

5. SUMMARY AND CONCLUSIONS

Implications of Soil Properties for the Natural Ecosystem

Anecdotal evidence from a wide variety of experienced tropical rainforest researchers (ecologists, foresters, primatologists, pedologists, agronomists) suggested that the primary productivity of the RNP primary rainforest was noticeably lower than other rainforests in similar settings around the world. For instance, the mammalian biomass per hectare at the RNP was loosely estimated to be 10% of that in the Peruvian Amazon basin (P. Wright, personal communication). The length of time required for forest regeneration and sustainable slash-and-burn cycles was judged by several experienced tropical agronomists and foresters to be 2-3 times longer than the regeneration rates observed elsewhere. It appears that research efforts currently underway by various universities are attempting to scientifically quantify these observations and confirm or refute the anecdotal evidence.

One major question posed by forestry researchers at the RNP was whether the change in forest stature (canopy height) near the upper escarpment edge was the result of changes in soil properties and/or mainly the effect of climate. No soil data support the hypothesis that soil changes are responsible for changes in forest structure, nor are there any significant changes in geology across this zone. However, climate does appear to change significantly just below the escarpment edge, where rapid changes in temperature were frequently noted at the point where clouds and fog were observed. The most probable explanation for changes in forest structure therefore appears to be elevation-controlled climate differences, at least where the same tree species may be observed to change in stature above and below the escarpment edge.

Even for plant species adapted to the high aluminum saturation levels, low levels of exchangeable bases, and extremely low available phosphorus levels, these soil properties impose constraints on forest primary productivity. When total elemental nutrient levels are considered, which relate to the long-term nutrient uptake by trees, the natural infertility of parent materials and soils defines a natural limit to forest productivity within the RNP region. This was reflected in the biocycling of bases and phosphorus in the characterized rainforest soils (Pedons 5, 8 and 16; Appendix 1), where there was a dramatic decrease in soil nutrients below the surface soil horizon(s).

Phosphorus may well be the most limiting nutrient with regards to net primary productivity in the RNP region rainforests. Walker and Syers (1976) developed a conceptual model for phosphorus changes during pedogenesis that not only hypothesized eventual conversion of available phosphorus to more unavailable (occluded) forms, but also predicted a loss of total P from ecosystems over time. Chadwick et al. (1999) demonstrated in Hawaii that phosphorus contributions from Asian-derived dust exceed phosphorus contributions from the parent rock in the oldest soils. This Aeolian input maintained ecosystem productivity at the site despite phosphorus losses over pedogenic time scales. However, Chester et al. (1991) reported that terrestrial aeolian inputs in the southern Indian Ocean near Madagascar are negligible, since the trade winds originate over a vast open ocean area with few landmasses. Since phosphorus contributions from marine aerosols are negligible (Chadwick et al., 1999), it appears that the eastern Madagascar ecosystem will naturally decline in overall phosphorus status over time.

The “tight” nutrient cycling processes within the rainforest suggest that significant disturbance to the forest soil surface layers may limit forest regeneration.

Add to this that lemurs, birds and other forest animals are the primary seed dispersers for many tree species (Turk, 1997), and the potential for complete forest regeneration after *tavy* appears low, even if only one cropping cycle is established and the field is left to fallow. The combination of nutrient-poor soils, a “tight” nutrient cycle within the upper soil horizons, *tavy*, invasive plant species, and loss of native tree seed dispersers in deforested areas all serve to create a precarious situation for a fragile ecosystem.

Implications of Soil Properties for Agriculture

The soils of the RNP region possess an unfortunate combination of high aluminum saturation, low amounts of exchangeable bases, and extremely low levels of available phosphorus. Many areas of the world with similar soil properties are productively farmed where soil amendments, systems of agricultural credits, transportation, and agricultural markets are accessible. However, these areas usually occupy regions with gentle terrain and warm temperatures. The steep terrain, seasonally cold temperatures, and frequency of cyclones/tropical storms in eastern Madagascar present additional technical challenges for soil management options, even before the socioeconomic aspects of agriculture are addressed.

The same soil constraints that limit natural ecosystem productivity also affect agricultural productivity, but with a few key differences. One, whereas nutrients may be recycled in a relatively “closed” natural ecosystem, nutrient removals (in the form grains, tubers, seeds, fruits, etc.) are an essential feature of agricultural systems. These nutrients must be replaced if agricultural sustainability is to be achieved. Almost universally, the rural Malagasy people around the RNP region practice indiscriminate

defecation, and the concept of using human waste (night soil) for agriculture is culturally abhorrent. Cattle are typically allowed to free-range within forest areas for approximately six months per year, in part to thwart attempts at cattle rustling (Peters, 1996). Therefore, two potential methods of recovering nutrients from the overall farming system are unavailable to the local farmers.

Another factor affecting upland soil agriculture around the RNP is the relative availability of nutrients to annual crops after slash-and-burn. The initial pulse of nutrients released upon forest burning, and the transient liming effect from ash, are either exhausted in the first few crops, converted into unavailable forms (e.g., occluded phosphorus), and/or eroded from the site. The soil quickly reverts to a low-nutrient status, but without the nutrient reserves in standing forest biomass. Invasion by weeds, exotic tree species, etc. further diminish the site's value for agriculture. Left fallow, most fields around the RNP eventually regenerate to some form of secondary forest, but where nutrient removal has been exhaustive, the combination of low nutrients, lost native tree seed pools, and dominance of seral vegetation make forest regeneration less likely.

If upland agriculture is to be stabilized and transformed into a sustainable system, or if paddy rice systems are to sustainably produce adequate yields, inputs of nutrients from outside sources are essential. This major conclusion stems not only from the low levels of *available* nutrients in these soils, but the remarkably low *total* elemental nutrient contents that govern long-term ecosystem and agroecosystem productivity. Some may argue that low-input strategies such as composting may promote sustainability, but even if these strategies are culturally acceptable, mining one portion of the landscape for nutrients and exporting them to another portion of the

landscape is essentially “robbing Peter to pay Paul.” Ultimately, this strategy would lead to degraded vegetation communities and soils everywhere within the region, as the delicate natural nutrient cycling processes are disrupted and overall ecosystem health declines. The “alternative” agronomic practices such as SRI or “system of rice intensification” (Stoop et al., 2002) ignore the landscape’s fundamental biogeochemical status, not to mention real agronomic constraints such as Liebig’s Law of the Minimum.

The problem of exchangeable aluminum saturation, if not addressed by *tavy* ash inputs, can only be ameliorated by inputs of lime or dolomite. The selection of acid-tolerant cultivars helps to some extent, but even these cultivars do not produce normal yields if exchangeable aluminum levels remain high. Kamprath (1970) observed that aluminum toxicity could be eliminated by liming soils according to the amount of exchangeable aluminum. The lime requirement may be estimated by the equation:

$$\text{Exchangeable Al}^{3+} \text{ cmol(+) kg}^{-1} \text{ soil} \times 1.5 = \text{CaCO}_3 \text{ cmol(+) kg}^{-1} \text{ soil}$$

Depending upon the amount of organic matter, the factor of 1.5 may require an increase to 2 or more.

One cautionary note on liming materials in Madagascar. A bag of commercially produced “dolomite” was purchased by the author for a home garden while living in Ranomafana. Dolomite is a preferable liming material in that it reduces exchangeable aluminum and increases both calcium and magnesium levels. When no response was observed after application, a sample of the “dolomite” was sent back to the NCSU lab for determination of its calcium carbonate equivalent value. When the material was found to have no liming value whatsoever, and x-ray diffraction analysis revealed that

the material was actually crushed albite. Therefore, it appears that much better quality control is required for the production of agricultural amendments.

Improving the phosphorus status of the RNP area soils follows a logic similar to that for other soil nutrients: inputs from outside sources are required for sustainability. relatively soluble rock phosphate exists on small islands off of Madagascar's northwest coast, but to the author's knowledge they are still not exploited for widespread agricultural applications. Because soil phosphorus levels are so low around the RNP, any level of phosphorus application that is not buffered immediately by soil colloids would be likely to have a measurable effect on yields. Balasubramanian et al. (1995) reported that root-dipping of paddy rice plants in a phosphate-soil slurry at a rate of 13 kg P ha⁻¹ produced equivalent grain yields as a 26 kg P ha⁻¹ broadcast fertilizer application. This higher efficiency was attributed to a concentration of P in the active rooting zone and minimization of P sorption by soil colloids. Phosphate-soil slurries using triple super phosphate or dicalcium phosphate are preferred because compound fertilizers (i.e., NPK) may produce root scorching at higher P concentrations. Additionally, the slurry acidity or alkalinity must be moderate. This P fertilization method is one example of the strategies required to maximize fertilizer use efficiency in eastern Madagascar, whatever the nutrient source.

The addition of soil amendments to upland soils presents at least three major challenges. One is the cultural acceptability of stabilizing agriculture, which involves cultural issues, perceptions of labor requirements, land tenure, etc. Another challenge involves access to soil amendments by impoverished farmers. Finally, even if these challenges could be overcome, there is an additional challenge of retaining and efficiently recycling nutrients in steep terrain with high rainfall.

Whatever the pathway to agricultural sustainability in the RNP region, the scientific reality is that nutrients may not be mined from one part of the landscape, even in the form of “natural” compost, without an overall degradation of the ecosystem if those nutrients are not replaced. If humans are going to continue to live in the RNP region at current population levels, then either the practice of *tavy* must change or the rainforest will be lost. The historical deforestation patterns in the region forcefully testify to this reality and the unsustainable nature of the existing system.

Some authors (D. Peters, 1996; W. Peters, 1998) have argued that the change from a *tavy*-based agricultural system to a fertilizer-based agricultural system would be culturally unacceptable to the Tanala people, who consider *tavy* a way of life. This certainly appears to be true, and for other groups (e.g., the Betsimisaraka) as well. However, the Tanala must make the same fundamental choices that societies everywhere must make when non-renewable resources are consumed, or when renewable resources are consumed at rates that preclude their renewal. They must either decide to change usage patterns, or the resource will be completely lost.

This author respects the Tanala’s right to make that choice in a spirit of self-determination. Nonetheless, the choice from the perspective of soil properties and human needs are quite clear. The Tanala may continue the unsustainable use of the forest for *tavy*, and the primary rainforest will one day cease to exist. The loss of the forest will then require the Tanala to change and abandon their way of life anyway. Or, the Tanala may choose as a people to avoid that fate by modifying their agricultural practices, with the help of technical experts and chemical fertilizer inputs. A change from *tavy* may at least preserve the remaining rainforest and with it some of their cultural heritage, not to mention some of the world’s richest biodiversity.