy and such great losses following logging. A series of mechanisms enter into play to maintain energy and biodiversity, which is not the case with conifers. This is why conifer stands are considered extremely **resistant**, despite their poor adaptation to today's climatic conditions. In contrast, hardwood forests are capable of adapting to competition and biodiversity by using the hypogeous ecosystem as a "food bank," which explains their superior productivity compared with conifer forests.

In this context, we suggest, at least for experimental purposes, that not only branches be chipped, but that the first regeneration growth be chipped as well in order to replenish energy reserves as quickly as possible, provided this is followed by stem selection. Proceeding in this way will ensure a fertile and "natural" stand structure with better stem distribution. Chipping should be the tool of choice for maintaining and rebuilding stand structure. It should enable us to reduce, if not completely eliminate, the use of silvicides. In addition, all logging or limbing debris should be immediately chipped and returned to the forest floor.

9.14 - Economic and Logistical Arguments are Losing Ground

Despite the economic and logistical arguments against chipping, we believe it to be the most sensible technique. But we must give it time; otherwise, we are headed straight for an ecological, and in the medium term, an economic crisis. In just over a century, large forests have been brought to the brink of extinction; let's hope that it does not take as long to reestablish ecological order. Otherwise, any remaining forests will be unproductive.

A recent study conducted by the forestry branch of the US Department of Agriculture **(Smith et al. [1994]**[108] shows the progression of logging in the United States. The balance between growth and harvesting was broken nearly fifty years ago, and in the past ten years the amount of forest lost has doubled. While our purpose is not to discuss this problem, which is both a social and economic one, such examples cannot be ignored, since understanding and rehabilitating our forests requires tremendous effort on all our parts. We are all aware that a crucial balance was broken long ago.

[108] **Smith, B.W., G.L. Faulkner & D.S. Powell (1994)**, "Forest Statistics of the United States, 1992", General Technical Report NC-168, 145 pages.

With regard to the carbon cycle, an oft-used term which, in my opinion, is meaningless in a forestry context, it is clear that because carbon is a component of the trophic levels as well as proteins, sugars, cellulose, lignin and, consequently, the benzene rings, chipping has a considerable impact on carbon availability. Metastability requires constant exchanges in order to establish and maintain balance between the various elements. All such systems are based first and foremost on carbon balance. In contrast, systems that are unbalanced as a result of depletion release large quantities of free carbon, which has a snowball effect we are only beginning to understand. Obviously, this carbon can become trapped and end up forming peat, coal or petroleum. Maximum carbon concentrations in trophic chains should occur when there is full metastability. It may be somewhat rash to think that, left on their own, forests can correct carbon balances; however, think of the Carboniferous period. Existing hardwood forests contain three to five times more carbon in their hypogeous ecosystem than in their epigeous ecosystem, making soil degradation the main source of CO_2 emissions to the atmosphere.

9.15 - Water Cycle

It goes without saying that a well-balanced tellurian system requires a regular water cycle, that is, neither a surplus nor shortage, although temporary extremes may occur depending on the season. An accurate assessment of biological water cycles is difficult in temperate climates such as ours, if only because of the unpredictable meteorological conditions. By comparison, noticeable increases in yields were measured under semi-arid tropical conditions, which leads us to believe that soil water has its own cycle which passes through the different trophic levels where large quantities of water can be stored under semipermeable membranes within the microbial biomass. The role of the canopy in the daily atmospheric water cycle where soil temperature is lower than the ambient temperature has been well documented for tropical rainforests.

Increased soil porosity due to the soil structure, degree of tellurian life, and soil air enables runoff to be absorbed, thereby reducing water and nutrient losses. In this context, lignin polymerization is regular, provided there is aerobiosis. Controlled transfers from the mycelia by bacteria that modify membrane permeability at the meeting points constitute another important exchange system. These bacteria are washed away under surplus water conditions.

10- RECOMMENDATIONS

We are now at the point where we need to put forward recommendations to help further our scientific knowledge and understanding. These recommendations will impact on forestry, agriculture and the general sciences, among which physics could be the first to benefit.

10.1 - Technical Experimentation in Forests

The experiences discussed in this document show that it is possible, in the medium term, to measure soil changes which will have major impacts in the future. These changes centre on rebuilding the biological and biochemical structure of soil in order to create new ecosystems based on metastability. We therefore recommend that:

a) Following felling, all branches under 10-15 cm in diameter be **chipped and spread on the forest floor either immediately** or, if this is not possible, no more than one week later;

b) Depending on site fertility, the first regeneration growth be chipped with a view to enhancing energy storage and biodiversity;

c) Initial trials include control plots of equal size and similar geographical location to test plots. Two identical, small watersheds would be useful for comparing nutrient losses following logging. They would also enable more accurate assessment of discrepancies in metastability;

d) Five-year studies (or longer) be conducted on plant life, regeneration, insects, fungal diseases, etc. Enclosures should be installed in order to prevent wildlife from browsing and altering the new vegetation structure;

e) Study results be published and presented at international workshops so as to discuss the mechanisms observed and measured under tropical conditions. The assistance of foreign institutions such as the International Center of Research in Agroforestry (ICRAF) in Nairobi should be solicited for interpreting results.

10.2 - Fungal Testing

Numerous scientific fields have to be explored in order to fully understand our findings and determine how to continue and interpret our achievements. Since the primary biological process in pedogenesis takes place at the fungal level, and given that only minimum experimentation has been conducted in this area, we feel this is where the priority should be.

a) Major efforts need to be devoted to identifying and cultivating the main types of soil fungi found in both young and old-growth forests. Similar research should be conducted in the laboratory to devise new protocols;

b) The role of the various fungus families need to be properly identified in order to understand their behaviour. Although this is a difficult task, it should not be neglected, as it will contribute considerably to understanding management results;

c) For each of the main basidiomycetes species, we must be able to identify what, where and under what conditions enzymes are produced. These are important mechanisms underlying the basic functions of the hypogeous ecosystem and its fertility.

10.3- Mesofauna and Microfauna

Major studies need to be conducted on the different microfauna and mesofauna levels occurring at each succession stage. These microfauna and mesofauna are often central to the dilemmas related to polyphenols and tannins in particular. Among other things, they can carry the fungi and bacteria responsible for producing several enzymes linked to nutrient availability, even in the presence of major chemical constraints. This is one of the most dynamic parameters in pedogenesis.

10.4- Phosphorus and Nitrogen Balance Sheets

Enzyme systems are obviously the basis of hypogeous ecosystem function, the very essence of living soil. In this respect, considerable effort should be made to try and understand how phosphorus is transferred and transported through mychorrhizae and the responsible enzymes. Specific energy transfers must certainly be involved and are worth examining.

Major research needs to be conducted on the role of bacteria responsible for **nonsymbiotic** nitrogen fixation. These bacteria definitely have a considerable impact on the ecosystem's nitrogen balance, but under certain conditions, their role may be just the opposite, that is, to maintain a balance between plant-soil nitrogen supply and demand. We are increasingly inclined to believe that the capacity of Leguminosae to fix nitrogen through rhizobia is a response to a nitrogen deficiency in the hypogeous ecosystem.

10.5 - Lignin and Polyphenols

The more we understand about the basic mechanisms involved, the more certain we are that polyphenol chemistry is the biochemical basis of pedogenesis. This belief is not unrelated to the fact that lignin depolymerization coincided with the appearance of fungi several hundred million years ago. We greatly suspect that lignin depolymerization is the biochemical basis of soil and, at the same time, controls the biological and chemical release of nutrients for plant growth. Rather than seeing millions of polyphenolic compounds as "the enemy" or a threat, a critical review of phenolic chemistry should be conducted in light of what we have just described. Polyphenols behave differently depending on the type, i.e. conifers or hardwoods, and age of stands. They should be treated as fundamental elements of fertility and fertility control. Through their benzene rings, polyphenols store the energy needed to maintain a dynamic structure composed of many trophic chains that enable or inhibit nutrient availability.

11 - WORKING MORE CLOSELY WITH THE PULP AND PAPER INDUSTRY

We need to work more closely with the pulp and paper industry which, thanks to new technologies, is now sensitized to the importance of enzyme systems, the same, or if not similar, enzyme systems to those responsible for forest soil fertility.

11.1 - Basic Science

Now we need to turn our attention to lignin, that important macromolecule which we know how to degrade, but which we also now suspect to play a fundamental role in all pedogenetic mechanisms. Not only does it produce polyphenols, but lignin gives physical structure to soil, is the source of humic and fulvic fractions, the basis of organic and mineral structure and polyphenolic condensed aggregates in soils devoid of fine minerals.

12- THE NEED FOR INVOLVEMENT OF RESEARCH INSTITUTES AND UNIVERSITIES AT THE INTERNATIONAL LEVEL

In keeping with the universality of pedogenetic mechanisms, one of my goals is to bring about a change in our national and international institutions and have them take charge of developments in the pedogenesis-related sciences. An international institute of pedogenesis could conduct studies to help solve the current problems of desertification, soil erosion, and the irreparable loss of forests around the world.

12.1 - From Philosophy to Physics

Newton's theory that time is nonending, linear and continuous, with the past being equal to the future, brought unparalleled confidence to the sciences, particularly those proper to engineering. This is the root of capitalism and the development of sciences at large. The permanency that flowed from this new sense of power saved mankind from its precarity, opening doors to a brighter future than ever before. However, the likes of Einstein, Bohr, Plank and Curie changed this optimism by giving birth to particle physics, which was to utterly change our knowledge of the universe by showing that space is curved and that time is not linear.

We would like to stress that time does not bear the same weight in agriculture as in forestry. If agriculture can afford to disregard time, at least in the long term, forestry cannot. And this is the fundamental difference which tends to be overlooked when we treat forests the same as farmland. The mechanisms underlying metastability are subject to time and cycles, and we must therefore think first of all in terms of sustainability ut not of eternity.

The main purpose of this research is to draw attention to the importance of physics and the current trends which often oscillate between physics and philosophy. If I have been able to demonstrate this fact to any degree, I will have accomplished something. But there is still a long road ahead of us. We have spent the past half-century collecting data, never thinking to discuss and renew our ideas based on what we have learned.

The time has come to rethink our views of the universe. As stressed by Prigogine, time is irreversible; evolution is inevitable and we are fated to redefine ourselves. Forests are no exception to this rule. Without human intervention, they would continue to exist, whereas agriculture would not. It is therefore fitting that we collectively rethink our fundamental concepts. Such an exercise would be in keeping with our preoccupation about the end of one millennium and the dawn of another.

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