

7. Agrominerals and rocks in agroforestry systems

Agroforestry is an old and widely used land use practice in which trees are grown in association with agricultural crops or pastures. It combines elements of agricultural production with elements of forestry in a sustainable production system. Growing trees on farms alongside crops and livestock can improve the livelihoods of the rural poor and protect the natural resource base. Agroforesters follow interdisciplinary natural resource management strategies with the final aim of improving livelihoods of resource-poor farmers.

Trees can play many biophysical, economic and social roles in farming systems, including the function of enhancing soil fertility. Trees provide canopy, the litter may protect the soil from erosion and minimize soil temperature and moisture fluctuations, and roots can loosen topsoils and improve soil structure. Trees can capture and cycle nutrients from the air, from underlying rocks and from decomposing organic matter. In the case of nitrogen, trees can contribute to soil nitrogen pools in two ways: firstly through nutrient input, for example through biological nitrogen fixation, and secondly through nutrient cycling – transfer of nutrients from one compartment of the soil-plant system to another. The transfer of nitrogen from the air to soils in a cost-effective way can be effectively managed through the use of legumes and certain non-leguminous plants. Leguminous fallows of agroforestry tree species like *Sesbania sesban* can nodulate and fix nitrogen from the air and, in addition, capture nitrate from subsoil levels at depths beyond the reach of most crop roots. The transfer of the nitrogen to the topsoil is through leaf litter and biomass decomposition (Mekonnen *et al.* 1997; Sanchez *et al.* 1997). But soil fertility around trees will also be affected through other improvements of the soil, such as soil structure, organic matter contents, and related water and nutrient management.

So far, the attention of agroforestry research has focused largely on nitrogen cycling, and phosphorus cycling in agroforestry systems has only been addressed in recent years. As there is no phosphorus equivalent to biological nitrogen fixation, phosphorus must be either cycled, transferred from nearby organic sources or added from external sources. Agroforestry species may play a crucial role in cycling P from the soil into more plant available P forms. Trees have extended root zones and some species may be able to acquire P from a larger volume of soil through mycorrhizal acquisition. However, the potential cycling of P from subsoil capture is likely to be low as the available P concentrations in subsoils are normally very low.

Nutrient budgets indicate that most P added to the soils through tree prunings and litter is the result of nutrient cycling, not new nutrient inputs (Palm 1995). However, the amount of P provided through litter and tree prunings is insufficient to meet crop demands (Palm 1995). Some plants have relatively high P concentrations in their biomass, for example the roadside and hedge shrub *Tithonia diversifolia* (0.3 - 0.38% P) and for low P application rates the incorporation of this type of green manure can transfer some P into the soil. The advantage is that biomass transfer will contribute to P cycling, bringing less available inorganic forms of P into more available forms.

It has become evident that in order to overcome gross P deficiencies and to supply the soils with sufficient P for crop production, external phosphorus must be added. Since water-soluble P fertilizers are too expensive for most resource-poor farmers, alternative P sources must be introduced. Locally available PR sources have been tested as a component of agroforestry systems in Kenya and Uganda. Decomposing organic materials can produce organic acids, which, in turn, can enhance PR dissolution. Composting of PR and organic matter can increase the availability of P from PR under certain conditions. However, to be effective and practical, local solutions to the P-problem must be found. Most beneficial results of phosphate dissolution through phospho-composting results have been achieved when using a sedimentary or biogenic phosphate rock as inorganic P-source (Bangar *et al.* 1985; Lompo 1993; Mathur *et al.* 1986; Singh and Amberger 1991; Ikerra *et al.* 1994; Tian and Kolawole 1999). Applying composts with less reactive mainly igneous PR sources showed no positive responses in P-deficient soils of eastern Uganda and this practice remains a challenge (Oshier 2002). Phospho-composting with the same PR but with other organic matter and on other soils proved successful in Kenya (Odongo 2002).

The effect of P-sorption on soils could also be influenced by the release of organic anions from tree or shrub biomass (Iyamuremye and Dick 1996; Nziguheba *et al.* 1998). Researchers found that the addition of green manure in the form of prunings of the agroforestry species *Tithonia diversifolia* not only provided nutrients and increased soil microbial biomass of C, N and P, but the application of this green manure also decreased P adsorption on soils, thus contributing to greater available P sources in the soil solution (Nziguheba *et al.* 1998). However, little is known about P solubilization and the sorption-desorption process in soils when organic materials are applied together with inorganic fertilizers (Palm *et al.* 1997).

Under certain conditions it might be possible to cycle P from rocks to crops. Results from a survey in eastern Uganda of inherent soil fertility and P concentration in the biomass of the roadside shrub *Tithonia diversifolia* growing on soils over different parent materials showed that the mean P concentration of *Tithonia diversifolia* (measured as dry matter) was significantly higher on soils of the PR mine (mean = 0.553% P) than on soils overlying granite (0.326% P) (van Straaten *et al.* 2001). It has to be investigated whether the roots of *Tithonia diversifolia* have the ability to actively increase the dissolution of phosphate rock or whether the results are only a reflection of higher soil fertility. It may be possible that *Tithonia diversifolia* can contribute to P cycling by bringing less available inorganic forms of phosphorus (from the underlying rocks and soils) into more available organic forms in the plant tissue. Unpublished research data indicate that *Tithonia diversifolia* is ecto- and endo-mycorrhizal and may secrete citric acid to the rhizosphere, thus enhancing dissolution of nearby minerals (Sanchez, pers. comm. 2000).

An intriguing option is the application of a combination of inorganic and organic P sources on P-deficient soils. Research in Kenya has shown that the combination of biomass from agroforestry shrubs with high rates of PR (in this case the reactive Minjingu PR) increased maize yield up to five times (Sanchez *et al.* 1997). A practical method to replenish soil P in highly weathered and P deficient soils is through integrating locally available organic resources with commercial P fertilizers or, even more practically, with phosphate rock resources if available in close proximity.

Phosphorus isotope studies have illustrated the effects of green manures, especially the agroforestry multipurpose trees *Gliricidia sepium*, *Acacia mangum*, *Leucena leucocephala*, and *Senna siamea*, on the phosphate solubilization from PR. The results of a study by Zaharah and Bah (1997) show that the solubility of the less reactive PRs increased, while the solubility of the more reactive PRs was depressed. The reason for this is not entirely clear.

Evidence from various parts of Africa indicate that growing maize after legumes with added phosphate rock will increase yield and organic matter in soils (IITA 1999; Jama, pers. comm. 2001). The combination of *Tithonia* biomass with P fertilizers and phosphate rock have been shown to be effective (Nziguheba 2001). When *Tithonia* leaves decompose in the soil, soluble carbon and nutrients are released to the soil, which in turn may enhance P cycling and conversion of mineral forms of P into organic P forms (Nziguheba *et al.* 1998).

Large one-time applications of PR or P fertilizers along with subsequent maintenance P applications and sound agronomic practices have enabled farmers in the Cerrado region of Brazil, with their highly weathered and high P-sorbing soils, to increase their agricultural productivity (Goedert 1983). They became food exporters rather than food importers. This success story lends support to the concept of large, one-time P 'recapitalization' in parts of Africa, a concept that has been discussed widely in agronomic and economic circles. In contrast to the one-time heavy application of P (recapitalization) is smaller amount applications. Initial results from agroforestry research in western Kenya indicate that one time applications gave similar yield responses to annual P applications. Given the high initial investment for P recapitalization (application rate 125-250 kg ha⁻¹, which is about US \$120-210 per hectare) the annual application rate seems more realistic under the current socio-economic conditions where most farmers make less than a dollar a day. Farmers, realizing the positive yield effect of *Tithonia* applications plus P fertilizers or PR, experimented with these resources and found that it was more profitable to apply these materials on high value crops, for example, vegetables, rather than on maize (Jama *et al.* 1997; Sanchez *et al.* 1997; Sanchez and Jama 2000).

The application of a combination of organic and inorganic sources, for example, organic sources from trees and shrubs, with inorganic PR sources, on high-value P-efficient crops like cabbage or kale could become key to successful N and P (and probably K) management in small holder farms.

Mycorrhizae play an important role in the acquisition and uptake of P by plants, including trees. The high efficiency of P uptake from various P sources by mycorrhizae-infected trees has been demonstrated in temperate climates (Finlay and Read 1986; Cumming and Weinstein 1990) but few data are available for sub-Saharan Africa. Direct application of PR with and without arbuscular mycorrhizae on multipurpose agroforestry trees has been carried out by Karanja *et al.* (2001). The results from greenhouse studies show that on nutrient-poor acid soils, the addition of 50 kg P ha⁻¹ as Minjingu PR alone resulted in significant increases of height and root collar diameter compared to the control. *Leucena leucocephala* recorded the highest increase in height and root collar followed by *Eucalyptus grandis*, indicating a high efficiency in P utilization. Additionally, Karanja *et al.* (2001) showed that inoculating seedlings of legume trees with arbuscular mycorrhizae increased nodulation. Adequate P supply is essential for the host, and for the survival of rhizobia bacteria, nodulation and N₂ fixation (Azcon *et al.* 1979).

The glasshouse experiments of Karanja *et al.* (2001) illustrate the importance of mycorrhizal infection to P uptake of trees and the importance of P fertilization of agroforestry multipurpose trees, and specifically the use of phosphate rocks. It is important to carry out experiments under field conditions to verify the effectiveness of these methods and the fertilizing phosphate rock materials.

No information on the use of other nutrient-containing rocks and minerals, for example K- and Mg-containing micas (e.g. biotite, phlogopite) and leucite-bearing volcanics or liming materials (limestone, dolomite) have been reported in agroforestry systems. Some of these agrominerals certainly warrant testing as they are slow-release naturally occurring nutrient sources.