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Abstract

Research work over the last twenty years on the use of ramial chipped wood (RCW) in both agriculture and in forestry has shown increases in productivity and fundamental modifications to the soil, in both temperate and tropical climates. Although we are not yet in a position to make substantiated proposals for its immediate use, we are able to suggest a series of hypothesis that need to be subjected to large-scale field tests. One clear relationship is that between the type of lignin and the behaviour of Gymnosperm and Angiosperm ecosystems. We note in particular the preponderant role that immature lignin, in the form of oligomers or monomers, plays in structuring the soil and in building trophic webs; the critical role played by Basidiomycetes in pedogenesis; and the importance of endogenous energy in the functioning of the hypogeous ecosystem, and its major influence on the conservation and distribution of biologically active water.

I - A brief history: the evolution of ecosystems and man's anthropocentric behaviour

1. History tells us that man, as the last of the larger mammals to appear on earth, possesses not only a very highly developed brain, but a tremendous ability to communicate both through the spoken word, and through his invention of writing and the use of symbols and abstractions. These are features that no other creature can match. They imbue man with, at the same time, magnificent qualities and countless faults..

2. Man's awareness of his own evolution, and his pride in his own accomplishments, have made him forget that he is a relatively recent arrival, and that, millennia before him, the earth's ecology was already well established, with rules that were well tried. Full of admiration for ourselves as the culminating masterpiece of evolution, we set about to subject nature to our will. We took advantage of the fact that the forces that brought about the current state of natural equilibrium are especially generous, and happily gorged ourselves at the trough, while giving thanks to God, Allah, Jehovah, Siva or some other deity. In this way, we made ourselves Masters of the World - but of a world that was ready to rebel against our excesses.

3. Recent events are now forcing us to revise the mistaken view of history that we had propounded for ourselves. We found that, in order to understand the field of our research - that of the soil and its dynamics - we had to realize that, long before man came upon the scene and invented agriculture to support himself, there were forests all over the earth, wherever conditions permitted. And we concluded that the mechanisms governing that forest must have evolved along with the behaviour of the soil, which in turn was modified by the vegetation growing on it.

4. We set ourselves this hypothesis, therefore: (1) ***If we admit that, in the absence of agriculture, forests dominated the earth for millions of years, and that once man had removed the forest cover for farming, the soil suffered major degradation and loss of fertility, then the factors governing the soil's fertility must have been due to the forest.*** This hypothesis implies that those governing factors are of a biological rather than a chemical origin.

5. Such a hypothesis will encounter two immediate realities. First, pedologists and agricultural soil scientists will be highly sceptical - after all, 98% of their publications deal with the issue from a chemistry perspective. Second, forestry experts will be indifferent at best, since in their approach

they cannot go beyond dealing with the descriptive aspects of soils. These two attitudes prevail not only in Quebec, but in countries all over the world with whom we have been dealing. This made us realize at the outset that funding for our research would be hard or even impossible to obtain, and that governments would not see it as a priority area for financing. In short, the entire undertaking seemed to be running against the tide - and that, as any researcher knows, simply heightens the challenge of seeking new knowledge on social and economic evolution.

II - The importance of the forest in tropical climates

6. It is noteworthy that in the tropics, vegetation exists mainly as forest cover or as desert-type growth. Here, the rain forest represents the culmination of diversity and productivity. It is composed of Dicotyledons, accompanied by various species of Monocotyledons and Cryptogams such as ferns. It was most likely this dicotyledonous forest, so rich in biodiversity, that suffered the first primitive agricultural clearings, which with the spread of mankind have reached the scale we see today.

7. Agriculture thus first took root in the tropical broad-leaf or hardwood forest, and spread to countries of the temperate world in the same manner. Today we recognize that agriculture has been a failure in coniferous forest areas, whether in the Tropics of America or at more northerly latitudes, all over the world.

8. This fact led us to pose a second hypothesis: (2) T***he mechanisms governing fertility, pedogenesis, biodiversity, and primary and secondary soil productivity depend on factors that have not been clearly explored in the scientific literature of the twentieth century. We conclude therefore that science has focussed solely on questions of soil output.***

9. The limitations that are apparent today in the use of chemical fertilizers, and their secondary effects, point to the importance of other mechanisms that have been little explored to date, although great effort has been devoted to studying the chemical cycle of nutrients, in every language and every country. The biological and biochemical aspects of the question have been largely ignored and remain poorly understood, while a great deal of work has been done on degradation and pollution, in an attempt to undo these by-products of our civilization.

10. The foregoing thoughts and hypothesis led us to approach the question from a strictly biological viewpoint, seeking not merely to describe individual situations, but to examine their comprehensive dynamics. We have thus phrased the question in the following terms:

a) the basic composition of wood, which is the characteristic product of forests;

b) biochemical factors in soil formation;

c) exogenous biological mechanisms that affect soil dynamics;

d) the system by which nutrients are cycled within the soil, including the role of water;

e) the question of endogenous and exogenous energy in governing soil fertility.

III The basic composition of wood

11. In all the literature that we consulted, it was generally agreed that plants are composed of cellulose, hemicellulose and lignin, resulting from the transformation of glucose. In trees,

photosynthesis produces these three related substances in a continuum, storing them as energy. One physical result of this is that tree branches are rigid, and grow in diameter year by year. The wood of trees is, in fact, very poor in nutrients, apart from those in the cambium layer. The wood itself serves as a physical support and carrier, and has no role in biological dynamics.

12. Thus, other things being equal, lignin alone among these basic constituents shows any marked variation in its structure. Lignin is one of the most complex and least understood natural macromolecules, which has been regarded until now as merely a useless by-product that posed major water pollution problems [for the pulp and paper industry]. We now know however that Gymnosperms (conifers), Dicotyledons and Monocotyledons contain different types of lignin. These are identifiable as symmetrical aromatic rings with two methoxyl groupings (OCH3) or "syringuil" lignin, in the case of Dicotyledons, while in Conifers this lignin is asymmetrical, with a single methoxyl grouping or "guayacil" lignin. Monocotyledons represent a mixture of these two types, and include a third type that has no methoxyl groupings at all on its aromatic rings.

13. Dicotyledonous trees are associated with deep brown soils, possessing a stable and elaborate structure based on aggregates. We find a great degree of biodiversity among the microfauna and microflora in their hypogeous systems, and in the epigeous macroflora. On the other hand, coniferous forests are associated with podzol soils, characterized by layers of iron precipitate underlying an accumulation of vegetation matter ["litter"] on the surface. This type of soil presents numerous obstacles to the free flow of nutrients. Biodiversity is much reduced, especially in the epigeous ecosystem where only a few species may thrive. Thus we find two basic types of ecosystem controls: one based on "mega-biodiversity", and the other on "oligo-biodiversity".

14. The third type of soil, that associated with Monocotyledons, usually contains aggregates that are dark in colour, but unstable in the presence of water. This soil type is found only in regions of low rainfall (steppes, pampa, the North American prairies, etc.). Plant matter accumulates faster than biological combustion can remove it, because of the lack of water needed for the transformation. These soils are fertile, but fragile. They degrade readily under agricultural use, and can thus support only a limited human population.

15. We were unable to find any description or classification for one extremely important part of trees and shrubs - their branches and twigs. It is in the branches that photosynthesis takes place, and glucose molecules are turned into plant tissues. As a rough estimate, branch growth amounts to billions of tons over the earth as a whole. In Québec alone, such production may run to 100,000,000 tons per year, to judge from figures provided by ENFOR, adjusted by a shrub productivity factor.

16. As early as 1986, we proposed using the term **ramial wood** [or **ramial chipped wood** - RCW - after processing] for this material, which has until now been regarded as merely a nuisance industrial waste. Besides cellulose, hemicellulose and lignin, ramial wood contains many kinds of proteins, all the amino acids, and nearly all the sugars and starches, as well as intermediate polysaccharides. It also contains countless enzyme systems and hormones, as well as polyphenols, essential oils, terpenes, tannins etc. that are associated to varying degrees with the nutrients necessary to generate and support life.

17. Many of these products, such as enzymes, amino acids and various types of proteins, are extremely fragile. Others can be used as immediate sources of energy, such as the sugars, celluloses and hemicelluloses. The remaining lignin, with its three-dimensional molecular structure, is one of nature's most complex creations. It too is an important energy source, but one that is difficult to access, since the energy is bound into aromatic rings that very few organisms are adapted to digest. Among those few are the protozoa and bacteria, but the most important are the fungi of the Basidiomycetic group.

1 - Lignin, its derivatives and their role in soil dynamics

18. Almost a century ago, theories were put forward about the important role lignin plays in the generation of soils. Scientific work over the past few decades however has focussed less on that aspect than on learning more about the molecular properties of lignin that can be used to accelerate its degradation as a pollutant. From this viewpoint, the work of the last ten years has produced several findings and conclusions about the structure of the lignin molecule, and the ways it evolves. (See E**rikson, K.E.L., Blanchette, R.A. & Ander, P [1990], Rayner, A.D.M. & Boddy, L. [1988]).**

19. Starting with glucose, coniferylic alcohol is formed, which produces lignin in the form of monomers that are then gradually polymerized over time. The most important of these in terms of structure and energy content will be aromatic rings: they serve as the principal building blocks of soil.

20. This molecular structure, even when highly polymerized, can undergo various transformations that give rise to polyphenols, fatty acids, essential oils, terpenes, tannins etc. (**Kristeva, L.A. [1953])**. Each of these can have perceptible effects on plant metabolism and on the various parameters of the trophic web.

21. Tannins, for instance, that work with proteins to produce the autumn browning of leaves, serve to prevent the leaves from degrading and losing valuable nutrients. On the other hand, only certain bacteria, those usually associated with micro- or mesofauna in the soil, have the enzymatic systems needed to degrade these tannins and thus free proteins and chemical nutrients from them. Here we have an excellent example of nutrients being cycled with the help of lignin derivatives, and yet we are still generally convinced that we need to learn more in order to improve plant nutrition: **what we really need to do is to decode soil nutrition and the factors responsible for distributing energy and nutrients.**

22. Virtually all the scientific literature to date has confined itself to treating the evolution of lignin and cellulose solely in terms of wood degradation. This narrow approach severely hampered our attempts to understand the dynamics of soil generation. Yet it did not shake our belief that we were on a very promising path towards achieving an understanding of the results of a series of experiments conducted between 1978 and 1986, which were at that time still inexplicable. **(Guay, E., Lachance, L., & Lapointe, R.A. [1982], Lemieux, G. & Lapointe, R.A. [1085], Lemieux, G. & Lapointe, R.A. [1989], Lemieux, G. & Lapointe, R.A. [1990], Lamieux, G. & Toutain, F. [1992].)**

IV - Stem wood and ramial wood

1. Stem wood and its lignin

23. In order to understand the mechanisms involved in the formation of fertile soil, we first had to recognize the difference between the wood from the stem or trunk of trees, and that from the branches. We concluded that it was the lack of nutrients in stem wood that made such wood resistant to degradation, a characteristic that protects the life of the tree, and allows certain kinds of *Sequoia* and *Sequoiadendron* to survive for thousands of years. Moreover we realized that the *post mortem* blockage of the degradation of trees, shrubs and monocotyledons can lead to the formation of peat, through the continued accumulation of vegetation matter that is resistant to water-logging and remains perfectly preserved. In both cases, it is the presence of highly polymerized lignin that is responsible for the products that stop depolymerization and keep the structure of wood and ligneous matter from degrading.

24. This high degree of polymerization of lignin, whether of the syringuil or guayacil type, can give rise to the tannins, catechin and catechic acid that are the cause of many problems encountered in using sawdust or wood shavings for improving or rebuilding damaged soil structures. In this case, the ratio of polysaccharides to proteins (the C/N ratio) ranges between 400 and 700/1. In most cases attempts to use such materials for composting have been failures, because of the great amount of nitrogen needed to obtain proper humification. [Losses in bulk and in thermal energy can be as high as 60%.]

25. These stem wood materials, when used as sheet composting or artificial litter, also required much additional nitrogen to trigger humification. This is because depolymerization must be achieved mainly by bacteria that work with a specific enzyme, laccase. It is a slow, costly and uncertain process.

2 - Ramial wood and its lignin

26. The first experiments where we spread and mixed RCWs into the top centimetres of soil have shown positive but rather startling results: while productivity increased, there were major changes in the growth patterns and pathology of common crops. We had to admit that we were facing a phenomenon on which there was no mention in the literature. We could find no description of this part of the tree - its branches - from a biochemical or nutrient viewpoint, and no attempt to relate the different components to each other, even where these were known. **(Lemieux, G. & Lapointe, R.A. [1986]).**

27. Branches of less than 7 cm in diameter1 contain lignin that is little polymerized, or exists in the form of monomers, and also contain relatively little in the way of hard-to-transform polyphenols, resins or essential oils. Field observations and the literature both show that most ruminants will eat ramial wood, but not stem wood. Insects, pathogenic fungi, bacteria and other life will also attack the twigs. The effects of mineral deficiencies in a tree are most likely to appear first on the leaves and young twigs. We concluded that ramial wood is indeed the tree's "factory" for producing wood, lignin, polysaccharides, "oxides"2, and proteins. It therefore represents an important source of nutrients and energy for living things at all levels.

3 - Agricultural and forestry trials using ramial wood

28. In the early 1980s, **Guay, Lachance & Lapointe [1982] p**ublished two technical reports on "The use of ramial wood chips and manure in agriculture", with notes and observations on several agricultural trials using twig chips from city tree prunings. The results they reported on productivity are of special interest.

29. It was as part of a broader search for new, non-traditional wood products that Edgar Guay, Assistant Deputy Minister in the Quebec Department of Forestry, undertook the first experiments on the use of RCW. Noting that millions of tons of twigs and branches of all types are wasted every year, he began to look for new product uses for them. One of the first possibilities he investigated related to the essential oils industry. He noted that existing distillation plants (still in their infancy) were surrounded by piles of unused branch chips, and he wasted no time in analysing their contents.

39. He quickly realized that these branch chips were very rich in chemical nutrients, and also in biochemical products such as proteins and amino acids. Putting aside for the moment the issue of essential oils, he focussed his attention on the possible use of this material as an agricultural mulch, particularly suited to potato growing. The results of his experiments, while modest in scale, were very interesting.

31. This first trial resulted from wide reading in which he learned to combine the American technique of surface or "sheet composting" and the promising methods used by Jean Pain in France for composting scrub and brush. Working directly with farmers, he decided to try spreading RCW on the fields and mixing it into the top centimetres of the soil.

32. Since the literature contained no guides, Guay, Lachance and Lapointe were inclined to view these twigs as just another form of conventional wood, which, as was known, required large quantities of nitrogen in order to decompose. They therefore decided to mix the branch wood chips with pig manure, a well-known source of nitrogen, thus making use of a product that is a major source of ground water and run-off pollution.

33. Results were not long in coming. Odours disappeared, the RCWs were transformed; agricultural productivity rose the next year, and continued to do so for some years longer. The following effects were noted:

An increase of more than 50% in organic soil content

An increase in pH values3

Productivity increases ranging from 30% to 300%, depending on the crop

These productivity increases can be measured in terms of volume or of dry-matter content, as in the case of potatoes4

Reduced water consumption

A major change in the growth and prevalence of weeds5

Major reduction in insects and diseases6

Improved resistance to frost and drought.

34. From our initial review of these results, we concluded that this was clearly an important discovery. It not only promised improvements in productivity, but even more importantly, it seemed to point the way to managing chemical and physical balances through the use of biological controls that we might actually be able to track down.

V - "Organic matter", one of the basic principles in agriculture

35. Since the changes noted in soil colour and structure persisted for many years, we concluded that our experiments had been acting on the mechanisms of pedogenesis, i.e. of soil generation itself, [which are well-known to foresters, but new to agriculture]. It also became clear that there was no scientific Principle underlying the use of traditional inputs, unless it was that of m**ineralization**. We were close to the source of the principles of **humification**, which would lead us into a misunderstood and largely unknown world, to which we could now gain access through the basic concept of forest pedogenesis, combined with a concern for agricultural productivity.

36. Little by little, we came to realize that we might actually be able to gain entry into the biological system controlling soil formation. With the help of RCW, we might be able finally to understand how the hypogeous ecosystem functions, and what is the nature of the biological dynamics that, together with geology, the laws of physics, of mineral and bio-chemistry, reign over this hidden world that is still unknown to us, save from the perspective of chemistry.

37. Up to this point, because people were unable to understand the mechanisms that govern the soil, they have contented themselves with looking at everything from the optic of chemical controls, using fertilizers, soil improvers etc. Pursuing that logic still further, people came to look upon the soil as simply a physical support [for plants], and then to try to eliminate it completely and turn to hydroponic cultures based on fertilizer solutions.

38. From that stage of thinking, it did not take long to the next step of regarding and measuring *"organic matter"* in the soil as merely a transition stage towards the release of chemical substances that would promote plant growth. This notion thus treated "o*rganic material*" as a chemical input that could also be used to maintain certain physical parameters - controlling soil atmosphere, eliminating the gasses produced by microbiological activity, and in general dealing with symptoms of **degradation**. And in this context, only fertilizers, particularly nitrogen, were given serious thought.

39. We were eventually able to formulate a third hypothesis: (3) *The RCW concept could be a valuable tool for studying and understanding soil formation and its dynamics, by which we mean above all the distribution of chemical nutrients essential for plant growth*.. It took us a good ten years before we began to understand the ins and outs of these mechanisms, and how they appear and disappear. Although there were several major works on the biological mechanisms related to nutrients published in the preceding ten years, the first comprehensive approach was that of **Perry, Amaranthus, Borchers and Borchers, & Brainerd,** in 1989. This important work from the Corvallis team in Oregon State University tackled various biological levels, focusing its experiments and research on mycorrhizae and their effects.

40. The Corvallis team's work, remarkable though it is, was aimed primarily at trying to explain things at a single level - life itself - which it viewed in terms of the competition and complementarity that were common characteristics of attempts at understanding our world at that time. With RCW, we were able to turn our attention to other levels, in both forestry and agriculture, and we were determined to enter into this complex world of the soil, so vital to our economy. It governs nutrients, but also shelters an incredible diversity of life forms, from viruses to highly-evolved mammals. It is also the "banker", the "manager" and the "motor" of terrestrial life. The same goes for all the chemical and biochemical nutrients that result from the synthesis and retrosynthesis7 of compounds, most often derived from lignin and the great variety of polyphenols, which we know as humus, humin, humates, humic and fulvic acids.

1 - Some a posteriori thoughts

41. Any explanations of the above-cited observations and measurements will have to be looked for at various levels, and from various optics. The results and implications are so numerous that they must be somehow linked in their fundamentals, whether physical, chemical or biological. Paradoxically, wherever there is a coherent set of data, there must also be an incoherent side, or else we would have a rigid system that always produces the same results. If we are to pose worthwhile working hypotheses, we must take into account both sides of the coin.

42. Our many meetings and discussions around the world, and our readings into the question, have convinced us that we are entering uncharted territory when we approach pedogenesis from a forestry optic. Moreover, our forestry experiments and their results suggest that the application of RCW has a major influence on ecosystem behaviour, in particular on plant germination and competition.

2 - The rationale for chipping

43. It has long been recognized that returning tree branches and leaves to the soil was beneficial, but there was little attempt to actually measure these benefits. In fact, most people did not worry about the issue at all, and were simply glad to see the "trash" disposed of. As proof of this, look at how branches are regularly shipped out of the forest when it is cut down for some other, more profitable use (**Freedman, B. [1990] in Lemieux, G. [1991]).** The chipping of branches was first done as a pure necessity to allow the soil to be tilled and worked. But as we came to understand the mechanisms in play, we have come to regard the practice rather differently - as akin to the way animals chew their food to promote more effective enzyme action.

3 - More like a food than a fertilizer.

44. The notion of food implies two aspects: its energy content, which a system needs to function, and its chemical components (fertilizers) and their biochemical intermediaries (proteins, amino acids, sugars, cellulose, etc.). Early on, man derived the traditional concepts that led to mineralization, i.e. separating the energy from the nutrient components. Man then made a practice of processing organic matter, whether of animal or plant origin, by means of composting, in which the energy and nutrient components were separated by bacterial fermentation and thermophilic fungi, whereby the thermal energy was dissipated and the nutrients and organic residues were recovered, mainly as degraded lignins and polyphenol by-products. Although this is a form of enzymatic combustion, it has many analogies to combustion by fire at high temperatures (**Kirk, T.K. & Farrell, R.L. [1987]).**

4 - The principles behind chipping

45. Although the effectiveness of transforming RCW was becoming crystal clear, the underlying principles continued to elude us. It was only in 1989 that we discovered for the first time the mechanisms that allow the release of energy while conserving important parts of the lignin, i.e. the high-energy aromatic rings.

46. In the early 1980s, various important works were published in America, Asia and Europe dealing with lignin, its structure and its degradation by enzyme action. The major works are those of **Kirk, T.K. & Fenn, P. [1982), Tien, M. & Kirk, T.K. [1983], Kirk, T.K. & Farrell (1983), Lewis, N,G,, Razal, R.A. & Yamamoto [1987], Leisola, M. & Waldner, R. [1988], Leisola, M. & Garcia, S. [1989], and Leatham, G.F. & Kirk [1982]. But we wer**e struck by the fact that all this research was directed exclusively towards achieving the kind of understanding of mechanisms and degradation processes that would be useful in eliminating lignin, as one of the major pollutants in the pulp and paper industry. This "negative" approach to understanding lignin had its use, of course, and was to be expected, given the mentality of our industrial society which uses its capital to promote its own growth, and ignores anything that threatens profit margins.

47. The key work in enhancing our understanding was that of Leisola (Finnish) and Garcia (French), in 1989. They explained the enzymatic mechanism responsible for the depolymerization of lignin., in terms of the production of two macro-molecules: one with a low molecular weight, related to fulvic acid, and the other with a higher weight, now known to be humic acid. More interesting still, they showed that under the action of a specific enzyme (manganese-dependent lignoperoxydase) the larger molecule would be attracted and become fixed to the mycelium of a Basidiomycetic fungus (*Chrysosporium phanerochaete)*, and would thereby be prevented from recombining with the fulvic molecule. This typically produces stable compounds with the antibiotic and other properties of the polyphenol group. The fixing of the macromolecule on the mycelium lends a brownish colour to its surroundings that is characteristic of brown soils. This change in soil colouration has been noted frequently when RCWs are applied in agriculture.

48. Many studies have examined the behaviour of enzymatic systems in the degradation of lignin. Some of these are: **Dordick, J.S., Marlette, M.A. & Kilbanov, A.M. [1986], Erickson, K.E.L., Blanchette, R.A. & Ander, P. [1990], Garcia, S. , Latge, J.P., Prévost, M.C. & Leisola, M.S. [1987], Jones, A. & O'Carroll, L. [1989].**

49. These publications all added to our understanding of the fact that Basidiomycetes - which is singularly absent from agricultural soils - plays a significant role in forest soils. Many authors refer to Basidiomycetes as "*white rot fungi"*, a term that still harks back to the "degrading" function of these organisms. Several studies also examine the role of Basidiomycetes from the mycorrhizal perspective: Amaranthus, M.P. **& Perry, D.A. [1987], Amaranthus, M.P., Li, C.Y. & Perry, D.A. [1987], Hintikka, V. [1982], Kirk, T.K. & Fenn, P. [1982], Perry, D.A., Amaranthus, M.P., Borchers, J.G., Borchers, S.L. & Brainerd, R.E. [1989]. Muc**h valuable information on the role of Basidiomycetes in soil structure, viewed once again from the degradation perspective, is found in: **Erikson, K.E.I., Blanchette, R.A. & Ander, P. [1990], Hintikka, V. [1982], Kirk, T.K. & Fenn, P. [1982], Levy, J.F., Rayner, A.D.M. & Boddy, L. [1988], Tate, R.L. [1987], Vaughan, D. & Ord, B.G. [1985].**

50. From all these authors, we learned a great deal about recent research efforts to understand the degradation of wood, by itself or within the forest ecosystem context. Once we delved into the concept of "*organic matter"* and the beneficial role it plays in agriculture, however, we found that the relationship between lignin and fertility was lost sight of, in favour of the concept of yearly fertility as measured by yields, with other parameters relegated to subsidiary status. Clearly, the notion of *"organic matter"*, which had been transferred without any modification from the agricultural domain to forestry, represented something of a barrier that we would have to surmount if we were going to understand what we had been observing.

51. In this way, we became interested in the relationships between different forms of life, in particular microfauna, and in the effects noted by various authors. These life forms seemed increasingly to go to the heart of the question that we were pursuing. The further we explored into the subject, the clearer it became that the role of fungi - however important that might be - was not enough to explain the dynamics of soil formation nor the cycling of nutrients. There must be some involvement by other levels of life in the formation of what we now call the *trophic web*, where all levels of life take part in the vital process of storing and releasing energy, and making available nutrients of chemical, mineral and biochemical origin.

52. We are indebted on this score in particular to: **Anderson, J.M. [1988], Anderson, J.M., Coleman, D.C. & Cole, C.V. [1981], Bachelier, G. [1978], Breznak, J.A. [1982], Larochelle, L. [1993], Larochelle, L., Pagé, F., Beauchamp, C. & Lemieux, G. [1993], Pagé, F. [1993], Parkinson, D. [1988], Sauvesty, A., Pagé, F. & Giroux [1993], Swift, M.J. [1976], Swift, M.J., Heal, O.W. & Anderson, J.M. [1979], Toutain, F. [1993]. These** authors all approach the question from the same dynamic: predation and energy transfer from one level to another, and their inevitable relationship to the transfer of nutrients. And yet, none of these authors has approached the question of energy mechanisms, apart from those already known, such as the transformation of adenosin triphosphate into adenosin diphosphate, where glucose is used as an energy source to release considerable energy.

VI - Lignin

53. As we pointed out earlier, branch wood has never been considered as a useful material, and has never been scientifically described. The presence of lignin in monomer form has thus never been examined in terms of its energy function. Several authors however have alluded to the complexity of this macromolecule, and have suspected that it may play an important role in the formation of humus

and also of certain undesirable polyphenol compounds: **Dordick, J.S., Marlette, M.A. & Kilbanov, A.M. [1986], Erikson, K.E.L., Blanchette, R.A. & Ander, P. [1990], Garcia, S., Latge, L.P., Prévost, M.C. & Leisola, M.S.A. [1987], Glenn, J.K., and Gold, M.H., [1985], Jones, A. & O'Carroll, L. [1989], Kirk, T.K. & Farrell, R.L. [1987], Leatham, G.F. & Kirk, T.K. [1982], Kirk, T.K. & Fenn, P. [1982], Leisola, M.S.A. & Waldner, R. [1988], Leisola, M.S.A. & Garcia, S. [1989], Lewis, N.G., Razal, R.A. & Yamamoto, E. [1987], Rayner, A.D.M. & Boddy, :. [1988], Stott, D.E., Kassim, Jarrell, J.P., Martin, M. & Haider, K. [1993], Tate, R.L. [1987], Vaughan, D. & Ors, B.G. [1985], and Vicuna, R. [1988] .**

54. These authors discuss various aspects of the structure of lignin and the importance of its methoxyl groupings, depending on the origin of the lignin; they examine the "fragility" and the "digestibility" of lignin when it is slightly polymerized, and the ease with which it can be depolymerized. This was where we first realized the importance of young lignin as a source of energy, not only after the cellulose has been transferred, but through the use as well of the considerable energy held in the aromatic rings, of which some are reserved for constituting humus. Lignin must then play a double role - as an energy source, and as a builder of the soil, which is the centre for regulating and governing life itself and the nutrients as they are cycled.

55. This then is where we must look to find the blockages that lead to the ever lower fertility levels that have been noted to occur even where there are ample essential nutrients for the growth of plants in the hypogeous ecosystem. We shall not attempt here to discuss the various routes that nutrients must take to become available in "proper order" for the support of plant life. We may cite earthworms as one example - these work together with the bacterial colonies inside their digestive tracts to attack the brown pigments of leaves. These brown pigments are formed by the association of a polyphenol (tannins) with proteins that prevent nutrient degradation **(Toutain, F. [1993])**. A similar process occurs in the relationship between Basidiomycetes and various species of acarians and collembola in cycling nutrients, whose mastication results in increasing fragmentation and opens the way to attack by enzymes or bacteria **(Swift, M.J. [1977], Larochelle, L, Pagé, F., Beauchamp, C. & Lemieux, G. [1993]).**

1 - The nutrients question

56. This question has traditionally been posed in rather simplistic terms, by ranking the elements from Mendeleyeff's periodic table according to their contribution in producing crops at the lowest possible cost. Three elements come out on top: nitrogen, phosphorus and potassium, to which we may add other elements such as iron, silicon and the entire group known as trace elements. This classification into *major elements* and *trace elements* is typical of the "industrial" perspective with which science approaches agricultural productivity, and which over the years has come to dominate the forestry vocabulary as well.

57. It is rather strange that man has persisted in looking at plant growth solely in terms of the mineral salts that promote it. The limitations to this output-oriented perspective are now clear enough, when we consider the effects of soil erosion, and the constant arrival of new parasites, and of fungal, bacterial or viral diseases. Our societies now spend enormous resources in trying to control such pests.

58. As several authors have shown **(Amaranthus, M.P. & Perry, D.A. [1987], Amaranthus, M.P. & Perry, D.A. [1988], Bormann, F.H., & Likens, G.E. [1979], Flaig, W. [1972], Gosz, J.R. & Fischer, F.M. [1984], Gosz, J.R., Holmes, R.T., Likens, G.E. & Bormann, F.H. [1978], Martin, W.C., Pierce, R.S., Likens, G.E. & Bormann, F.H. [1986]), it is** possible to make major changes in ecosystem behaviour by varying those biological factors that have an impact on nutrients, or rather on their form, where the physical and chemical repercussions may be imponderable.

59. We conclude from this that there is a direct relationship between biological parameters and the availability of nutrients. We already know what the chemical and physical relationships are - but we have only a vague understanding of the chemical and biochemical ones, and of the energy transfer mechanisms involved.

60 The startling discoveries that have been made in the tropics, where the presence of a rainforest canopy is always associated with relatively poor soils, have opened the door to some fundamental new understanding. Those discoveries suggest that ecosystem life structures rely solely on mechanisms that are dependent on the forest, and by extension, on the trees themselves. This may well explain why it is so difficult in Africa now to produce enough food to sustain a decent and stable standard of living.

2 - The biological cycle in tropical waters

61. We will now pose our fourth hypothesis: (4) ***The hypogeous ecosystem, i.e. the living soil, has been able to overcome climatic problems in the tropics by creating a network of multiple life forms, whereby plants can recover nutrients without need of the chemical fertilizers so widely used in temperate-zone agriculture. This fact could be particularly important for water management, since water could act as a nutrient if it were not sensitive to osmotic pressure from salt soil solution .*** Preliminary observations in Quebec and in Senegal show higher yields and lower water consumption. Our hypothesis must rest for now on such observations, since although we have been able to achieve such results repeatedly, we cannot find any convincing explanation in the literature.

3 - "Chemical" nutrients

62. When it comes to nutrients, at least as regards nitrogen, phosphorus, potassium and magnesium, we observed no shortages [in our treated soils] - indeed, we noted increased reserves, particularly of phosphorus.

4 - Nitrogen

63. At the outset, we took it for granted that the nitrogen found in the soil was the direct result of the degradation of proteins and the microbial biomass. Yet, since plants showed no evidence of nitrogen shortages even after three years, we were forced to look for a reason. Along with many authors, we came to the conclusion that the mechanisms at play were of forest origin, mainly from non-symbiotic nitrogen fixation through a variety of bacteria in the rhizosphere. See the following authors: D**ommergues, Y & Bauzon, D. [1975], Rouquero, T., Bauzon, D. & Dommergues, Y. [1975], Thomas-Bauzon, D., Weinhard, P., Villecourt, P & Balandreau, J. [1979], Thomas-Bauzon, D., Weinhard, P, Villecourt, P & Balandreau, J. [1982], Thomas-Bauzon, Kiffer, E., Pizelle, G. & Petitdemange, E. [1990], Thomas-Bauzon, D. Kiffer, E., Janin, G., & Toutain, F. [1995], Parkinson, D. [1988], Stott, D.E., Kassim, G., Jarrell, M., Martin, J.P. & Haider, K. [1993], Swift, M.J. [1976], Tate, R.L. [1987], Vaughan, D. & Ord, B.G. [1985].**

64. In general, it appeared that nitrogen fixation depends on a group of bacteria whose active enzyme contains iron as the central element, similar to the structure of haemoglobin. As distinct from the leguminous *Rhizobium*, this would explain why nitrogen is so abundant in forest soils, and in those we treated with RCW. On this basis, we pose the following hypothesis: ***(5) The nitrogen cycle is fed primarily by the microbial fixation of N2, and secondarily by the action of fungi and mycorrhizae,***

in soils treated with RCW.

5 - Phosphorus

65. This element has always been a problem in plant nutrition, because of its fleeting availability. It can be immobilized by iron under acidic conditions, and by calcium under alkaline conditions, thus making it almost impossible for it to become part of the soil solution. And yet it is a vital element that is volatile only under agricultural conditions. There is no lack of phosphorus in forest soils. We know that a particular enzyme, alkaline phosphatase, can "flush out" this element, which is essential for the transfer of energy to support plant growth. We also know that proper mycorrhization increases the availability of phosphorus (**Rouquerol, T., Bauzon, D. & Dommergues, Y. [1975]**).

66. Some unpublished studies show that alkaline phosphatase increases with the growth of the microbial biomass in agricultural soils treated with RCW. Another study, dealing with research on the enzymes available in RCW, shows remarkable amounts of both alkaline and acidic phosphatase in the branches of the red oak, *Quercus rubra,* which is one of the most promising species in our climate. It is too soon to draw any conclusions about the presence of these and other enzymes, such as lipase, but we expect to be able to publish our results shortly, and thus open a new avenue of approach to the multiple processes involved in soil generation. I have not done as thorough a search of the bibliography here as I did for nitrogen, but can note the following authors: **Flaig, W. [1972], Ratnayake, M., Leonard, R.T. & Menge, J.A. [1978], Swift, M.J., Heal, O.W. & Anderson, J.M. [1979], Vaughan, D. & Ord, B.G. [1985]. We ca**n now pose another hypothesis: (6) ***RCW contributes to the soil not only nutrients, but also a number of mechanisms that regulate their synthesis or release*** 8.

67. The results of both forest and agricultural experiments led us to explore the impact [of RCWs] on nutrition, while recognizing that there could be no comprehensive answer, and that no conclusions could be drawn from a qualitative and quantitative description, however refined. Our preliminary experimental results have merely set us at the beginning of a road little travelled in the current literature. We may cite here the major works in the field of RCW experimentation: **Beauchamp, C. [1993], Guay, E., Lachance, L. & Lapointe, R.A. [1982], Larochelle, L., Pagé, F., Beauchamp, C. & Lemieux, G. [1993], Lemieux, G. & Lapointe, R.A. [1985], Lemieux, G. & Lapointe, M. [1993], Pagé, F. [1993], Seck, M.A. [1993], Seck, M.A. in Lemieux G. [1994], Toutain, F. [1993], Tremblay, Y [1985]. These** publications, which have appeared over the last ten years, have so far attracted only a limited degree of curiosity, and that only from the traditional viewpoint of those interested in empirically proven agricultural techniques for extracting nutrients from crop wastes.

68. We thus found ourselves compelled to undertake a broad survey in order to understand why more scientific attention was not being paid to our discoveries, disturbing as they might be from the economic and technical point of view.

VII - A tentative theory

1 - Too much or too little water

69. After obtaining repeat results from our research over a number of years, we began to regard RCWs as a "food", identifiable in its own right, that acts on the organomineral complex through depolymerization, retrosynthesis, degradation and enzymatic combustion. Water is the key factor in this system. Since it is almost impossible for lignin to depolymerize in water, i.e. without oxygen, water may well be the key blocking mechanism that we have observed at work, both in agriculture

and in forestry. The best yields are always obtained on soils that are well drained, but not too dry..

70. The gradual evolution of lignin will produce tannins and other polyphenols in plant tissues as they accumulate and turn into peat that, in turn, will last for thousands of years. On the other hand, if water is in short supply and plant tissues are prevented from evolving, they will tend to build up on the surface, with frequently high concentrations of polyphenolic compounds synthesized by the plants themselves (Dicotyledons are an example of this). This is often the case under temperate climatic conditions, where the geological structure is highly porous or its slope is very steep. The situation is different in the tropics, where water availability depends more directly on the pattern of rainfall.

71. An even but deficient distribution of rainfall on sedimentary rock formations rich in calcium will promote the profusion of Monocotyledons in deep black soils. But because such soils lack a real structure, they will become unstable in the presence of excessive water. On the other hand, when rainfall is scarce, these soils are very likely to suffer from wind erosion, as has happened many times on the North American prairie.

2 - The soil-structuring role of lignin

72. In this last case, soil instability is likely to be the direct result of the structure of the lignin itself, and the methoxyl groupings it may contain. At the same time, such soils are often well-suited to large-scale Monocotyledonous crops, although their yields tend to be low. Mechanized working of these soils tends to do damage to their structure and to speed up their metabolization, unless losses can be replaced.

73. We now propose the following hypothesis :(7) ***The origin of the lignin, and the positioning and number of methoxyl groups within it, may play an important role in the structure of the soil, depending on the ground water system and rainfall patterns***.

3 - The role of the trophic web

74. If the hypothesis we are putting forward could be verified, we would have a full-fledged explanation of why the vegetation in tropical climates is so fragile, especially under Sahelian conditions. Competition to find water may be due to the collapse of the living telluric systems, where water behaves just as other nutrients, provided that it is protected from the constraints, both chemical and biological, imposed on the soil by high daytime temperatures. This might be the answer to our observations that where the biological system is in active equilibrium, yields are higher and less water is required to support growth. These observations are valid for both temperate and tropical climates.

75. These observations allow us to formulate a further hypothesis that may shed new light on the interpretation of our results: ***(8) Biodiversity and the health of the soil are the prime factors in the conservation and use of the water that is stored and available within biological systems, by protecting it from the soil's own chemical cycles.***

4 Living beyond the soil's chemical constraints

76. We think this is a highly plausible hypothesis, in light of the ability that the forest has developed

over millions of years to short-circuit the harmful and destructive effects of chemicals produced by vegetation in the hypogeous ecosystem. This would provide a logical explanation for the degradation of soils that were at one time dependent on the biodiversity nurtured and sustained by the forest, and which, once that forest had disappeared, were no longer sufficiently nourished to be productive. From this perspective, the soil becomes the very centre of life, by storing, releasing and managing the availability of the nutrients "demanded" by the plants themselves.

77. For this kind of management to happen there must be a very stable source of energy, a source that is highly diversified and contains substances that are compatible with the system itself. Such a broad diversity is found only in branch or ramial wood, whereas stem wood is deficient in many respects, and moreover contains lignin that is highly polymerized. The most useable sources are the aminoacids and proteins, along with the sugars. Next as sources of energy come cellulose, hemicellulose, and finally lignin and its derivatives.

78. There we have a list of "edible" energy products that can be used in whole or in part by the different trophic levels, and so allow different types of life to grow, flourish and reproduce. Besides its role in the energy chain, lignin is also one of the most important influences in the physical constitution of the soil, through its ability to reduce and concentrate aromatic rings, which, as they become humic acid, represent the very basis of soil structure. It is lignin and its derivatives, together with iron chelation and aggregate formation, that are responsible for this relationship between nutrients and the mineral content of the soil.

79. These soil aggregates play a key role in soil fertility. Indeed they constitute the very basis of the soil's structure, its atmosphere etc., and are at the same time a potential source of food for microorganisms. They will therefore have a rather short life, and must be continuously replenished. They also give shelter to microorganisms such as bacteria and various encysted life forms, while serving as a source of energy and nutrients.

5 The major cause of tropical soils degradation

80 Since we need to be able to interpretation our measurements and observations, we have opted for a forestry-science approach to interpreting our findings. We do so with the following hypothesis: (9) ***RCWs can be a source of nutrients and energy, with lignin as the principal factor for stability and soil control, provided that the lignin is in the form of oligomers that can be readily depolymerized by Basidiomycetes. The fractional elements so obtained can be easily utilized by biological systems, or they can be retrosynthesized, or turned into humus, which is the basis for managing the soil's fertility, its nutrients and its reserves of energy.***

81. Seen from this standpoint, it is a major catastrophe when the forest ecosystem and all those mechanisms that depend on lignin and its transformation disappear. [When forests are destroyed to make way for agriculture, the immediate and inevitable result is] loss of soil and dramatic drops in yields. Mineral fertilizers are no help in this case - on the contrary they force yields even lower. In this respect, cultivation methods imported from northern countries must be viewed as a man-made disaster, which everyone denounces, but no one has any solutions for.

82. We now pose the following hypothesis: (10) Sin***ce the forest was the source of the mechanisms responsible for soil fertility all over the world, the disappearance of the forest will lead, over the short, medium or long term, to a drop in fertility and productivity. And, if chemicals are used as fertilizers, the soil structure will collapse, food shortages will arise, and parasites and disease will appear.***

83. The problem of soil degradation goes beyond the availability of nutrients. When tropical soils are

degraded, they lose the endogenous energy needed to regulate the flow of nutrients and water. In tropical climates, nutrients are generally stored in the branches of trees, rather than in the soil itself. All attempts to compensate by using chemical fertilizers on soil deprived of its energy are doomed to failure, as recent experience in Africa has shown.

6 The basics of forest ecosystem functioning

84. As we improve our understanding of the mechanisms responsible for life and fertility, we can begin to distinguish the different roles more clearly. It becomes obvious that, everywhere and at all times, for any forest ecosystem the key factors are the biological, chemical and biochemical equilibrium of its soil. My initial reference to the long-ago origins of the forest was meant to reinforce the idea that all the mechanisms involved have been around for hundreds of millions of years. The fact that we humans have never taken proper care of them says a lot about how anthropocentric we are.

85. The description we have presented applies to all forest ecosystems, but it is those within the tropics that are the most interdependent and sophisticated, thanks to the prevailing high temperatures or the lack of variation in temperature and water conditions. In our view, energy is at the core problem, in the sense of energy as an "ingestible", in other words where exogenous energy is introduced into living organisms along with biochemical nutrients (sugars, fats, oils etc.),which are themselves endogenous carriers of energy.

86. Thus, between 70% and 80% of the endogenous energy produced by a tree is sent directly into the soil ecosystem, leaving only 20% or 30% to support the production of plant tissues such as wood (Fogel, **R, & Hunt G, [1983], Meyer, J.R. & Linderman, R.G. [1986], Rambelli, A.[1983], 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]). In the** case of grasses, only 10% to 40% of total energy is directed to the hypogeous ecosystem.

87. Thus, endogenous energy is directed toward the hypogeous ecosystem (the soil) by way of the roots, where mycorrhizae, besides being major consumers themselves, play a key role in carrying nutrients from the soil to the plant and returning to the soil the energy it needs. It is through their relationship with fungi, most commonly the Basidiomycetes, that plants are able to draw most of their nutritional benefits from the soil. **(Allen, T.F.H. & Starr, T.B. [1982], Amaranthus, M.P., Li, C.Y. & Perry, D.A. [1987], Amaranthus, M.P. & Perry, D.A. [1987], Anderson, J.M., Huish, S.A., Ineson, P., Leonard, M.A. & Splatt, P.R. [1985], Borchers, S. & Perry, D.A. [1987], Clarholm, M. [1985], Coleman, D.C. [1985], Fogel, R. & Hunt, G. [1983], Hogberg, P. & Piearce, G.D. [1986], Ingham, R.E., Troffymow, J.A., Ingham, E.R. & Coleman D.C. [1985], Janos, D.P. [1980], Lynch, J.M. & Bragg, E. [1985], Malloch, D.W., Pirozynski, K.A. & Raven, P.H. [1980], Meyer, F.H. [1985], Meyer, J.R. & Linderman, R.G. [1986], Olsen, R.A., Clark, R.B. & Bennet, J.H. [1981], Perry, D.A., Molina, R. & Amaranthus M.P. [1987], Rambelli, A. [1973], Reeves, F. B., Wagner, D., Moorman, T. & Kiel, J. [1979], StJohn, T.V. & Coleman D.C. [1982], Trappe, J.M. [1962], Vogt, K.A., Grier, C.C., & Meier C.E. [l982, Whipps, J.M. & Lynch [1986]**.

88. On many occasions we have referred to the importance of lignin in the constitution of the soil and in nutrient management at various trophic levels. In Dicotyledonous forests there are two regular sources of lignin supply: the first is the continuous shedding of various plant tissues from the canopy, such as leaves, fruits, twigs, etc. that fall on the ground. The second one, perhaps more important and yet invisible, is the very small rootlets that are constantly being metabolized. They are rich in unpolymerized lignin and are palatable to microfauna. In sugar maple stands we have estimated the annual production per hectare of biomass in the form of such rootlets at between 2 and

3 tons every year **(Pagé, F. [1993])**.

7 The role of ramial wood in pedogenesis

89. Research in both agricultural and forest settings has produced results that have been subsequently verified: **(Aman, S., Despatie, S., Furlan, V. & Lemieux, G. [1996]), (Beauchamp. C. [1993]), (Guay, E., Lachance, L, & Lapointe R.A. [1982]), (Lemieux, G. & Lapointe, R.A. [1985]), (Lemieux, G. & Lapointe, R.A. [1986]), (Lemieux, G, & Lapointe, R.A. [1988]), (Lemieux, G. & Lapointe R.A. [1989]), (Lemieux, G. & Lapointe, R.A. [1990]), (Lemieux, G. & Tétreault, J.P. [1993]), (Lemieux, G. & Toutain, F. [1992]), (Lemieux, G. [1995]), (Seck, M. A. [1993]). After checking** for repeatability, which showed some variations depending on annual fluctuations of the natural environment, the results were generally found to be positive. Where failures were recorded, we were able to trace these back to some error and propose a satisfactory explanation that would confirm the basic principles

90. We can now put forward the following hypothesis: (1***1) Ramial chipped wood, when exposed to attack by Basidiomycetes, can replace all biological functions that require chemical and biochemical nutrients. RCW also contains the energy needed to support the processes and to provide a margin for the demands of entropy. The energy released covers the electromagnetic spectrum, wholly or in part, - The second law of thermodynamics: entropy and soil biology.***

8- *The second law of thermodynamics: entropy and soil biology.*

91. Many of our observations on the energy aspects of soil biology have as yet found no echo in the recent literature. We have always been struck by the low productivity of tropical areas, where soils are degraded, and that of subarctic zones, where in contrast plant tissues accumulate from year to year, but cannot evolve and so remain unproductive.

92. The rapid transformation of RCWs under tropical conditions and the stagnation of plant tissues in the Arctic both seem to represent problems with the distribution of exogenous, i.e. solar energy. In both cases, the soil is unable to meet the demands of entropy by radiating energy. This reasoning leads us straight to the heart of the energy question, about which our understanding is now rapidly increasing as a result of discoveries in astronomy. Better knowledge of the subject is the key to better understanding. Thus, the constitution of the universe and the relationship among all its components in the form of a continuum covers the entirety of the electromagnetic spectrum, from quarks to molecules to living organisms. We can see this progress by looking at macromolecules, viruses, cells, tissues and species, where the most highly evolved are the least numerous. (**Reeves, H. [1992], Prigogine, I. and Stengers, I. [1984).**

93 No one would deny that one of the features that distinguishes life from death is the radiation of heat. This phenomenon requires the presence of an endogenous energy source that can only manifest itself in the presence of the necessary amount of exogenous energy (ambient temperature).

94 Endogenous energy, far more than the amount of fertilizers that may be applied, is the determining factor in the fertility of any soil. Yet, the behaviour of polyphenol compounds can block this energy, and destroy the soil's fertility, even when exogenous energy is plentiful. This is what happens with organic soils in the Arctic, which are handicapped both by their lack of exogenous energy and by the polyphenols and tannins that result from natural evolution.

95 Under tropical conditions soil degradation can be seen as a resulting from lack of available endogenous energy, due to an over-abundance of exogenous energy, which forces the ecosystem's metabolism to consume everything at once, leaving very little room for any but inactive and

unproductive forms of life.

96. The tropical forest alone has developed the tools to overcome the soil's metabolic hyperactivity by limiting access to biochemical nutrients, and to endogenous energy at the same time, which would otherwise benefit the hypogeous ecosystem to the prejudice of epigeous. From this viewpoint, the constant accumulation of fallen plant tissues rich in nutrients and lignin, most of which is released into the soil, and the transformation of the lignin by the root system, allow the necessary energy to be supplied to the soil. Since metabolism is very rapid under such conditions, the nutrient "reservoir" becomes the tree itself, which allows for only a limited but active development of life in the hypogeous ecosystem.

97. Under these circumstances, the demands of entropy must be met by the trees, and then by the soil in general. It then becomes clear why the industrial exploitation and destruction of the forest's trees can be a catastrophe, leaving behind only poor soils with very limited agricultural fertility, as is the case in Africa today.

98. We now pose the following hypothesis: (1***2) By providing access to various nutrients, RCW brings with it the endogenous energy needed to meet the inevitable demands of entropy. It also contributes the enzymatic mechanisms needed to synthesize those nutrients or make them accessible .***

9 Nutritional features of RCWs

99. This hypothesis implies that RCWs must be perceived first of all as a complete "food", in which both nutrients and energy are intimately linked together. In putting forward such an idea we are quite aware that it runs counter to the conventional wisdom that has allowed agriculture to make unheard-of productivity gains. We are also aware of the fact that we cannot change over-night the basic industrial concepts underlying man's life on earth. Yet we are also convinced that this hypothesis can, and must, lead to profound changes to the ecology and economy of a great many countries, especially those in the tropics.

100. The ability of RCWs to effect major modifications in agriculture, through raising productivity, is put forward here by analogy to a multifaceted "food", which in turn gives the soil its living character. In the soil, life is highly diversified and interwoven, comprising every possible level, each of which is dependant on the others. Here life and death alike are closely bound up with the chemical nutrient system, the structure of which will be determined in large part by the evolution of lignin and polyphenol compounds.

101. Moreover we must recognize that a large number of physicochemical, chemical and biochemical mechanisms underlie these equilibria. We may mention the chelation of heavy metals such as iron, the regulation of the dissociation between hydrogen and hydroxyl ions, or the production of protein systems: these are always reversible, with enzymes working in the presence of nitrogen and phosphorus inputs. These reversible mechanisms form the very basis of soil regulation, but they are not the only ones. There is another regulating mechanism where life itself takes over, releasing the energy accumulated within its own biomass, and providing numerous supplementary elements that in turn are also reversible, creating a structure or controlled atmosphere that contains many biological inhibition factors of the polyphenol type.

***10** - Pedogenesis under the Gymnosperm canopy.*

102. This reversibility of "intimate pedogenesis phenomena" is the essence of life itself, where nutrients are linked to energy, which can be released again through biological degradation. There are many questions that can be asked about the quality of such "food", and the extent to which it is homogeneous or richly diverse. We have noticed a large variety of behaviour in the species used for the production of RCWs. The first point concerns conifers and hardwood trees, and relates to the efficiency of soil transformation: conifers cause blockages that prevent soil structures from evolving and inhibit the growth and germination of plants. Gymnosperms would seem in fact to have developed a restrictive system for eliminating their competition, based largely on the inhibiting effects of polyphenol compounds. Here, the lignin structure is asymmetric, with only one methoxyl group. This gives rise to many polyphenolic compounds, such as aliphatic acids, terpenes, resins, etc. that render ineffective any lipases that may be present. Many families of plants among the Angiosperms, such as Umbelliferae and Labiatae, still retain some Gymnosperm characteristics. This is also true of the Australian Eucalyptus: the devastating manner in which it excludes all competition makes this species undesirable as an alternative crop to agriculture.

11 Pedogenesis in the Dicotyledonous Angiosperm forest

103. Hardwood species on the other hand seem to depend on a completely opposite system, by accepting and nurturing all types of species and making them compatible with each other. This is a strategy based on biodiversity and complementarity, but the various species are far from being equal. There is a great deal of work to be done in order to identify and understand the activities that take place within pedogenetic mechanisms. Our experiments with tree germination over a period of five years (**Lemieux, G. & Lapointe, R.A. [1989]**) proved this point clearly. The same can be said of the Ivory Coast's experiments on maize **(Aman, S., Despatie S., Furlan, V. & Lemieux, G. [1996]**), where a systematic comparison of yields for four different species showed wide variations. Similar results were recorded in Ziguinchor, in southern Casamance region of Senegal, where specific effects were noted with *Acacia mangium*, *Guiera senegalensis* and *Combretum micranthum* (**Lemieux, G. [1994]).**

104. These two approaches to managing competition, the one seemingly archaic and the other more "modern", have suggested to us the following hypothesis: (13) ***The structure of lignin and its transformation throughout the pedogenetic process can be taken as directly responsible for the form of competition within ecosystems, due to the way it evolves within the soil, and its effects on the control of chemical and biochemical nutrients.***

12 Origin and distribution of soils suitable for agriculture

105 This hypothesis is related to another one, to be presented later, as regards the evolution of agriculture. Recent observations in the Dominican Republic (**Lemieux, G., Marcano, J. & Gonzalez A.[1994])** show that even under tropical conditions, the soils of conifer forests *(Pinus occidentalis)* are no more suitable for agricultural purposes than they are in temperate climates. We had always assumed that coniferous forest soils were rendered unsuitable for agriculture by factors such as excessive precipitation, the number of frost-free days, excessively high or low pH values, poor soil structure, too porous a parent rock structure, etc. We now believe that, no matter how real these criteria may be, the true explanation has to do with the type of pedogenesis that promotes polyphenolic soils, and thus effectively eliminates all competition, leaving only a few specially adapted species to grow in large concentrations.

106. These remarks and observations open the way to another hypothesis that would confirm the influence of lignin type on pedogenetic mechanisms A survey of the development history of

agriculture-based settlements shows that it was the use and transformation of hardwood forest soils that originally made agriculture possible, and that thus led to the gradual accumulation of wealth and human well-being. It was within the hardwood forests of East Africa that mankind apparently first developed, some million years ago. This was certainly not an accident! Similar observations can be made about for Europe, Asia and America.

107 The African forest as a whole is dominated by tropical hardwoods, while in America, although lying at similar latitudes, forest systems are much more diverse, with many conifer ecosystems. This fact made us aware that there are differences between hardwood and conifer ecosystems, and a survey of tropical areas confirmed for us that it is in fact the hardwood forest that produces soils suitable for agricultural. We observed the same pattern in more northerly latitudes of America, Europe and Asia. The question then immediately arises: why are African soils so poor, when they originated from the hardwood forest? The answer, as we now see it, has to do with the collapse of biological pedogenetic mechanisms, rather than with any chemical or physical mechanisms, as had been generally thought.

108. Thus we put forward the following hypothesis: (14) ***The pedogenetic processes found in hardwood forests are clearly related to the structure of their lignin components, and they produce soils that not only permit the smooth cycling of nutrients but have proven highly adaptable and extraordinarily productive. Thus, in the hardwood forest we typically find a climacic forest type, with trees of various ages and numerous species, while in forests where Gymnosperms dominate there is no chance for regrowth or renewal and only a limited number of species can survive. Everywhere on earth, it was in the hardwood forests that agriculture was able to take root and flourish.***

13 Some thoughts on ramial wood

109. It was the idea of increasing productivity by means of ecologically harmonious mechanisms that led us to think of RCWs as a basic nutritional factor in agriculture, within the overall context of pedogenetic factors and causes. Since RCWs have shown beneficial results on both agricultural and forest soils, we have concluded that they could form the basis of a new field of knowledge, one that, as the literature of the past century demonstrates, has never been approached from this angle.

110. These results help to highlight the importance of mechanisms that originate in the forests themselves for governing the evolution of soil structure, fertility and productivity. We therefore suggest the following hypothesis: (***15) At all latitudes, the soils now devoted to agriculture were originally wrested from the hardwood forests. They should be considered as forest soils that have been degraded in order to meet human needs. With help of RCW technology, soil fertility can be restored, because with it all the biological mechanisms can be regenerated, the trophic web can be reactivated, and the structure of the soil can recover.***

111. We expect of course that such a statement will be received with some incredulity to begin with, but we are confident that this reaction will diminish as the facts come to be appreciated. We are constantly struck by the degree to which the "agricultural" approach dominates modern forestry thinking, in the context of continuously adapting agriculture to man's industrial needs. We propose, using the new knowledge we have developed, to take a fresh look at agricultural soils from the perspective of their pedogenetic mechanisms, first the biological ones, then the biochemical ones, and finally the chemical and physical ones. The techniques applied to agricultural soils should start from a consideration of the nutritional factor, before we think about the their chemical, hydrodynamic, physico-chemical or other aspects.

112. Man has taken the wrong track many times during this century, and restricted his creative

thinking to the use of increasingly artificial systems based on the two concepts of "mineral plant nutrition" and"organic matter".

113. The first of these concepts has made it possible to gather a tremendous amount of scientific data that was mathematically verifiable and has brought about a veritable social revolution all over the world. Nonetheless, we must recognize that economic growth has now reached a plateau, and our continued attachment to artificial solutions is causing costs to skyrocket, and output to plummet.

114. The second concept is far more pernicious: its weakness is evident in the fact that it cannot be defined in chemical terms, and its results can hardly ever be reproduced. Organic agriculture, which represents a return to past traditions, has become fashionable, and the use of trash compost and manure is promoted everywhere. Yet this is really tantamount to promoting mineralization for short term benefits. Africans we talked with had this to say about the organic matter concept that is so popular in the throw-away culture of the North: "We don't have any excess organic matter, and when we do have any, it is immediately consumed in the soil". It would seem that the "organic" future is highly precarious under such conditions, especially since reserves of compostable trash are uncertain and limited, and the process represents a considerable loss of energy, which otherwise could be introduced directly into the soil system..

115. These then are our reasons for proposing that forestry techniques for producing RCWs be used to meet needs that are strictly agricultural. It is technically possible and economically profitable to produce RCWs in the quantities needed to establish management mechanisms for the soil that are based on biology and its attendant biochemistry. Moreover we believe that, with some effort, it should be possible to convince farmers themselves to make these techniques a part of their culture and traditions. RCW production, after all, can and indeed must be scaled accordingly to need - a goal that is impossible to achieve with trash composting techniques, which are much too costly in terms of human energy.

14 Endogenous soil energy and desertification

116. The proposals we have spelled out can open the door to a new understanding of desertification processes, and point to simple techniques that will address the problem at its very source. *Considerable efforts will be needed to make people understand the need to return back to the soil the energy required to conserve and maintain it and make it more productive*. The solution will no doubt require an understanding of the mechanisms involved in depolymerizing the polyphenol chains so as to allow regulatory mechanisms to work - among which water will be the most readily appreciated factor. We therefore suggest as a hypothesis that: (16) ***The energy question, and in particular the role of lignin and its derivatives, should form the basis for a campaign to halt the desertification process and to restore the productivity of arable lands.***

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117. We are inclined to think that this "campaign" should be undertaken as part of a broader plan could be communicated by means of the traditional oral techniques common to all African peoples. It is essential that these ideas be translated into the spoken language in a way that is compatible with traditional understanding. We must avoid the kind of scientific discourse that can only be communicated in writing. The word will have to be spread through ethnic languages - otherwise the campaign will surely fail.

VIII Research programme

118. The research programme should encompass several aspects, including the following basic topics:

a) The energy question, from the physical standpoint within the context of thermodynamics. This work could take be undertaken in northern as well as southern countries.

b) The role of polyphenolic compounds in energy management and

distribution, and their role in managing chemical nutrients and in maintaining the trophic web.

c) The biological transformation of RCWs in connection with the storing and release of nutrients

d) Identifying and studying the various enzymatic systems, with an emphasis on those originating from RCWs.

e) Selecting the best species of trees to grown in order to produce RCWs.

f) When and how much to apply.

g) Chipping and spreading methods for RCWs.

IX Hypothesis

(1) ***If we admit that, in the absence of agriculture, forests dominated the earth for millions of years, and that once we had removed the forest cover for farming, the soil suffered major degradation and loss of fertility, then the factors governing the soil's fertility must have been due to the forest.***

(2) ***The mechanisms governing fertility, pedogenesis, biodiversity, and primary and secondary soil productivity depend on factors that have not been clearly explored in the scientific literature of the twentieth century. We conclude therefore that science has focussed solely on questions of soil output.***

(3) The RCW concept could be a valuable tool for studying and understanding soil formation and its dynamics, by which we mean above all the distribution of chemical nutrients essential for plant growth.

(4) The hypogeous ecosystem, i.e. the living soil, has been able to overcome climatic problems in the tropics by creating a network of multiple life forms, whereby plants can recover nutrients without need of the chemical fertilizers so widely used in temperate-zone agriculture. This fact is particularly important for water management, since water could act as a nutrient if it were not sensitive to osmotic pressure from soil salt solution.

(5) The nitrogen cycle is fed primarily by the microbial fixation of N2, and secondarily by the action of fungi and mycorrhizae, in soils treated with RCW.

(6) RCW contributes to the soil not only nutrients, but also a number of mechanisms to regulate their synthesis or release.

(7) The origin of the lignin, and the positioning and number of methoxyl groups in it, may play an important role in the structure of the soil, depending on the ground water system and rainfall patterns.

(8) Biodiversity and the health of the soil are the prime factors in the conservation and use of the water that is stored and available within biological systems, by protecting it from the soil's own chemical cycles.

(9) RCWs can be a source of nutrients and energy, with lignin as the principal factor for stability and soil control, provided that the lignin is in the form of oligomers that can be readily depolymerized by Basidiomycetes. The fractional elements so obtained can be easily utilized by biological systems, or they can be retrosynthesized, or turned into humus, which is the basis for managing the soil's fertility, its nutrients and its reserves of solar energy.

(10) Since the forest was the source of the mechanisms responsible for soil fertility all over the world, the disappearance of the forest will lead, over the short, medium or long term, to a drop in fertility and productivity. And, if chemicals are used as fertilizers, the soil structure will collapse, [food] shortages will arise, and parasites and disease will appear.

(11) Ramial chipped wood, when exposed to attack by Basidiomycetes, can replace all biological functions that require chemical and biochemical nutrients. RCW also contains the energy needed to support the processes and to provide a margin for the demands of entropy. The energy released covers the electromagnetic spectrum, wholly or in part.

(12) By providing access to various nutrients, RCW brings with it the endogenous energy needed to meet the inevitable demands of entropy. It also contributes the enzymatic mechanisms needed to synthesize those nutrients or make them accessible .

(13) The structure of lignin and its transformation throughout the pedogenetic process can be

taken as directly responsible for the form of competition within ecosystems, due to the way it evolves within the soil, and its effects on the control of chemical and biochemical nutrients.

(14) ***The pedogenetic processes found in hardwood forests are clearly related to the structure of their lignin components, and they produce soils that not only permit the smooth cycling of nutrients but have proven highly adaptable and extraordinarily productive. Thus, in the hardwood forest we typically find a climactic forest type, with trees of various ages and numerous species, while in forests where Gymnosperms dominate there is no chance for regrowth or renewal and only a limited number of species can survive. Everywhere on earth, it was in the hardwood forests that agriculture was able to take root and flourish.***

(15) At all latitudes, the soils now devoted to agriculture were originally wrested from the hardwood forests. They should be considered as forest soils that have been degraded in order to meet human needs. With help of RCW technology, soil fertility can be restored, because all the biological mechanisms can be regenerated, the trophic web can be reactivated and the structure of the soil can recover.

(16) ***The energy question, and in particular the question of lignin and its derivatives, must form the basis for the campaign to halt the desertification process and to restore the productivity of arable lands.***

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1 An arbitrary definitionf these, depending on local usage. Generally, the smaller the diameter, the higher the content of lignin, proteins and nutrients.

2 generic term embracing all the sugars (glucose, saccharose, fructose, mannose, etc.)

3 ring subsequent experiments in Senegal, where pH exceeds 8.0, we found a resulting sharp drop in pH towards neutrality. The explanation may be found in the behaviour of enzyme systems.

4 Experiments conducted with maize in Ivory Coast 2 years later showed increases in dry matter of 400%.

This result is more noticeable in tropical countries

A significant reduction in *Sclerotinia sclerotinum* was noted on potato tubers, as was a reduction of aphids on strawberries. In tropical areas, root nematodes (*Meloidogyne javanica, M. Mayagensis and Scutellonema cavenessi*) disappeared completely.

5 reliminary cost estimate in 1985 suggested Cdn$ 1000 per hectare, spread over five years.

6 logism for the fractioning of complex molecules to produce new ones that are at least as complex,

using new enzymatic systems that result from changes in the levels of life caused by an increase in biodiversity and energy availability.

Ramial Chipped Wood (RCW) in English, Bois Raméal Fragmenté (BRF) in French, Aparas de Ramos Fragmentados (ARF) in Portuguese, Madera Rameal Fragmentada (MRF) in Spanish, and Fragmentiertes Zweigholz (FZH) in German.

7 is regulation is best achieved through enzymatic systems, but it can also be done through chemical displacements. Such systems may be allogenous (induced by RCWs) or endogenous (arising from microbiological action).

8 This is a macromolecule, for which the literature provides no clues as to its structure. The same is true for humus, humates and humin. They appear to be highly varied remnants of lignin after various chemical and biological attacks, with a high molecular weight and a weakly acid tendency. Humus and "organic matter" are frequently confused in the literature.

9 The genus *Pinus* is the most important.