AMELIORATION OF SOIL BY TREES IN THE TROPICS

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Although high insolation and precipitation regimes offer the prospect of high biological production in the tropics in comparison to other climatic zones, a variety of factors both physical and cultural mitigate against its realization. Of particular importance among these are poor and edaphic soil conditions, impoverishment of lands by intensive use over successive generations, inadequate knowledge of plant and animal species especially trees for manipulation by human societies, and inadequacy of technology in the cultural repertoire of human societies to optimise land use and landscape integration. Nevertheless, knowledge about soils, trees and agro-ecological interactions is several millenia old having emerged quite independently in several tropical civilisations. Renewed interest in these interactions emerged over the last 20 years through the initiation of the International Biological Programme (IBP), through our understanding of the limitations of the Green Revolution and extensive agricultural development in coping with human population growth, and through the marginalisation of land by careless agricultural technology. This synthesis endeavours to bring together considerations on the above factors in relation to the amelioration of soil by trees especially in the tropics (Figure 1).

Tropical Soils

Highly productive soils offer plant roots the prospect of deep and easy penetration, access to ground water supply, an environment of good gas circulation, access to nutrient reserves maintained by a high exchange capacity, and an association with soil flora and fauna capable of regenerating nutrient reserves by mineralizing organic matter (Blume 1985). However, tropical soils vary greatly in structure and productivity. While geologically-recent soils of volcanic or sedimentary origin are often highly fertile, those derived from older igneous rocks are heavily leached and acidic, and have a low moisture and nutrient-holding capacity. The high precipitation regime in the tropics causes the leaching of soluble nutrients well below the root zone, so that many soils have low levels of natural fertility especially of N and P, and become acidic. As a consequence, plants have adopted the strategy of containing the nutrients in the biomass in the tropics. Soil infertility or acidity in the tropics may be due to aluminium toxicity, calcium and magnesium deficiency, manganese toxicity and a low cation exchange capacity. It may be overcome by liming or by the planting of acid-tolerant plant species.

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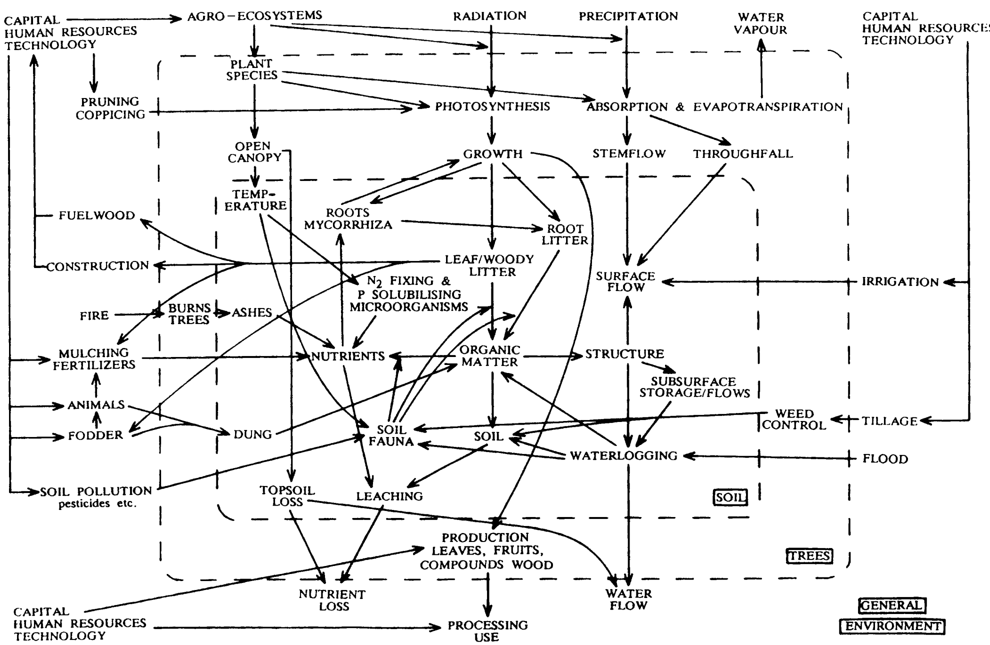

Figure 1:
The Amelioration of Soil by Trees showing the interaction between the soil, trees and the general environment.

The high insulation and humidity regimes in the tropics facilitate the rapid breakdown and decomposition of organic matter, so that tropical soils are in organic matter content. This limits the supply of nitrogen and sulphur to plants, lowers the cation exchange capacity, facilitates phosphorus fixation, weakens soil structure, and limits the formation of complexes with micronutrients. The maintenance of organic matter is therefore essential for biological production, either through animal manures or through green manures and mulching. In seasonal climates, nutrients may be released rapidly and for a brief period at the onset of rains, for which plant species must be available to capture available nutrients to optimise production. Anderson (Chapter 2) discusses the efficiency of tight nutrient cycling in tropical rain forests which support a high biomass and productivity, in comparison to farming systems where nutrient-rich plant materials are harvested for human use, thereby leading to the impoverishment of soil fertility. Farmers in the tropics have traditionally recognised the importance of soil fertility and conservation. However, in transforming the natural ecosystems with man-made systems, farmers have either conserved soil fertility or used high material inputs to ensure high production and soil fertility, depending on the availability of labour and technology. Tropical farmers thus face a choice of fertility-management options depending on the level of scientific and technological accultivation of their societies.

Many tropical soils are infertile with low essential nutrients such as nitrogen, phosphorus and sulphur. Symbiotic nitrogen fixation is particularly important in the tropics, not only by rhizobial bacteria but also by non-rhizobial bacteria and blue-green algae. The state of knowledge about the latter is particularly weak. Nitrogen poverty is compensated by the application of fertilizers, by intercropping with nitrogen-fixing plants, or by integrated farming systems involving animal husbandry and/or aquaculture. Phosphorus deficiency is due to phosphorus fixation by iron and aluminium oxides in highly acidic and weathered soils. It is compensated by the application of phosphorus fertilizers or of low-cost phosphorus sources such as rock phosphates, depending on the availability of capital. Sulphur deficiency is widespread in the tropics being found in highly weathered soils, sandy soils and in savanna areas subjected to annual burning.

Tropical soils may be "mined" by continuous cropping without nutrient replenishment. Under these circumstances, organic production may be harvested cheaply with low support energy but will lead to the decline in soil fertility and yields on site, eventually to an unproductive "low level equilibrium" which is inefficient in the use of solar energy but very efficient in the use of support energy (Ruthenberg 1971). Alternatively, the farmer requires high support energy to maintain and increase soil fertility, which in turn results in a more efficient use of solar energy but is expensive. This alternative is usually not available to the poor farmer in the tropics. The farmer thus searches for a farming system that compromises between a solar-energy efficient and support-energy inefficient highly-productive system and a solar-energy inefficient and support-energy efficient poorly-productive system. The shifting cultivation system is one such compromise where there is a tree/shrub and herb/fallow rotation. The shrubs and herbs deplete the soils of nutrients, whereas the trees mobilise the leached nutrients through their deep roots and leaf fall. The beneficial effects of trees to soil fertility are discussed in Chapter 2.

Tropical soils are characterised by a variety of moisture regimes, and exhibit water deficits due to short-term drought. The capacity of the soil to retain water and to supply it to plants is a critical factor for tropical agriculture. Droughts reduce yield, and may be overcome by protecting the soil surface with mulches and/or a continuous canopy. Many traditional farming systems show sound management alternatives for conserving soil water supply to plants.

Tropical soils are susceptible to erosion when exposed to the high precipitation regime, primarily because of their poor structure. The extent of soil erosion in the tropics is increasing because of extensive deforestation, overgrazing on pasture lands, and poor use of shifting cultivation on steeply sloping lands. Contour planting, the use of trees on slopes and/or protecting the soil by plant residues or canopy cover can enhance soil conservation.

Tropical soils are marked by special edaphic conditions, such as acid sulphate, saline or peat conditions. These pose special problems to the amelioration of soil by trees and are usable for biological production under careful management prescriptions.

Biota Especially Trees

Plant and animal species can be used potentially to ameliorate soil by a variety of combinations. Although some plants such as Acacia and Casuarina are useful for ameliorating acidic soils, knowledge about plant species is in its infancy in relation to such manipulations for various soil types. In the choice of plant species, it should be noted that trees have a nutrient conservation strategy superior to shrubs and herbs, and that monocotyledons are superior to dicotyledons in this respect. Furthermore, plants through their architecture have differing impacts on light extinction and photosynthesis, interception of precipitation and on protection of soil. Most plant species used in agriculture are species belonging to the early successional phases in community structure, and have been selected for their rapid growth characteristics. These species are low in secondary compounds and are therefore susceptible to pest infestations. In contrast, plant species belonging to the late successional phases in community structure are rich in secondary compounds, and are therefore less susceptible to pest infestations. There is a clear need for selecting species for intercropping and rotational cropping that will ameliorate soils in relation to various dimensions of soil conservation. Selection of species may be extended further for integrated farming coupling land to water.

Agro-ecological technology

Agro-ecological techniques can manipulate the combination of plant species over space and time, the integration of animal species and the coupling of land to water as in integrated farming systems. Each step in the technology towards integrated farming systems requires a measure of cultural pre-adaptation, and the expenditure of capital, labour and human skills. Agro-ecological options can combine the characteristics of biological production with those of soil and water conservation, as in the combination of herbaceous plants with trees in agroforestry systems. Such combinations facilitate multiple outputs as uses such as for food, fuel, fibre, fertilizer and soil stabilization. Although the traditions of agro-ecology are old, the science is relatively new especially of polyculture systems in the tropics, since much of the research effort over the past 100 years or so has been focused on the dynamics of monoculture systems. Species combinations can be supplemented by chemical, mechanical and physical manipulations, all of which are expensive and demanding on human skills. Young (Chapter 5) discusses management practices which control the quantity, quality and timing of organic decomposition required to maintain soil fertility; while

Swift (Chapter 2) discusses further the complexity of the decomposition processes. The complex relationship between agro-ecological management practices and soil fertility (Figure 1) is poorly understood. Further scientific research and technological development (R&D) is needed to elucidate these relationships so that the farmer may choose the appropriate management system for use in relation to the combination of species and the kinds of soils at critical time sequences. Such a focus constitutes the basis of a cooperative project developed through the catalytic action of the Commonwealth Science Council.

In examining the impact of trees on soil in various agro-ecosystems, it is pertinent to note four system properties that need to be optimised from traditional agro-ecosystems to advanced ones (Conway 1984):

- Productivity or desired output of the system measured in terms of crop yield or net income.

- Stability or short-term homeostasis of the system measured in terms of the coefficient of variation of yield or net income.

- Sustainabilty or ability of the system to persist through repeated stress or major perturbations like deteriorating soil structure, growing pollution or the sudden appearance of a new pest or disease. This property is difficult to identify and measure, although it may be observed after a system has collapsed.

- Equitability or the pattern of distribution of the products or benefits of the system among human individuals interacting with it, and is easy to measure in the formal economy as a function of capital, land and/or other resources but is difficult to measure in the informal economy, in terms of non-fiscal incentives or rewards, or at the level of self-actualization.

System properties	Productivity	Stability	Sustainability	Equitability
Gradations of Agro-ecosystems:				
A (Traditional)	Low	Low	Medium	Medium
B (Green Revolution)	High	Low	Low	Low
C (Advanced Green Revolution)	High	High	Low	Low
D (Advanced)	High	Medium	High	High

The Problem for Research

The response of soils to trees will be assessed by the measurement of a standard selection of soil properties and processes, related to nutrient cycling, soil physical factors and soil biological processes.

(1) **Nutrient Cycling:** The two factors need to be measured in association with nutrient cycling, litter decomposition and the status of soil organic matter.

(2) **Soil Physical Properties:** Four soil physical properties need to be measured: soil water, soil structure, soil stability and soil temperatures.

(3) **Soil Biological Properties:** Four biological characteristics of the soil will be measured as indices of soil amelioration: microbial biomass, nitrogen-fixing organisms, mycorrhizal activity and soil fauna.

The experimental design within which the above properties will be measured is as follows:

- that it permits the investigation of specific hypotheses on the effects of trees on particular soil properties;

- that it is appropriate in terms of choice of trees and land-use systems to the area;

- that it is appropriate to the soil ameliorative requirement of the area;

- that it will achieve standardisation of methods to enable exchange of data between sites;

- that wherever possible it can incorporate options on choice of trees, mixture of trees and mixtures of farming systems.

The 'problem' soils chosen represent the priority developmental needs of Commonwealth countries:

- soils of low fertility - both naturally and due to nutrient exhaustion;

- sloping lands with erosive risk under dense population pressure;

- saline and alkaline soils;

- semi-arid lands.

Among the various agro-ecosystems appropriate for experimentation on soil amelioration of these 'problem' soils, alley-cropping has been chosen because it lends itself to experimental manipulation, has wide applicability and has proven potential in many areas.

The objectives of the project are:

- To build up a model of plant-soil nutrient cycling under tree-crop mixtures.

- To identify and demonstrate successful agroforestry systems of soil amelioration by trees for the area in which the experiment is carried out.

The major variables measured will include plant species, spacing (between and within rows) and management (pruning etc). In the experimental design, there will be unvegetated control plots, tree plots, crop plots and tree-crop interfaces as well as alley cropping trials. The tree plots will be used for species selection as well as for the study of organic matter and nutrient cycling of the tree component. Trees will be managed as they would in the alley cropping situation. The crop plots will be used for crop yield determinations as well as for the study of organic matter and nutrient cycling under the crop component. Detailed measurements along transects between trees and crop will be made. Alley cropping trials will consist of:

- 3 x between-row tree spacings
- 4 x within-row tree spacings
- 8 x tree species

The whole design, without replication, could be contained on a site of four hectares. Other possible designs, eg split plots, fans, and randomised block designs, could be considered. Organic matter and nutrient cycling studies would be made on selected blocks, besides basic measurements (eg litter and pruning biomass, soil organic matter) on all plants. Further features of the design could be developed on the basis of the recommendation published by ICRAF (eg Systematic Designs ICRAF Working Paper No. 12).

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