Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

J P P Journal of Pharmacognosy and Phytochemistry

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2017; 6(5): 2044-2048
Received: 03-07-2017
Accepted: 04-08-2017

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Bioremediation of problematic soils through Agroforestry practices

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Abstract
The review article shows the capacity of trees to maintain or improve soils characteristics 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. We can improve problematic soils using tree crops along with agricultural crops without using pesticides, fertilizers and insecticides. Soil transects frequently show higher organic matter and better soil physical properties under trees. Some species, most notably *Faidherbia abide*, regularly give higher crop yields beneath the tree canopy. Leguminous tree crops increases the fertility and productivity of soils.

Keywords: Bioremediation, Agroforestry, Saline soil, Acidic soils and saline-acidic soils.

Introduction
"Remediate" means to solve a problem and "Bio-remediation" means to use biological organisms to solve an environmental problem such as contaminated soil or groundwater. Agroforestry is the collective name for all land use systems in which woody perennials are deliberately grown with agriculture crops and/or animals either in some form of spatial or temporal sequence. In agroforestry system there must be ecological and economic interaction between the components. Agroforestry systems have the potential to make use of marginal and degraded lands through the soil improving effects of trees (Lundgren and Raintree, 1982) [5]. Problematic soils are those soils which are not suitable for arable farming because of specific limitations.

Soil
Trees, whose roots reach deep into the underlying rock of most northeastern soils, break that rock down with both the mechanical force of root pressure and the chemical force of humic acids. They then take up the resulting minerals and other nutrients into their biomass as trunk, branches, leaves, roots, etc Eventually this material is deposited back in the forest floor as organic matter to build the soil. Over a lifetime, trees shed many times their own mass to the soil in which they grow. Trees have evolved in combination with another complex form of life, fungi. As Paul stamens makes clear in this issue and elsewhere, it is hard to overestimate the importance of mushrooms in forest life. Their mycelia form a complex forking network of interwoven strands of cells that grow beyond the immediate tree's root zone, extending, in extreme cases, over many acres. The mycelia content of topsoil in a Pacific Northwestern Douglas Fir forest has been estimated to be as much as 10% of biomass! Each mycelium gives off enzymes which unlock organic compounds in the surrounding matrix, releasing carbon, nitrogen, and other elements that are then absorbed and concentrated directly into the network. Most of this work occurs in the rhizosphere, the area where roots and soil come into contact. About a millimeter in width, it surrounds both tree root hairs and mycorrhizae (the mycelia of certain mushrooms which form a symbiotic relationship with the roots of host plants). At the boundary of the root hairs, soil and mycelia, so many cells interpenetrate each other it is not so much an interface as a jelly, constantly exchanging water, carbohydrates, organic acids, vitamins and other substances. Both fungi and tree benefit from this collaboration, and ecologists believe that a healthy forest is dependent upon the presence of an abundance and variety of micro Because of their ability to rapidly decompose complex hydrocarbons into their basic constituent elements, fungi have recently been the focus of interest in decontaminating toxic waste sites. They can be used on-site without transporting the toxic material, a significant cost advantage over other technologies. Varieties such as white rot fungi and brown rot fungi, which produce powerful lignin peroxides and celluloses, are particularly efficient at such bioremediation.

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 agro ecosystems;
- 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 programmers' are under way to select or, in the longer term, breed trees tolerant of adverse soil conditions. Tree litter and pruning's 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 hedgerow, 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 Stalinization.

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

- A high rate of production of leafy biomass.
- A dense network of fine roots, with a capacity for abundant mycorrhizal association.
- The existence of deep roots.
- A high rate of nitrogen fixation.
- A high and balanced nutrient content in the foliage; litter of high quality (high in nitrogen, low in lignin and polyphones).
- An appreciable nutrient content in the root system.
- Either rapid litter decay, where nutrient release is desired, or a moderate rate of litter decay, where maintenance of a soil cover is required.
- Absence of toxic substances in the litter or root residues.
- For soil reclamation, a capacity to grow on poor soils.
- Absence of severe competitive effects with crops, particularly for water.
- Low invasiveness.
- 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 abide*, 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 fulfill soil improving functions, but there is much scope to increase this range.

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. 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 An account of using trees to lower the water table, referred to above, is given by Burgess *et al*. (1998) [3]. Recent successful projects in soil fertility improvement by trees are described by Niang *et al.* (1999) [7]. A continuity of land disturbance from up- to down slope will facilitate sediment transport to streams. Roads, trails and footpaths within these land management mosaics will further exacerbate linkages to streams. Fragmented intensive land uses that are interspersed by trees or brush land appear to be a viable solution for mitigating down slope sediment transport by providing areas of high infiltration along with ‘roughness elements’ on the landscape where sediment deposition can occur. A better understanding of sediment transport and routing processes is needed at the catchment scale to develop improved predictive methods and to assess the cumulative effects of distributed tropical land uses. Recognition of the “truths, myths, and uncertainties” related to erosion processes and consequences in tropical Southeast Asia will assist land managers, land owners, and policy makers in formulating appropriate and prudent decisions that will contribute to more sustainable use of forest lands as well as options for rehabilitation of previously forested lands that have been degraded. While widespread land cover changes in support of recreation have been noted to increase erosion and sedimentation in the region few studies have attempted to link either surface erosion or landslide processes with specific recreational impacts, such as forest clearance, resort construction, water diversions, roads, hiking and animal trails, and all-terrain vehicle tracks, in steep terrain. Agroforestry proves to be one of the cheapest and best mode for the reclamation of all such degraded lands.

Kinds of Problem Soils

There are two types of problems.

1. Physical problems	2. Chemical Problems
• Fluffy paddy soil	1. Acidic soils
• Sandy soil	2. Salt affected soils –Saline soils
• Subsoil hardening or hardpan	-Sodic soils
• Surface crusting	-Saline-sodic soils
• Water logged soil	
• Peat and marshy soils	

1) **Fluffy Paddy soils –** these are the low mechanical strength soil developed under continuous rice cultivation practice. Puddling break soil aggregates into a uniform structure less mass.

2) **Sandy soil-** Sandy soils are the result of the weathering and disintegration of a variety of rocks such as Granite, Limestone and Quartz. This soil is found in Haryana, U.P., Bihar states of India.

3) **Hardpan soil-** these occurs in red soils due to illuviation of clay in association with oxides of Fe, Al and calcium carbonate. It prevents root proliferation and limits nutrient uptake from surface soil.

4) **Surface crusting –** it refers to the crust formation at the surface of the soil.This is due to presence of colloidal oxides of iron and aluminium in Alfisols which binds the soil particles under wet regimes.

5) **Peat and Marshy Soil-** Occur in Humid region Formed by accumulation organic matter black in colour and High acidic. Areas: Kottayam and Alleppey in Kerala, Coastal Odisha, Sunderbans of W.B.

6) **Waterlogged Soil-** In any land where Excessive water content and inadequate aeration in the soil called waterlogged soil.

Bioremediation through agroforestry

- Tree species: *Eucalyptus robusta, Syzygium cumuni, Terminalia arjuna, Salix tetrasperma, Dalbergia latifolia, Eucalyptus camaldulensis, Eucalyptus grandis*
- Grasses: *Brachiaria mutica, Dichanthium caricosum, Paspalum notatum, Brachiaria decumbens.*

Table 1: Major properties of waterlogged soils relevant to plant survival and growth.

Property	Waterlogged
Electrical conductivity of water extracted from a saturated soil paste	not applicable
Exchangeable sodium percentage	not applicable
pH	pH fluctuations
Major products	Anaerobic respiration end products
Physical structure	Variable: low 02 concentrations
Soil water	Excess supply
Essential nutrients	Imbalance

(Marcar and Khanna (1997) [6].

Chemical Problem

Acid soils – This soil having pH less than 7 is called Acidic Soil and extremely acidic soil has pH between 4- 4.75.These are formed due to leaching of bases in high rainfall zones and also due to development of soils from acidic parent materials like granite and sandstone and application of acid forming fertilizers. It is common in Pine forest.

Areas: Karnataka, M.P., Odisha, West Bengal, Kerala, Assam, Bihar.

Adverse effect on plant growth

- High solubility of elements like Al, Mn and Fe in toxic amounts due to high soil acidity.
- Beneficial activities of soil micro- organisms are adversely affected.
- Due to soil acidity, nutrients such as Ca and K may be deficient.

Salt affected soils – the salt affected land affect plant growth due to presence of excess soluble salts, high concentration of specific ions, adverse influence on different metabolic processes and imbalance in the uptake of ion. They develop from normal soils through the accumulation of salts from applied irrigation water, upward movement of salts from subsoil due to excess evaporation sea water inundation and deposition of wind blown salts. The main distinguishing chemical characteristics of different classes of salt affected soils are summarized below:

Class	EC (mmhos/cm)	ESP	pH
Saline soil	>4	<15	<8.5
Alkali or sodic soil	<4	>15	>8.5
Saline-alkali soil	>4	>15	>8.5

Kinds of salt-affected soils

1. Saline soils: Salt problems in general
2. Sodic soils: Sodium problems
3. Saline-sodic soils: Problems with sodium and other salts

1. **Saline Soil-** The soil with excess salt (NaCl) is called Saline soil. It is found in Uttar Pradesh, Gujarat, West Bengal.

Causes

Salty irrigation water: The application of irrigation water without proper management (lack of drainage & leaching facility) increase the water table & surface salt content in soil.

Upward movement of groundwater: Water move upward through capillary activity and salt accumulate on the soil surface in the form of crystallization.

Canal and Sea: Sea water enters into the land by inundation and deposits salts on the soil surface.

Saline Soil Problems: It is caused by the accumulation of soluble salts in the root zone. These excess salts reduce plant growth by altering water uptake and causing imbalance.

Mechanism for reclamation of saline soils

Halophytes are the native flora of saline soils. Few are suitable for reclamation. The basic principle of reclamation is the removal of excess salt to a desired level in root zone. Providing proper drainage, use of salt free irrigation water, acidic fertilizers, organic manures etc. are some of the mechanisms adopted. The process of salinization is accelerated by_rapid evaporation from the surface. Leaching with water of good quality and adequate drainage of excess water from the soil is carried out. The selection of salt tolerant species is done which include suitable tree species such as *Prosopis juliflora*, *Tamarix articulate*, *Acacia nilotica* etc. Agricultural crops include barley, sugarbeet, cotton wheat, rice beans etc.

- The removal of excess salts to a desired level in root zone.
- Leaching and adequate drainage.
- Mulching to reduce salinity.
- Organic matter addition keeps the salts in diluted form and increases water holding capacity of soil.
- Green manuring, tree planting.

Bioremediation through Agroforestry

- Promising woody species for saline soils are *Salvadora spp.*, *Prosopis juliflora*, *Acacia nilotica*, *Parkinsonia aculeata*, *Butea monosperma*, *Terminalia arjuna*, *Salix spp.*, *D. sissoo and Casurina equisetifolia.*
- Highly salt tolerant and high biomass producing grass species include *Aeluropus lagopoides*, *Sporobolus helvolus*, *Cynodon dactylon and Brachiaria ramosa.*

2. Sodic Soil

Alkali or Sodic soil is defined as a soil having a conductivity of the saturation extract less than $4dSm^{-1}$ and an exchangeable sodium percentage (ESP) greater than 15. The pH is usually between 8.5-10.0. Formerly these soils were called black alkali soils and the soil so formed is called solod, soloth or degraded alkali or sodic soil.

Areas: Haryana, Punjab, Uttar Pradesh, Bihar, Rajasthan & Madhya Pradesh.

Causes: Sodic soil may impact plant growth by –
1) Specific toxicity to sodium sensitive plants.
2) Nutrients deficiencies or imbalance

3) High pH.

Mechanism for reclamation of alkali soils

- The reclamation practice include proper drainage of water to remove salts from the root zone use of salt free irrigation water, addition of organic matter, addition of molasses, alkali tolerant crops sush as paddy, cotton, mustard, wheat, tomato, onion etc. Green manuring of dhaincha has been found to be beneficial. Higher dose of N because of volatilization. Application of zinc in initial years of reclamation.

Bioremediation through Agroforestry

Prosopis juliflora and Karnal grass improves the soil condition to such an extent that after some time or years, less tolerant but more palatable fodder species such as-
Berseem (Trifolium alexandricum) senji (Melilotus parviflora) and shaftal (Trifolium resupinatum) can be grown under trees (Singh *et al*., 1993; Singh, 1995) [9].

Table 2: Changes in soil organic carbon (C) over a period of 30 years in a sodic soil planted with (*Prosopis juliflora).*

Soil depth (m)	Soil organic C (Mg ha^{-1})			
	Original soil	After 5 years	After 7 years	After 30 years
0.00–0.15	3.5	5.0	14.3	21.5
0.15–0.30	3.5	3.5	7.2	10.1
0.30–0.60	2.7	2.7	7.4	10.8
0.60–0.90	1.6	1.6	3.7	8.3
0.90–1.20	0.5	0.5	6	3.6
Total	11.8	13.3	34.2	54.3

(Bhojvaid and Timmer, 1998) [2]

Table 3: Effect of *P. juliflora -Leptochloa fusca* silvopastoral system on alkali soil properties after 6 years.

Soil property	Original (year 0)	P. juliflora only	P. juliflora + L. fusca
pH	10.3	9.3	8.9
Electrical conductivity (ds/m)	2.2	0.46	0.36
Organic carbon (%)	0.18	0.43	0.58
Available nitrogen (kg/ha)	79	133	165

(Gurbachan Singh *et al*., 1995)

3. Saline and Sodic Soil

Soil that is high in both salt and sodium is considered to be saline - sodic soil. Due to high pH and the dominance of sodium (Na^+) ions in alkali soil, part of the soil organic matter dissolves and comes into the soil solution. Extracts of such soils have a characteristic dark brown or black colour. The dissolved organic matter in the soil solution becomes deposited as a thin film on the soil surface. The prevalence of such black stains in such soils are called "Black alkali".

Areas: Parts of Gujarat, Rajasthan, Punjab, Haryana, Maharashtra.

Mechanism for reclamation

Such soils have the mixture of characteristics of both saline and alkali soils. Therefore soils showing high salinity should be reclaimed for both first for salinity and later for excessive exchangeable sodium. Growing of crops tolerant to high exchangeable sodium ensures reasonable returns during initial years of reclamation. Cropping practice including a green manure crop and/or legume is common. Low organic matter and high pH deters the biological activity and thus decreases the transformation of\and availability of nutrients, and causes significant volatilization of nitrogen from applied nitrogenous fertilizers. Tolerant crops such as rice, sugarbeet and dhaincha are used. Trees species include *Prosopis juliflora, Acacia nilotica, Prosopis chinensis etc*.

Bioremediation through Agroforestry

Acacia auriculiformis, Azadirachta indica, Casurina equisetifoia, Dalbergia sissoo, Alianthus excelsa, Prosopis cineraria, Acacia tortilis and A. nilotica tree species are used for bioremediation of the saline and sodic soils.

Table 4: Effect of agri-silvi-horticultural system on physico-chemical properties of salt-affected wastelands.

S. No.	Soil characteristics	Wasteland land (1991)	After 5 years of practicing Agroforestry(1996)
1	Soil colour	Grey	Grey
2	Texture	Silt loam	Silt loam
3	Bulk density (gm/cm3)	1.8	1.5
4	Infiltration rate (mm/hr.)	0.23	0.26
5	Organic carbon (%)	0.12	0.22
6	EC (mmhos/cm)	3.7	3.5
7	ESP (%)	40	31
8	N (kg/ha)	230	252
9	P (kg/ha)	14.0	17.5
10	K (kg/ha)	130	160

(Singh, 1990)

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