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Agroforestry and Soil Productivity

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ARTICLE ID: 07

Introduction

Significant changes have lately occurred in the management of soil, including issues with poor soil fertility and deterioration. The previous idea was to reserve the marginal lands for extensive usage only and focus on increasing production from the more productive areas. The majority of steeply sloped and extremely drought-prone lands were left uncultivated because it was rarely cost-effective to produce in these locations. Inputs such as better crop types, fertilisers, chemical pest and disease management, and irrigation were supposed to overcome soil restrictions.

In recent years, there has been a notable rise in crop production through the use of newly designed high yielding crop varieties, enhanced agronomic management practices, chemical fertiliser use, effective water management and timely plant protection measures. However, because of the physical deterioration of the soil and the deficiency of micronutrients, the continual application of fertilisers has decreased. Above all, a great deal of impoverished farmers is unable to acquire expensive fertilisers and other inputs, nor do they have the funds to assume the associated risks. The amount of freshwater that can be used for irrigation has also been severely limited, making it impossible to increase the area under irrigation.

A new set of approaches has been recommended by Young (1997) to overcome these soil related constraints and to maintain or enhance the productivity level of soil.

1. To find ways for sustainable use of marginal lands
2. To reclaim and restore degraded lands
3. To improve germplasm to produce plant varieties suitably adapted to soil constraints
4. To maintain soil organic matter and biological activity, with benefits of both for soil physical conditions and balanced nutrient supplies
5. To improve nutrient cycling and nutrient use efficiency in agro ecosystem.

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6. To use fertilizers and other external inputs at moderate levels seeking strategic use to overcome deficiencies that cannot otherwise be remedied.
7. To improve water use efficiency

Agroforestry has a significant role to play in several of these areas and can positively impact all of them. Agroforestry systems have potential in marginal, semi-arid, and sloping soils due to trees' ability to flourish in challenging climatic and soil conditions, as well as their capacity to conserve soil and improve nutrient cycling. Tree litter and prunings can significantly contribute to the preservation of soil organic matter and enhance the physical characteristics of the soil, which will result in an ongoing supply of nutrients.

Trees improve soils

Due to trees' ability to improve soil, agroforestry systems have the potential to utilise marginal and degraded lands. Since trees have longer residence times, accumulate more biomass, and have more extensive root systems than annual crops, they have a different effect on the characteristics of the soil. Facts supporting the concept that trees benefit soils include the following

1. The soil under natural forest is fertile. It is well structured, has a good water holding capacity and has a store of nutrients bounded up in the organic matter. From time immemorial, farmers have known that they will get a good crop by planting in forest clearings.
2. In natural forests, nutrients are efficiently cycled with very small inputs and outputs from the system. A forest ecosystem is a relatively closed system in terms of nutrient transfer, storage and cycling in contrast to agricultural systems.
3. Reclamation of degraded land through afforestation or a similar type of tree based land use system is found to be best to restore soil fertility in many areas.
4. The practice of shifting cultivation demonstrated the power of trees to restore fertility lost during cropping.
5. The conversion of natural forest ecosystems to arable farming systems leads to a decline in soil fertility and a degradation of other soil properties unless appropriate corrective measures are taken.

Trees that are nitrogen fixers and produce a lot of biomass are the best kind of trees. Many of the attributes, nevertheless, are unique to the goals of the systems that employ the

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trees. The characteristics that are probably going to make a tree good for maintaining or enhancing soil fertility are

1. A high rate of production of leafy biomass.
2. A high rate of nitrogen fixation.
3. The existence of deep roots and a dense network of fine roots with a capacity for abundant mycorrhizal association.
4. A high and balanced nutrient content in the foliage; litter with high nitrogen, low lignin and polyphenols.
5. An appreciable nutrient content in the root system.
6. Rapid litter decay, where nutrient release is desired, and a moderate rate of litter decay, where maintenance of a soil cover is required.
7. Absence of toxic substances in the litter or root residues.
8. A capacity to grow on poor soils for reclamation.
9. Absence of severe competitive effects with crops, particularly for water.
10. Low invasiveness
11. Productive and service functions other than soil improvement.
12. The existence of productive functions is not directly concerned with soils but is of the highest importance if the trees are to be effective in fertility maintenance. A species needs to be acceptable and desirable in agroforestry systems from production point of view.

Effects of agroforestry practices on soils

Depending on the crop type, temperature, and geography, agroforestry can have varying effects on soil quality through changes in ecosystem functions and services brought about by the direct and indirect effects of trees. By pumping back nutrients that have been leached through their deep roots, trees contribute significantly to the cycling of nutrients by acting as a "safety net" against nutrient losses from the cycle.

The addition of trees to farms improves the soil's organic matter (OM), field capacity (FC), available potassium, available phosphorus, and bulk density (BD). This increases the soil's ability to hold water, or WHC, and progressively releases it into the plants, acting as a sponge. In order to decrease bulk soil density and promote soil aggregation, OM is added. In arid and semi-arid regions, this decreased soil BD improves groundwater recharging, air

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circulation, water dispersion in the rhizosphere, and soil nutrient quality. The primary source of nutrients and organic carbon (OC) in agroforestry systems is the buildup of litter from the shedding of leaves and twigs. Both directly and indirectly, the soil organic carbon (SOC) affects how efficiently nutrients are used in agriculture. Because high OM soils have higher absorption and availability and active deep root systems, the nutrient utilisation efficiency will be improved. Furthermore, the addition of OM is likely to have enhanced microbial diversity, which in turn produces mycorrhizae that release P and make it available to crops.

The incorporation of trees alongside agricultural crops affects the microorganisms that live in the soil in addition to the physical and chemical aspects of the soil. Because it significantly improves fertility and productivity, the soil microbial community indirectly supports plant growth. Plant growth is influenced indirectly by the soil microbial community, which also plays a significant role in increasing productivity and fertility. Microbial communities receive the essential energy source from falling litter and root exudation in the form of amino acids, sugars, organic acids, and other materials.

Beneficial effects of trees on soil

1. **Maintenance or increase in soil organic matter:** Trees are believed to increase or at least maintain the organic matter levels of the soil. This is mainly through litter fall and continuous degradation or sloughing off of roots of standing trees. Pruning materials from the woody perennials used in agroforestry systems add a huge quantity of organic matter to the soil, and this is generally high in nitrogen. The root biomass of trees is usually 20-30% of total plant biomass. The ability of the root system to improve soil organic matter is crucial factor in low input agricultural systems with low productivity levels. Roots also store considerable quantities of nutrients.
2. **Nitrogen fixation:** Biological nitrogen fixation takes place through symbiotic and non-symbiotic means. Symbiotic fixation occurs through the association of plant roots of many leguminous plant species with N2 fixing microorganisms, *Rhizobium or Bradyrhizobium*. A few non-leguminous tree species such as *Casuarina* also nodulate with a genus of actinomycetes, *Frankia.*
3. **Nutrient uptake:** Trees are more efficient than herbaceous plants in taking up nutrients released by the weathering of soil at deeper horizons. Potassium, phosphorus, calcium, magnesium and micronutrients are released by rock weathering, particularly

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in the B/C and C soil horizons which tree roots often penetrate. Thus, nutrients in deeper soil horizons, that are unavailable to shallow rooted crops, are taken up by deep rooted trees.

4. **Atmospheric input**: Atmospheric deposition makes a significant contribution to nutrient cycling. It consists of nutrients dissolved in rainfall (wet deposition) and those carried in duct (dry deposition). Trees reduce wind speed considerably and thus favour dry deposition.
5. **Increased water infiltration**: Trees facilitate water infiltration along the root channels due to higher organic matter content in the soil. The substantially reduces run off and increases water input to the soil.
6. **Water retrieval**: The taproots of trees draw water from soil well below the depth ordinarily reached by roots of crop plants. This process increases water input in plant soil system.

Reduction of losses from the soil

1. **Protection from erosion:** Soil erosion causes loss of soil organic matter and nutrients, and thus results in reduction in crop yield. Agroforestry system reduces erosion through ground litter cover by tree leaves and understorey vegetation. The tree canopy may also reduce the erosion to a little extent by slashing raindrops. Trees and shrubs through their proper planting arrangements and management can act as effective barriers to control soil erosion.
2. **Nutrient retrieval and recycling:** The tree tap root systems including fine feeder roots and associated mycorrhiza intercept, absorb and recycle nutrients in the soil that would otherwise be lost through leaching, thereby making a more closed nutrient cycle.
3. **Reduction of water loss through evapotranspiration:** Tree canopies lower temperature and increase relative humidity in an agroforestry system which leads to low transpiration rate. Tree litter and prunings act as mulch on ground surface that reduces the evaporative loss of soil moisture. The water storage capacity of soil is also increased due to improved soil organic matter.
4. **Reduction in the decomposition rate of humus**:The rate of decomposition of organic matter is comparatively low under trees than in agricultural use through lower topsoil temperatur and less soil disturbance.

Effect on physical conditions of the soil

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1. **Maintenance or improvement of physical properties:** The soil physical properties such as structure, porosity, water holding capacity and erosion resistance are much improved in an agroforestry system than that of an open area or area with seasonal field crops.
2. **Modification of extremes of soil temperature:** A cover of tree leaf litter and prunings greatly reduce the surface temperatures of ground in the tropics, which sometimes exceed 50°C and adversely affect crop growth. In temperate regions, there is some protection from ground frost by the blanketing' effect of litter.
3. **Penetration of compact layers by roots:** Tree roots are capable of penetrating the layers of laterite, calcrete or hard pans in the soil, so drawing nutrients and water beneath.

Effect on chemical conditions of the soil

1. **Reduction of acidity:** Trees tend to moderate the effects of leaching through the addition of bases to the soil surface. The bases released by litter decay can help to check acidification caused by the application of fertilizers to the crops in an agroforestry system.
2. **Reduction of salinity and sodicity:** Perennial woody species in an agroforestry system can reclaim saline and alkaline soils by lowering salinity and reducing sodium saturation of the exchange complex. Trees as such cannot contribute to reduction of salinity, but they assist in water management that leads to soil amelioration and leaching out salts. Afforestation with Acacia nilotica and Eucalyptus tereticornis in Karnal region successfully reduced the soil pH from 10.5 to 9.5 over five years (Dagar, 2009).
3. **Reduction of soil toxicities caused by pollution:** The trees do not extract pollu tants from a chemically polluted soil, bu t some species are tolerant to them. The trees build up soil organic matter and ameliorate fertility which results in reducing pollution levels in the soil.

Effect on biological conditions of the soil

1. **Improvement in the activity of soil fauna:** The presence of tree litter in soil is frequently associated with higher rates of activity of soil fauna.
2. **Effects of shading:** Shade caused by the tree canopy in an agroforestry system lowers ground-surface temperatures, which reduce the rate of loss of soil organic matter by oxidation. Shading is allowed to a certain extent while trees are grown with crops. In

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most of the cases the branches are pruned up to 1/ 3rd height of the trees with advancement of age of the trees.

3. **Root nodulation:** Roots of some nitrogen fixing trees have more nodules where they are in close contact with roots of nonnitrogen fixing plants, the latter stimulating the former.
4. **Exudation of growth-promoting substances into the rhizosphere:** Root exudates by a few tree species are believed to work as growth-promoting substances for other plant species.

Adverse Effects of Trees on Soil

1. **Removal of organic matter and nutrients through tree harvest:** Trees accumulate large quantities of carbon and nutrients in their biomass, part of which is removed in harvest. The problem is greater where there is whole-tree harvesting, with gathering of fine branches and litter by local people after a timber harvest. From a soil management point of view, all branches and litter should be allowed to decay in situ, although such a practice appears unreasonable to the local people.
2. **Competition between trees and crops for nutrients:** Usually an established root system of trees or shrubs dominates that of newly planted annual crops. Ideally, trees in agroforestry systems should have a deep penetrating taproot system with limited lateral spread. Whereas lateral spread of the canopy can be controlled by pruning, root pruning is generally too expensive to be practical.
3. **Competition between trees and crops for moisture:** In the semiarid and arid zones, this is possibly the most serious problem encountered in agroforestry.
4. **Production of substances which inhibit germination or growth:** Some Eucalyptus species produce toxins which can germination or growth of some annual herbs. Some trees release organic compounds to soil which are phytotoxic and may cause problems in agroforestry systems.