# Soil and Water Conservation through Agroforestry


**Submitted By**

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**ABSTRACT**

A considerable amount of land is degraded throughout the world due to manmade and natural activities. Soil fertility and productivity are being decreased due to intense cropping system and improper management of soil. A broader field is that of soil and water conservation, since reduction in water loss through runoff is an integral part of soil conservation. Soil is conserved through enhancing soil fertility. Improvement in soil fertility takes place by the process of checking soil erosion and runoff, maintaining soil organic matter, enhancement of soil physical, chemical, and biological properties, increment of nitrogen input by N-fixing trees and shrubs, and mining of minerals from lower horizons by roots and its recycling through litter fall on ground. Agroforestry system has the potential to conserve soil through reducing erosion. Ground water quality also improved by agroforestry system. Agroforestry is a medium and a combination of agricultural and forestry technologies to create integrated, diverse and productive land use systems. Trees help to reduce direct raindrop impact on crop through reducing erosive force and water is available for crop. In agroforestry systems, soil erosion is controlled and soil fertility is increased remarkably, while water is also conserved through enhancing infiltration rate, hydraulic conductivity.



**Keywords: Agroforestry, Soil fertility, Water conservation, Land degradation.**

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# CHAPTER 1

# INTRODUCTION

The soil and water resources of our planet are finite and are already under intensive use and misuse. Soil and water conservation deals with the wise use of these two important resources. Soil and water have always been vital for sustaining life, and these resources are becoming more limited and crucial as population increases. So the importance of conserving soil productivity and protecting the quality of both soil and water must be taken under consideration because declining productivity and increasing pollution can cause disaster for all residents of the earth (Janzen et al., 2011). Soil and water conservation are deteriorated through degradation of soil. Large-scale degradation of land resources has been reported from many parts of the world (Hillel, 1991). The economic impact of land degradation is extremely severe in densely populated South Asia 13.417 million $km^2$, and sub-Saharan Africa 10.458 million $km^2$. It appears that about 70% of the total land of the world is under degradation (Dregne and Chou, 1994). Agroforestry helps to conserve soil and water.  Agroforestry practices encompass an entire spectrum of land use systems in which woody perennials are deliberately combined with agricultural crops and/or animals in some spatial or temporal arrangement (Lundgren and Raintree, 1982). Advocates have contended that soil conservation is one of its primary benefits (Young, 1989). The cover function involves reducing raindrop impact and wind action on soil particles by increasing soil cover through litter and pruning. The service functions include shade, reduction in wind speed, control of erosion and maintenance and improvement of soil fertility. The presence of woody perennials in agroforestry systems may effect several bio-physical and bio-chemical processes that determine the health of the soil substrate (Nair, 1993). The less disputed of the effects of trees on soil include: amelioration of erosion, primarily through surface litter cover and under story vegetation; maintenance or increase of organic matter and diversity, through continuous degeneration of roots and decomposition of litter; nitrogen fixation; enhancement of physical properties such as soil structure, porosity, and moisture retention due to the extensive root system and the canopy cover; and enhanced efficiency of nutrient use because the-tree-root system can intercept, absorb and recycle nutrients in the soil that would otherwise be lost through leaching (Sanchez, 1987). The leaf litter and humus built up under the tree stands control flow of water and allow them to percolate into the soil.

**Objectives of this Review**

- To make clear concept of soil and water conservation
- To know the different ways of soil and water conservation through agroforestry

# CHAPTER 2

## MATERIALS AND METHODS

This seminar paper is exclusively a review paper. So, no specific methods of studies are followed to prepare this paper. All data and information were collected and used from secondary sources. This seminar paper has been complied through reading of different books, journals, booklets, proceeding, newsletters, souvenir, consultancy report that are available in the libraries of BSMRAU.

Finally, this seminar paper was prepared with the consultation of my respective major professor and honorable seminar course instructors.

# CHAPTER 3

# REVIEW OF FINDINGS

## Land degradation - a global concern

Large-scale degradation of land resources has been reported from many parts of the world (Hillel, 1991). Land degradation is the global concern in the world, in Africa and South America 73 %, in Asia 71 %, in Australia 54 %, in Europe 65 %, in North America 74 %, (Table 1) (Dregne and Chou, 1994).

**Table 1. Estimation of all degraded lands (in million km$^2$) in dry areas**

| Continent | Total area | Degraded area | % Degraded |
|---|---|---|---|
| Africa | 14.326 | 10.458 | 73 |
| Asia | 18.814 | 13.417 | 71 |
| Australia and the Pacific | 7.012 | 3.759 | 54 |
| Europe | 1.456 | 0.943 | 65 |
| North America | 5.782 | 4.286 | 74 |
| South America | 4.207 | 3.058 | 73 |
| Total | 51.597 | 35.922 | 70 |

**(Source: Dregne and Chou, 1994)**

## Concept of soil and water conservation

Soil conservation is defined as soil fertility maintenance through control of erosion together with maintenance of organic matter, soil physical properties and nutrients, and avoidance of toxicities (Young, 1989). Soil and water are conserved through reducing of soil loss from runoff and increasing of infiltration rate. Only crop is not sufficient to reduce the velocity of runoff. When trees are grown with crops this system gives much strengthen to soil through permeability of water which is available for crop. As a result water is also conserved. In agroforestry system trees also add nutrient to the soil. Trees with deep rooting system improve ground water quality through capturing of nutrient, materials and these are deposited in surface and subsurface of soil. Therefore, soil fertility become enriched (Dury, 1991).

**Traditional Agroforestry system of South Asia**

*Jhum* is the most primitive and popular agroforestry system practiced across the entire North Eastern Hill region. Usually all the essential crops such as paddy, maize, tapioca, *colocasia*, millets, sweet potato, ginger etc. are grown on the same piece of land as mixed crop. *Jhum* in its most traditional form is not a very unsustainable land use practice particularly when the *Jhum* cycle is more than 20 years. The soils get enough time to rejuvenate and restore their health and productive capacity. However, with increase in population pressure on land resources, the *Jhum* cycle is getting reduced very fast and reached at 4 years at present. This makes the system unstable and lead to severe land degradation as a result of soil erosion and associated factors such as reduction in soil organic matter, nutrients etc. In terms of percentage of the total geographical area, Mizoram (36.15 %) and Tripura (30.49 %) are the most severely affected by *jhum* cultivation (Roy et al., 2002, Rao and Bhattacharyya, 2005).

**Beneficial effects of agroforestry on soil and water**

On the basis of various experimental evidences, Dwivedi (1992) pointed out some beneficial effects of agroforestry on soil, such as:

(i) Reduction of loss of soil as well as nutrients through reduction of run-off,

(ii) Addition of carbon and its transformation through leaf, twig, bark fall etc.,

(iii) Nitrogen enrichment by fixation of nitrogen by nitrogen fixing trees, shrubs etc.,

(iv) Improvement of physical conditions of soil such as water holding capacity, permeability, drainage etc.,

(v) Release and recycling of nutrients by affecting biochemical nutrient cycling,

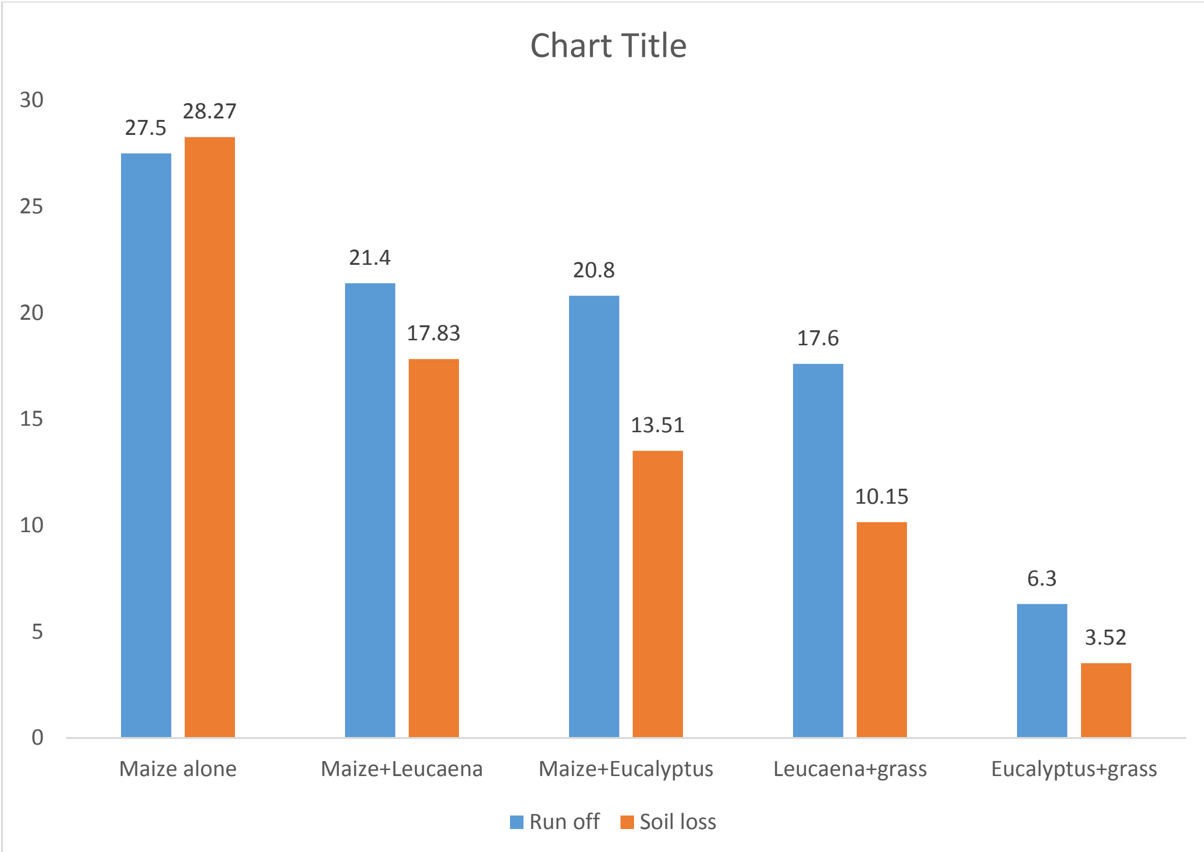
(vi) More microbial associations and addition of more root biomass,

(vii) Moderately effect on extreme conditions of soil acidity and alkalinity,

(viii) Lowering effect on the water-table in areas where the water table is high.

**Agroforestry for erosion control**

Alley cropping or hedgerow cultivation is very helpful in controlling of soil erosion in the hilly area. Hill Tract Development Board of Bangladesh identified five nitrogen fixing trees species like *Leucaena leucocephala, Gliricidia sepium, Indigofera tysmani, Fleminigia spp.* and *Desmodium rensonii* etc. and two grass species *Vetiviera zizanoides* and *Thysanolaena maxima* for controlling run off and erosion in the hilly region of Bangladesh (Khisa et al., 2002). It was found that runoff and soil loss were substantially reduced when small watersheds with agriculture were replaced either by trees and grasses (silvipasture) or with mechanical measures (Singh et al., 1990). To control erosion it is necessary to reduce average runoff as well as soil loss. In Agroforestry systems run-off percentage and soil loss is lower as compared with sole crop system. In Maize alone runoff is 27.5 %, whereas in Eucalyptus with grass treatment runoff is 6.3 %. In case of soil loss, in Maize alone soil loss is 28.27 ton $ha^{-1}$ but in Eucalyptus with grass treatment soil loss is decreasing 3.52 ton $ha^{-1}$ (Figure 1) (Young, 1989).




**(Source: Young, 1989)**

**Figure 1: Average runoff and soil loss under different land uses**

In a study, Wiersum (1984) found that different agroforestry systems cause lowest soil erosion. In multistoried tree garden systems erosion is often negligible. Table 2 summarizes a comparison of erosion rate in various tropical moist forest and tree crop system. The data point out that a good direct soil cover is important for decreasing erosion. In undisturbed tree stands such cover is usually present in the form of litter. Litter production is limited as a result of leaf harvest or wide spacing. Erosion rates is increase when litter and understory vegetation are removed (Table 2).

**Table 2: Rates of soil erosion in tropical ecosystems**

| Land use system | Erosion (t/ ha/ year) | |
|---|---|---|
| | Minimum | Maximum |
| Multi storey tree gardens | 0.01 | 0.14 |
| Natural rain forest | 0.03 | 6.16 |
| Shifting cultivation, fallow period | 0.05 | 7.40 |
| Forest plantation, un disturbed | 0.02 | 6.20 |
| Tree crops with cover crop or mulch | 0.10 | 5.60 |
| Shifting cultivation, cropping period | 0.40 | 70.05 |
| Taungya, cultivation period | 0.63 | 17.37 |
| Tree crops, clean weeded | 1.20 | 182.90 |
| Forest plantations, litter removed or burned | 5.92 | 104.80 |

**(Source: Wiersum, 1984)**

## Agroforestry for improving soil fertility

### Nutrient buildup

The effects of long-term (7 years) cultivation of crops under different agroforestry systems as compared to crops alone are given in table 3. It can be seen from the table 3; the total content of N was higher in soil tree crop stand as compared to crop systems in top soil (0-15 cm). The C: N ratio was narrow in tree crop system as compared to sole crop stand. There was too much retrieval of exchangeable Ca, Mg, K and available P in agroforestry system in the subsurface through roots and recycled by litter fall, and were high in agroforestry systems caused by its additional input through fertilize (Table 3) (Dhyani, 1998).

**Table 3. Nutrients build up in top soil (0-15 cm) in the sole tree stand and under agroforestry systems**

| Agroforestry system | Total N(%) | C/N | Exchangeable nutrients (me/100) | | | Avail. P (ppm) |
|---|---|---|---|---|---|---|
| | | | $Ca^{2+}$ | $Mg^{2+}$ | $K^{+}$ | |
| **Tree+crop** | | | | | | |
| Alder | 0.23 | 7.1 | 2.91 | 2.05 | 0.41 | 12.1 |
| *Albizia* | 0.20 | 8.0 | 3.02 | 4.46 | 0.39 | 18.1 |
| Cherry | 0.15 | 9.6 | 2.11 | 1.90 | 0.23 | 10.5 |
| Mandarin | 0.17 | 9.2 | 2.52 | 2.00 | 0.27 | 11.8 |
| **Sole crop** | 0.11 | 12.2 | 0.53 | 0.51 | 0.19 | 5.8 |
| Sd | 0.04 | 1.61 | 0.83 | 1.28 | 0.08 | 3.39 |

**(Source: Dhyani, 1998)**

In Sikkim, farmers cropped Mandarin based Agroforestry System for organic matter (%), available Phosphorus (ppm), available Potassium (ppm) which ultimately helps in minimum fertilizer use. With the increasing of Orchard age, organic matter, phosphorus, and potassium are also increased. The highest (7.37±0.42) % organic matter was found in orchard age above 40 years and lowest (6.34±0.43) % was found in below 20 years orchard age. The highest (80.0±11.3) ppm and lowest (64.4±14.4) ppm available phosphorus were found in orchard age of above 40 years and below 20 years. The highest (234.6±40.8) ppm and lowest (166±50.0) ppm available potassium were found in orchard age of above 40 years and below 20 years (Table 4) (Upadhyaya et al., 1994).

**Table 4. Soil fertility builds up in mandarin orchards of Sikkim**

| **Fertility indices** | **Orchard age (years)** | | |
|---|---|---|---|
| | **Below 20** | **20-40** | **Above 40** |
| Organic matter(%) | 6.34±0.43 | 6.81±0.39 | 7.37±0.42 |
| Available P, ppm | 64.4±14.4 | 72.5±13.2 | 80.0±11.3 |
| Available K, ppm | 166±50.0 | 204.1±28.6 | 234.6±40.8 |

**(Source: Upadhyaya et al., 1994)**

This agroforestry system has resulted buildup of organic matter, available P and K with increased orchards age due to regular addition of organic manure to trees and intercrops. Therefore, this system is sustainable there from soil productivity point of view, because it has positive effect, even on over yielding system (Upadhyaya et al., 1994).

**Nitrogen fixation and nutrient cycling**

Nitrogen fixing trees can make substantial centrifugations to nitrogen inputs. NFTs can substantially increase nitrogen inputs to agroforetsry systems. It is well established that *Leucaena* can fix 100-500 kg N per ha per year or more in pure stands and 75-100 kg when grown in hedgerow intercropping systems. *Sesbania rostrata* grown in association with Swamp rice systems can also attain 500 kg. N per ha. per year. *Frankia albida* and *Acacia senegal* are estimated to fix 20-60 kg. N per year. Other fast growing species including *Sesbania sesban, Gliricidia sepium, Albizia lebbek*, *A. mangium* and non-legume casuarina fix amounts of the order of 50-100kg. N per ha per year. Increasing the nutrient use efficiency through agroforestry can be achieved by increasing the cycling of nutrients from tree litter and prunings via the soil into the crops, reducing losses by leaching reducing the losses by erosion. The nutrient transfer from tree residues to crops is through litter and prunings. Agroforestry systems and other tree-based systems are commonly credited with more efficient nutrient cycling than many other systems because of the presence of woody perennials in the system. These woody perennials have theoretically more extensive and deeper root systems and have a potential to capture and recycle a larger amount of nutrients. Their litter contribution to the soils surface is greater than that of herbaceous plants. About 20 to 30% of the total living biomass of the trees is in their roots and there is a constant addition of organic matter to the soil through dead and decaying roots. The deep rooting ability of trees, helps trees to absorb nutrients from the soil depths that crop roots cannot reach and recycle them to the surface soil layers through addition of litter (Jadhav et al., 2006). The extent of litterfall in some of the systems and the quantities of nutrients are recycled. From the table it is observed that woody species in Alley cropping gives higher amount of nutrients than other species in shade system and infertile soil with Alley cropping system. Fertile soil with alley cropping system gives the higher amount of dry matter than other species in shade system and infertile soil with alley cropping system (Table 5).

**Table 5. Dry matter and nutrient inputs via litterfall/ prunings in various production systems in the humid tropics**

| **System** | **Dry matter t/ ha/ year** | **Nutrient inputs kg/ ha/ year** | | | | |
|---|---|---|---|---|---|---|
| | | **N** | **P** | **K** | **Ca** | **Mg** |
| Fertile soils- Alley cropping | | | | | | |
| *Leucaena* | 5-6.5 | 160 | 15 | 150 | 40 | 15 |
| *Gliricidia* | 12.3 | 358 | 28 | 232 | 144 | 60 |
| *Erythrina* | 8.1 | 198 | 25 | 147 | 111 | 26 |
| Shade systems | | | | | | |
| Coffee/ *Erythrina* | 17.2 | 366 | 30 | 264 | 243 | 48 |
| Cacao/ *Erythrina* | 5.8 | 95 | 11 | 57 | 108 | 43 |
| Cacao/ mixed shade | 8.4 | 52 | 4 | 38 | 89 | 26 |
| Infertile soils- Alley cropping | | | | | | |
| *Inga edulis* | 5.6 | 136 | 10 | 52 | 31 | 8 |
| *Erythrina spp.* | 1.9 | 34 | 4 | 19 | 8 | 4 |

**(Source: Jadhav et al., 2006)**

### Agroforestry Systems as carbon Sinks and for soil fertility

In India, average sequestration potential in agroforestry has been estimated to be 25 ton Carbon

$Ha^{-1}$ over 96 million ha, but there is a considerable variation in different regions depending upon the biomass production. However, compared to degraded systems, agroforestry may hold more carbon. For example, the aboveground biomass accumulation in a Central Himalayan agroforestry system has been found to be 3.9 ton per ha per year compared to 1.1 ton per ha per year at the degraded forestland (Table 6).

**Table 6. Regional Examples of soil- fertility enhancement in multifunctional agroforestry systems in India**

| Region | Challenge | Changes observed due to agroforestry |
|---|---|---|
| Himalayas (Kurukshetra) | Improvement of sodic soils | Increase in microbial biomass, tree biomass and soil carbon: enhanced nitrogen availability |
| Himalayas | Restoration of abandoned agricul-tural sites | Biomass accumulation (3.9t/ha in agroforests compared to 1.1 t/ha in degraded forests): improvement in soil physico-chemical characteristics; carbon sequestration |
| Western Himalayas | Reducing soil and water loss in agro-ecosystems in steep slopes | Contour tree- rows (hedge-rows), reduced run off and soil loss by 40 and 48% respectively (in comparison to 347 mm run-off, 39Mg /ha soil loss per year under 1000 mm rainfall conditions) |
| Sikkim Himalaya | Enhancing litter production and soil nutrient dynamics | Nitrogen-fixing trees increase N and P cycling through increased production of litter and influence greater release of N and P; nitrogen-fixing species help in maintenance of soil organic matter, with higher N mineralisation rates in agroforestry systems |
| IndoGangetic Plains (UP) | Biomass production and nutrient dyna-mics in nutrient deficient and toxic soils | Biomass production (49 t/ha/decade) |
| Western India (Karnal) | Improvement of soil fertility of moder-ately alkaline soils | Microbial biomass C which was low in rice-berseem crop (96.14 g/g soil) increased in soil under tree plantation (109.12 g / g soil); soil carbon increased by 11-52% due to integration of trees and crops |
| Central India | Soil improvement | Decline in proportion of soil sand particles: increase in soil organic C, N, P and mineral N |

**(Source: Pandey, 2007)**

Soil organisms are the key engineers in nutrient turn over, organic matter transformation, physical architect of soil structure. The microbial biomass includes both primary and secondary decomposers, represents an important component in the cycling of nutrients in soil, and governs the breakdown of organic matter and the availability of nutrients, particularly N-mineralization which indirectly linked with soil conservation. Microbes under agroforestry systems mostly concentrate to the soil surface. The dense network of fine roots of trees, with a capacity for abundant mycorrhizal association increases the availability of nutrients to the under story crops. Soil degradation due to physical disturbances associated with cultivation, depletion of organic matter, reduced floral diversity, and absence of plant cover for the part of the year leads to reduction of the population of soil microarthopods (Curry and Good, 1992). Population density and composition of the fauna in soil are the indicators of condition and rehabilitation of ecosystem quality (Curry and Good, 1992). The population of microarthopods was positively related to lignin content of the leaf litter. The population of microarthopods of natural regrowth and planted fallows in Nigeria are given (table 7). It can be seen from the table that the population of soil microarthopods was higher in natural fallow and planted woody fallow species as compared to continuous cropping of maize. Soil and crop techniques employed in agroforestry are considered to favour and enhance the activity of soil fauna (Kang et al., 1985), which affects the rates of soil turnover, mineralization and humification of soil organic matter, soil texture and consistency, porosity, infiltration rate and soil-water retention characteristics (Lal, 1988). In Agroforestry based system no. of population of microarthopods are increasing than cropping system because of their rooting system. In Acacia based agroforestry system the no. of population of microarthopods are increasing most followed by other agroforestry system compared with only cropping system (table 7).

**Table 7. Effect of fallows on population of soil microarthopods over the years in Southwestern Nigeria**

| **Microarthopods** | **No. of population/ m²** | | | |
|---|---|---|---|---|
| | **Continuous natural regwowth** | ***Leucaena* based agroforestry** | ***Acacia* based agroforestry** | **Sole cropping** |
| Soil mites (Acari) | | | | |
| Oribatids | 7218 | 6662 | 8394 | 2569 |
| Actinedids | 1216 | 1183 | 1568 | 467 |
| Gamacids | 3525 | 2568 | 3754 | 1174 |
| Springtails (Collembola) | 2483 | 1697 | 3098 | 724 |
| Others | 248 | 104 | 207 | 43 |
| Total | 18591 | 15911 | 22621 | 7952 |

**(Source: Adejuyigbe et al., 1999)**

**Effect on soil physico-chemical properties**

**Changes in chemical properties of the soil**

The soil chemical properties before and after the harvest of maize are presented in Table 8. Soil pH did not vary significantly among the treatments, which varied from 5.8 to 6.1. Variation in organic C content among the alley treatments was insignificant, but this was significantly higher than initial and control soils. The highest (0.69%) and lowest (0.58%) organic C contents were noted in *G. sepium* alley and control soils, respectively. The highest total N content of soil (0.081%) was observed in *L. leucocephala* alley, which was followed by other alleys (0.079, 0.077 and 0.076% in *G. sepium, C. cajan and S. siamea* alleys, respectively), but this was significantly higher than those in initial (0.076%) and control (0.070%) soils. However, total N content in alleys, except *L. leucocephala*, did not change a remarkably compared to initial soil. CEC (Cation exchange capacity) content was the highest in *G. sepium* alley soil (50.57 meq 100g-1), which did not vary remarkably in *L. leucocephala* alley (20.32 meq $100g^{-1}$), but varied significantly over *C. cajan* (19.95 meq $100g^{-1}$) and *S. siamea* (19.92 meq $100g^{-1}$) alleys. Although, the lowest value of

CEC (19.21 meq 100g$^{-1}$) was recorded in control soil, it did not vary much with initial soil (19.56 meq 100g$^{-1}$). The increase in soil pH under *G. sepium* may be due to its faster leaf decomposition and higher foliar Ca levels. Miah et al. (1997) observed higher soil pH and organic C in alley cropping system with *G. sepium*. Higher N content in the *L. leucocephala* alley might be due to higher N-fixing ability (100-500 kg ha$^{-1}$ year$^{-1}$) of the species (Nair, 1993) and higher leaf N content (Anthofer et al., 1998). CEC was also higher in the alley cropping treatments compared to control and initial soils. Increased top-soil CEC in alley cropping of the present study is supported by De Costa et al. (2005) (Table 8).

**Table 8. Soil properties change in alley cropping system by incorporation of prune materials of four woody species after harvesting of maize**

| Treatment | P$^{H}$ | Organic c (%) | Total N(%) | CEC ( meq100/ g) |
|---|---|---|---|---|
| *L. lecocephala* | 6.1 a | 0.68 a | 0.081 a | 20.32 ab |
| *C.cajan* | 6.1 a | 0.67 a | 0.079 ab | 19.95 bc |
| *S.siamea* | 6.0 a | 0.67 a | 0.079 ab | 19.92 bc |
| Control | 5.8 a | 0.58 a | 0.070 c | 19.21 d |
| Initial | 5.8 a | 0.65 b | 0.076 b | 19.56 cd |

**(Source: Rahman et al., 2009)**

**Changes in physical properties of the soil**

By adding organic matter, trees can improve the physical properties like structure, porosity, and water holding capacity etc. of soil and also modify the temperature by shading and litter cover. In agroforestry system tree species ameliorate soil by adding both above and below ground biomass into the soil system. However, variations do exist in the inherent capacity of different tree species in rehabilitating degraded lands. Five different trees species suitable for agroforestry systems were studied at ICAR Research Complex for NEH Region at Umiam, Meghalaya (Saha *et al.* 2007).

Soil samples were collected from 0-15 cm and 15-30 cm soil depth under five multipurpose tree species such as Khasi pine (*Pinus kesiya*), Alder (*Alnus nepalensis*), Tree bean (*Parkia roxburghii*), Champak (*Michelia oblonga*) and Gambhar (*Gmelina arborea*). A control plot in the form of natural fallow was also maintained near these tree-based land use systems for the purpose of comparison. Effect of tree species on bulk density (BD), organic carbon (OC) and porosity of the soil was significant. All the tree species lowered BD, and increased OC and porosity compared to the natural fallow. The water stable aggregates (> 0.25 mm) increased significantly under the different multipurpose tree species. Water stable aggregates were highest for the soils under *Pinus kesiya* (82.4%) followed by *Michelia oblonga* (78.5%) and *Alnus nepalensis* (77.6%). Soil erodibility decreased with the tree species as compared to control. Therefore, these species were instrumental in decreasing erodibility of soils of the NEH region (Table 9).

**Table 9. Effect of various multi-purpose trees on soil physical properties**

| **Tree species with crop** | **Organic C(g kg$^{-1}$)** | **Bulk density(mg m-$^{3}$)** | **Total porosity (%)** | **Micro aggregates (<0.25 mm)** | **Erosion ratio** | **Erosion index** |
|---|---|---|---|---|---|---|
| *Pinus kesiya* | 3.54 ± 0.33 | 1.04 ± 0.12 | 54.3 ± 6.22 | 17.6 ± 5.68 | 0.20 ± 0.03 | 0.11 ± 0.01 |
| *Alnus nepalensis* | 3.22 ± 0.47 | 1.09 ± 0.09 | 55.6 ± 5.87 | 22.4 ± 3.30 | 0.23 ± 0.01 | 0.12 ± 0.02 |
| *Parkia roxburghii* | 2.31 ± 0.61 | 1.23 ± 0.20 | 52.2 ± 3.20 | 28.8 ± 8.22 | 0.30 ± 0.04 | 0.14 ± 0.01 |
| *Michelia oblonga* | 3.36 ± 0.96 | 1.05 ± 0.32 | 55.5 ± 4.58 | 21.5 ± 7.45 | 0.22 ± 0.03 | 0.11 ± 0.03 |
| *Gmelina arborea* | 2.86 ± 1.24 | 1.14 ± 0.09 | 52.4 ± 6.04 | 38.0 ± 8.69 | 0.24 ± 0.02 | 0.12 ± 0.02 |
| **Control** (no tree) | 1.56 ± 0.92 | 1.32 ± 0.11 | 48.7 ± 8.09 | 44.2 ± 6.02 | 0.39 ± 0.03 | 0.15 ± 0.03 |
| LSD ($P$<0.05) | **0.39** | **0.15** | **5.06** | **3.05** | **0.05** | **0.03** |

**(Source Saha et al., 2007)**

Protection of soils directly against erosive forces of raindrop and surface run off by improving soil physical and hydrological parameters have been reported in many studies in India (Jha et al, 2009)

**Water conservation through Agroforestry**

**Effect on soil hydrological properties**

Tree species improved moisture retention capacity of soil as compared to the control. At -0.03 M Pa suction, soil moisture under different tree species was more than that of the control. Similar was also the trend in available water under the different tree based systems. Hydraulic conductivity was higher in tree based system as compared to control. Profile moisture storage in both dry season and rainy season was higher in tree based system than control. Infiltration of water in the soil was also influenced by the tree vegetation. Infilltration rate under *Pinus kesiya* was almost twice that of the control (3.84 mm $hr^{-1}$) (Table 10).

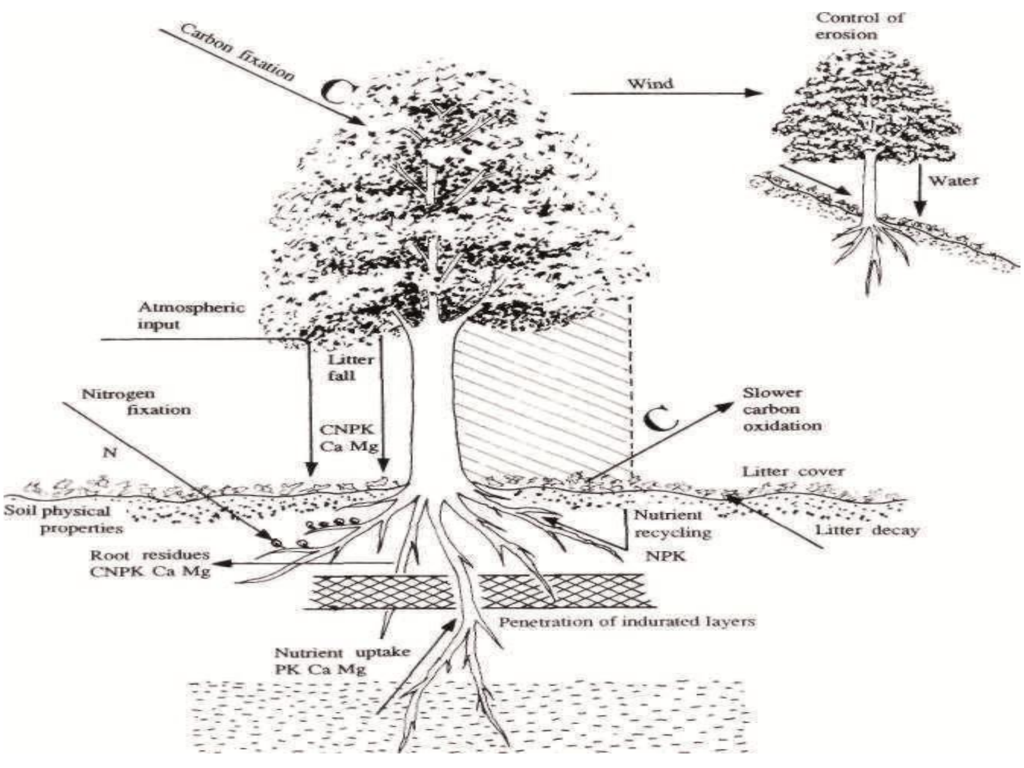
**Table 10. Effect of various multipurpose trees on soil water retention characteristics**

| **Tree species with crop** | **Available water ($m^3$ $m^{-3}$)** | **Infiltration rate (mm $h^{-1}$)** | **Hydraulic conductivity (mm $h^{-1}$)** | **Profile moisture storage (cm/60 cm)** | |
|---|---|---|---|---|---|
| | | | | **In dry season** | **In rainy season** |
| *Pinus kesiya* | 0.220 ± 0.03 | 8.04 ± 1.28 | 5.44 ± 2.02 | 20.45 ± 3.22 | 24.60 ± 1.04 |
| *Alnus nepalensis* | 0.201 ± 0.02 | 7.28 ± 0.95 | 4.82 ± 1.46 | 19.44 ± 2.50 | 22.68 ± 0.98 |
| *Parkia roxburghii* | 0.192 ± 0.01 | 4.85 ± 0.56 | 3.23 ± 2.11 | 13.85 ± 3.61 | 18.52 ± 0.62 |
| *Michelia oblonga* | 0.210 ± 0.02 | 6.10 ± 1.23 | 4.84 ± 1.54 | 18.54 ± 2.37 | 21.66 ± 1.10 |
| *Gmelina arboria* | 0.183 ± 0.01 | 5.36 ± 0.82 | 3.50 ± 1.65 | 14.60 ± 2.11 | 19.41 ± 0.24 |
| Control (No tree) | 0.151 ± 0.02 | 3.84 ± 1.46 | 2.12 ± 2.35 | 11.45 ± 2.05 | 15.34 ± 0.72 |
| LSD ($P < 0.05$) | 0.11 | 1.06 | 0.18 | 2.17 | 2.30 |

**(Source Jha et al., 2009)**

**Agroforestry system in improving soil water quality**

Agroforestry practices such as windbreaks and shelterbelts reduce wind velocity and thereby limiting wind erosion. Excess fertilizer is washed away from agricultural fields via surface runoff or leached into the subsurface water supply, thereby contaminating water sources and decreasing water quality (Cassman 1999). For example, agricultural surface runoff can result in excess sediment, nutrient, and pesticide delivery to receiving water bodies and is a major contributor to eutrophication. Agroforestry systems such as riparian buffers help clean runoff water by reducing the velocity of runoff, thereby promoting infiltration, sediment deposition, and nutrient retention. Trees with deep rooting systems in agro forestry systems can also improve ground water quality by serving as a “safety net” by capturing nutrients (Figure 2) (Source: Dury, 1991).




(Source: Dury, 1991)

**Figure 2: Processes by which trees improve soil as well as water quality**

From the above figure it is clear that soil fertility increases through litter fall, nitrogen fixation, nutrient cycling. When litter fall into the soil it decayed and organic matter is produced. Leguminous trees fix nitrogen from atmosphere through producing nodule in their root. Carbon oxidation process is also become slower. Though trees have deep rooted system they can uptake nutrient from lower, as a result crop get enough nutrient from surface and sub-surface layer of soil.

# CHAPTER 4

# CONCLUSION

Soil and water conservation is a broader field. Agroforestry plays a vital role in conserving soil and water for the production systems. The following conclusion can be drawn from the paper:

- Soil conservation is equal to maintenance of soil fertility which requires control of erosion, maintenance of organic matter, maintenance of soil physical properties, maintenance of nutrients; and water is also conserved through reducing erosive force of rainfall as well as enhancing infiltration rate.
- Effects of various multipurpose trees on soil physical properties and soil water retention characteristics were superior than sole cropping treatment. Nutrient availability of soil was superior in different agroforestry systems than that of sole cropping system.
- In multistory tree garden, soil erosion was minimum that is 0.01-0.14 ton $ha^{-1}yr^{-1}$, which was lower than other land use systems. Alley cropping is a suitable agroforestry system that can provide 160-358 kg nitrogen $ha^{-1}yr^{-1}$.
- Total microarthopods in different agroforestry system varies from 15911 $m^{-2}$ to 22621 $m^{-2}$.
- Organic carbon was higher in different agroforestry system than sole cropping system.

Therefore, the paper revealed that agroforestry is a sustainable land use system that has the potentiality to conserve soil and water for the production practice.

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