The Natural Farmer

Effects of Trees on Soils - Spring 2002
Special Supplement on AgroForestry

by Dr. Anthony Young

Soil Fertility and Land Degradation

Approaches to soil management, including problems of soil degradation and low soil fertility, have recently undergone major changes. The former view was to concentrate on achieving high levels of production from the more fertile areas, leaving the marginal lands for extensive use only. Steeply sloping and highly drought-prone areas were preferably not to be cultivated at all. Soil constraints were to be overcome by inputs: improved crop varieties, fertilizers, chemical control of pests and diseases, and the use of irrigation.

It had been demonstrated that crop yields could be raised by a factor of three to five times or more by the use of fertilizers, applied to the newly developed high-yielding crop varieties. This approach was successful in giving large increases in crop productivity in Western countries and Asia and moderate improvements elsewhere, but it encountered problems of many kinds. Fertilizers are costly in terms of energy resources to produce them, and continued high rates of use lead to environmental problems. Yield responses to fertilizers have declined, for example because of soil physical degradation or micronutrient deficiencies. Above all, large numbers of poor farmers simply cannot afford high levels of fertilizers and other purchased inputs, nor do they have the capital to take on the risk which these involve. Finally, the former solution of increasing the area under irrigation has run into severe constraints in the form of limits to available freshwater resources.

Aspects of this new approach include:

- find ways of making the use of marginal lands sustainable;
- reclaim and restore degraded land;
- improve germplasm to produce plant varieties which are adapted to soil constraints;
- maintain soil organic matter and biological activity, with benefits both for soil physical conditions and balanced nutrient supplies;
- improve nutrient cycling and nutrient use efficiency in agroecosystems;
- use fertilizers and other external inputs at moderate levels, seeking strategic use to overcome deficiencies that cannot otherwise be remedied;
- improve water-use efficiency.

Agroforestry can contribute to all these aspects and has a major role to play in some. The capacity of trees to grow under difficult climatic and soil conditions, coupled with their potential for soil conservation, gives agroforestry a potential in the main types of marginal lands: semiarid, sloping and those with soil constraints. There is a demonstrated potential for reclamation of degraded land. As well as crop breeding, research programmes are under way to select or, in the longer term, breed trees tolerant of adverse soil conditions. Tree litter and prunings can substantially help to maintain soil organic matter and improve physical properties and at the same time supply nutrients. The contrast between natural and agricultural ecosystems suggests a high potential for agroforestry to lead to improved nutrient cycling and hence fertilizer use efficiency. In the case of water-use efficiency, there is a known potential, as demonstrated in studies of windbreaks and contour hedgerows, although tree-crop competition for water presents problems.

How Do We Know That Trees Improve Soils?

Underlying all aspects of the role of agroforestry in maintenance of soil fertility is the fundamental proposition that trees improve soils. How we know that this is true?

1. The soil that develops under natural forest and woodland is fertile. It is well structured, has a good water-holding capacity and has a store of nutrients bound up in the organic matter. Farmers know they will get a good crop by planting on cleared natural forest.
2. The cycles of carbon and nutrients under natural forest ecosystems are relatively closed, with much recycling and low inputs and outputs.
3. The practice of shifting cultivation demonstrated the power of trees to restore fertility lost during cropping.
4. Experience of reclamation forestry has demonstrated the power of trees to build up fertility on degraded land.

What Makes a Good Soil-Improving Tree?

It would be useful to have guidelines on which properties of a tree or shrub species make it desirable for the point of view of soil fertility. This would help in identifying naturally occurring species and selecting trees for systems which have soil improvement as a specific objective.

Nitrogen fixation and a high biomass production have been widely recognized as desirable. However, many properties are specific to particular objectives of systems in which the trees are used. Even species that are shunned for their competitive effects may have a role in certain designs. An example is the way in which Eucalyptus species with a high water uptake, which adversely affects yields in adjacent crops, have been employed to lower the water table and so reduce salinization.

The properties which are likely to make a woody perennial suitable for soil fertility maintenance or improvement are:

1. A high rate of production of leafy biomass.
2. A dense network of fine roots, with a capacity for abundant mycorrhizal association.
3. The existence of deep roots.
4. A high rate of nitrogen fixation.
5. A high and balanced nutrient content in the foliage; litter of high quality (high in nitrogen, low in lignin and polyphenols).
6. An appreciable nutrient content in the root system.

7. Either rapid litter decay, where nutrient release is desired, or a moderate rate of litter decay, where maintenance of a soil cover is required.
8. Absence of toxic substances in the litter or root residues.
9. For soil reclamation, a capacity to grow on poor soils.
10. Absence of severe competitive effects with crops, particularly for water.
11. Low invasiveness.
12. Productive functions, or service functions other than soil improvement.

Not all of these properties are compatible: for example, litter of high quality is not likely to have a moderate rate of decay. The last property, the existence of productive functions, is not directly concerned with soils but is of the highest importance if the tree is to be effective in fertility maintenance. A species needs to be acceptable and desirable in agroforestry systems from other points of view, especially production. A tree might have all the desirable properties above, but, if it is not planted and cared for, it will not be effective in improving soil fertility.

Summary of Effects of Trees on Soils

The capacity of trees to maintain or improve soils is shown by the high fertility status and closed nutrient cycling under natural forest, the restoration of fertility under forest fallow in shifting cultivation, and the experience of reclamation forestry and agroforestry.

Soil transects frequently show higher organic matter and better soil physical properties under trees. Some species, most notably Faidherbia albida, regularly give higher crop yields beneath the tree canopy. Trees improve soil fertility by processes which:

- increase additions to the soil;
- reduce losses from the soil;
- improve soil physical, chemical and biological conditions.

The most important sets of processes are those by which trees:

- check runoff and soil erosion;
- maintain soil organic matter and physical properties;
- increase nutrient inputs, through nitrogen fixation and uptake from deep soil horizons;
- promote more closed nutrient cycling.

Trees may also adversely affect associated crops. The effects of allelopathy (inhibition effects) have probably been exaggerated by mistaking them for, or confounding them with, other processes. Competition for water is a serious but not insuperable problem in all dry environments, whereas competition for nutrients has rarely been demonstrated.

Where the net effect of tree—crop interactions is positive, the length of the tree—crop interface, or extent of the ecological fields, should be maximized. If the net effect is negative, the aim of agroforestry system design should be to reduce the length of the interface

.

A range of properties have been identified which make tree species suited to soil improvement. For many purposes, high biomass production, nitrogen fixation, a combination of fine feeder roots with tap roots and litter with high nutrient content are suitable. Tolerance to initially poor soil conditions is clearly needed for reclamation. About 100 species have been identified which are known to fulfil soil-improving functions, but there is much scope to increase this range.

The following are the principal trees and shrubs that have been employed for soil improvement (from Webb et al., 1984; von Carlowitz, 1986; von Carlowitz et al., 1991; MacDicken, 1994; Young, 1989a, p. 159). Names in parentheses are synonyms formerly in use. Species marked with an *asterisk were not listed in the Original Source, but have been added on the basis of recent research.

Acacia auriculiformis
Acacia cyanophylla
Acacia mangium
Acacia mearnsii
Acacia nilotica
Acacia senegal
Acacia seyal
Acacia tortilis
Albizia lebbeck
Albizia saman (Samanea saman)
Anacardium occidentale
Alnus acuminata
Alnus nepalensis
Alnus spp.
Atriplex spp.
Azadirachta indica
Bactris gasipaes
Bamboo genera
Cajanus cajan
Calliandra calothyrsus
Casuarina cunninghamiana
Casuarina equisetifolia
Casuarina glauca
*Centrosema pubescens
Cordia alliodora
*Crotalaria spp.
Dalbergia sissoo
Dactyladenia barteri (Acioa barteri)
Dendrocalamus spp.
Erythrina caffra
Erythrina orientalis
Erythrina poeppigiana
Faidherbia albida (Acacia albida)
Flemingia congesta (Flemingia macrophylla)
Gliricidia sepium
Grevillea robusta
Inga edulis
Inga jinicuil
Leucaena diversifolia
Leucaena leucocephala
Melaleuca leucadendron
Melia azedarach
Musanga cecropioides
Paraserianthes falcataria (Albizia falcataria)
Parkia biglobosa (Parkia africana)
Paulownia elongata
Peltophorum dasyrrachis
Populus deltoides
Prosopis chilensis
Prosopis cineraria
Prosopis glandulosa
Prosopis juliflora
Prosopis tamarugo
Schinus molle
Senna reticulata
Senna siamea (Cassia siamea)
Senna spectabilis (Cassia spectabilis)
Sesbania bispinosa
Sesbania grandiflora
Sesbania rostrata
Sesbania sesban
Tamarix aphylla
Tephrosia candida
*Tephrosia vogelii
*Tithonia diversifolia
Ziziphus mauritiana
Ziziphus nummularia
Zizyphus spina-christi

Recent Study

The soil-improving capacities of trees, and how these can be applied in practical agroforestry systems, continues to be a major focus of agroforestry. In a recent overview of agroforestry research (Nair and Latt, 1997), six out of ten review articles were concerned wholly or in substantial part with soil fertility aspects. One important recent change of emphasis is that less attention is being given to hedgerow intercropping (alley cropping), in view of the observed reluctance of farmers to adopt this system, whilst more emphasis is now placed on systems of managed tree fallows (Buresh and Cooper, 1999). An account of using trees to lower the water table, referred to above, is given by Burgess et al. (1998). Recent successful projects in soil fertility improvement by trees are described by Rao et al. (1998) and Niang et al. (1999).

References

- Burgess, S. and 5 others. 1998. **Trees as water pumps: restoring water balances in Australian and Kenyan soils**. Agroforestry Today 10(3): 18-20).
- MacDicken, K.G. 1991. **Selection and Management of Nitrogen Fixing Trees**. Winrock International, Morriltion, Arkansas, USA.
- Nair, P.K.R., and Latt, C.R. (eds.) 1997. **Directions in tropical agroforestry research**. Agroforestry Systems, Special Issue, 38: 1-249.
- Niang, A. and 5 others. 1999. **Soil fertility replenishment in western Kenya**. Agroforestry Today 11(1-2): 19-21.
- von Carlowitz, P.G. 1986. **Multipurpose Tree and Shrub Seed Directory**. ICRAF, Nairobi.
- von Carlowitz, P.G., Wolf, G.V., and Kemperman, R.E.M. 1991. **Multipurpose Tree and Shrub Database**. An Information and Decision-support System. GTZ, Eschborn, Germany.
- Webb, D.B., Wood, P. J., Smith, J.P., and Henman, G.S. 1984. **A Guide to Species Selection in Tropical and Sub-tropical Plantations**. Commonwealth Forestry Institute, Oxford, UK.
- Young, A. 1989. **Agroforestry for Soil Conservation**. CAB International, Wallingford, UK.

The above excerpts are adapted from Chapter 2 of Agroforestry for Soil Management 2nd Edition with permission of the author and publisher. Details of the processes involved are discussed in detain in the original text. Agroforestry For Soil Management 2nd Edition presents a synthesis of evidence from agriculture, forestry and soil science, drawing on over 700 published sources dating largely from the 1990s. These include both results of field trials of agronomy systems, and research into the plant-soil processes which take place within them. It is a valuable resource for research scientists, or for practical scientists, agronomists and foresters. The book can be purchased through many resellers including www.amazon.com, www.amazon.co.uk, and www.bookshop.co.uk as well as through the publisher CAB International at: http://www.cabi.org/bookshop/index.asp.

Reprinted by Wilkinson, K. M. and Elevitch, C. R. in The Overstory #61, 2000, Permanent Agriculture Resources, P.O. Box 428, Holualoa, HI 96725, Web site: http://www.overstory.org