Role of Agroforestry in Soil Health Management

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Soil interacts dynamically with the lithosphere, atmosphere, hydrosphere, and biosphere, collectively forming pedosphere. The function and relevance of soils in agroecosystems has been recognized in the context of sustainable management, soil quality, soil resilience or soil conservation, and protection of local or regional agroecosystems. Development of sustainable agriculture management systems has been complicated by the need to consider their utility to humans, their efficacy of resource use, and their ability to maintain a balance with the environment that is favourable both to human beings and to most other species (Hardwood, 1990). Restoration of degraded soils and ecosystems will require thorough understanding of soil resilience characteristics, exogenous and endogenous factors affecting it, and technological options to restore soils' life support processes.

In the northeastern hills (NEH) region, sustainable management of soil and water resources will require special emphasis, because this is the fragile hill ecosystem with serious problems of soil and environmental degradation, insufficiency of food production, and unprecedented population growth (Patiram, 2002). The marginal soils cultivated with marginal inputs produce marginal yields and support marginal living. Drastic reduction of soil organic matter, depletion of plant nutrient reserves, exposure of nutrient poor acidic subsoil, and decline in soil structure of uplands agriculture to accelerate soil erosion of sloppy lands with continuous and short cycle of shifting (*jhum*) agriculture will have to be arrested and reversed for good soil health and productivity. A major shift in the paradigm for agricultural scientists of this region is the enhancement of soil health (quality) for diverse functions, including agricultural production, restoring degraded lands, mitigating the greenhouse effect of *jhum*, and maintaining the beautiful outlook of hills. The population pressure on land as well as on forests, rising demand for fuel and fodder and finally the requirement of timber for multifarious purposes have reinforced, as never before 100 years back, the absolute and inseparable nexus between agriculture and forestry. In order to ecologically sustainable hill agriculture, agroforestry systems offer an excellent opportunity in buffering and in maintaining the production capacity of agricultural systems rather than increasing crop production. It embraces an ecosystem focus considering the stability, sustainability, and equitability of land use systems, in addition to their diverse productivity. In this paper, an attempt has been made to review the impact of agroforestry on soil health to increase the productivity of hill soils.

Land degradation

The deterioration of the soil productivity of mountain environment has now been defined as a function of deterioration in the vegetative cover of uncultivated lands. Over the past several centuries, there was close relationship between human population growth, expanding area under subsistence crops, and increase in livestock number. These have intensified the demands on the forest to supply animal fodder, fuel wood, and land for agriculture. The tribes through trial and errors over generations have evolved their own adaptation mechanisms. Once this region was full of forest cover with small cluster of forest dwellers, which met their basic demands through shifting agriculture (*jhum*), food gathering and hunting of forest animals. In the passage of time, they have either modified the mountain features (e.g., terracing, plantation crops, valley rice, etc.) to suit their needs or used the system as such in different forms of shifting cultivation (*jhum*) relying on the self-regeneration of soil productivity through natural vegetation without any outside inputs excepting seeds and human labour. Drastic anthropogenic intervention in this fragile mountain ecosystem with the existing land tenure systems of different tribes has resulted severe degradation of land resources, decline in soil productivity, poverty, malnutrition, and economic regression.

Degraded lands are those land, whose conditions has deteriorated to such an extent that it can not be put to any productive use, except current fallow due to various constraints. Soil degradation is the reverse of soil health, resulting persistent decrease of soil potential productivity and loss of environmental regulatory capacity. The land degradation has been degraded mainly due to over exploitation of forest for fuel, timber and fodder surrounding human settlement, shifting cultivation on hill slopes, improper land use practices, infrastructure development, land tenure systems of different ethnic tribes, and mining activities without proper changes in land management (Patiram, 2002). In NEH, there are high percentage of area under wasteland due to shifting cultivation (*Jhum*) in Nagaland, Assam hills, Manipur, Meghalaya and Mizoram and in Sikkim and Darjeeling hills is caused by degraded forest (Table 1). Land degradation occurs mainly due to human interference of the ecosystem not only to meet their actual demands but their greediness to achieve luxuriant livelihood by exploiting the nature's gifts. The existing community/private land system has been excessively exploited for survival and realization of short-term objective without taking care of soil health. The major cropland areas of hill agriculture are eroding faster than natural processes and have been significantly degraded. Ecologically degraded lands include degraded forestlands, severely gullied and eroded lands, and areas affected by shifting cultivation. Land degraded as a result of developmental activities consists of mined lands; waterlogged areas and industrial wastelands.

Soil erosion is one of the major causes of soil degradation on steeply sloping lands devoid of vegetative cover and often subjected to landslides or landslips during rainy season (May to September). This process not only affects the land/soil but also cause loss of bio-diversity including base resource itself, and human life. In the north-eastern hill (NEH) region of India, shifting cultivation (*Jhum*) is the single largest factor for the loss of forest cover in this region (State of Forest Report, 1997). The loss of soil under shifting agriculture has been reported in the tune of 5 to 83 t/ha depending upon crops grown and slope of the land (Prasad *et al*., 1986). The increased population in subsistence mountain society has led to: (a) reduced amount of land per capita, (b) deepening poverty, (c) massive deforestation, and (d) cultivating marginal sloppy lands with much less fertile, which are the major cause of the degradation of land productivity. The loss of soil through runoff on such lands varied from 10.8 t/ha to as high as 62 t/ha depending upon land use for different types of agriculture (Prasad *et al.,* 1986). The loss of topsoil reduces the inherent productivity of land through the loss of nutrients and degradation of the physical structure of the soil. The loss/removal of nutrient rich surface layer cannot be compensated for by additional inputs (Table 2). It also increases the cost of food production.

Table 2. Response of rice to nitrogen at different rate of soil removed (Hussain *et al*., 2000)

Soil removed (cm)	Rate of nitrogen (kg/ha)				
	0	60	120	180	Mean
	Rice grain yield (q/ha)				
0	40.2	43.6	41.7	41.5	41.8
5	27.2	34.6	36.7	31.5	32.5
10	21.4	37.7	35.5	30.7	31.3
15	15.2	33.1	31.7	32.8	28.2
Mean	26.0	37.2	36.4	34.1	33.4
C.D. at 5% for soil removed		5.52			
C.D. at 5% for nitrogen		5.13			

Cultivation of crops like potato and ginger for quick returns, the land resources are being intensively utilized unmindful of its long-tem implications along the slope under the *jhum* (closed burning of biomass on raised beds '*bun*') in *Khasi* hills of Meghalaya. Under this system of cultivation, shallow hill soil gets eroded very fast and continues till the entire ridge becomes barren/wastelands. In such type of uplands, the soil productivity cannot be fully restored even by heavy applications of fertilizers and manures. The deforestation of hill slopes has resulted increased sediment load of rivers emerging from the hill and mountains, causing the greater sedimentation load in Brahmaputra and its tributaries (Patiram, 2002) as compared to Ganges and local damage being proportionate to angle of slope.

Agroforestry and ecosystem

Sustainable management of natural resources involves the concept of using, improving, and restoring the productive capacity and life support processes of soil. The soil properties which are important indicators to recover the loss of soil health/quality are; soil structure, microaggregates, soil water retention and transmission properties, cation exchange capacity, exchangeable cations, soil organic matter content and transformation, nutrient supplying capacity, soil pH, rooting depth, soil biodiversity, soil fauna and microbial activity. There is strong relationship between soil quality and conservation farming for sustainable agriculture.

Ever since man began cultivating crops and domesticating animals in NEH region, started agroforestry with the forest, some examples are shifting cultivation (*jhum*) by utilization of forest biomass, growing of large cardamom, tea and coffee under the shade of trees, intercropping with horticultural tree crops, trees on farm boundary, and home gardens. In fact, most farmers still grow agricultural crops and rear animals following agroforestry with their physical and chemical environment that have been transformed to produce food, fibre, fuel and other products for human consumption and processing. Each of the agroforestry practices has different effects on productivity, stability and resiliency within the farm system, depending on the location specific opportunities, resource constraints and in most cases, on household needs and market.

Agroforestry includes any system where trees are deliberately planted or encourage on land where crops are grown or animals grazed. Although agroforestry systems are modified or disturbed environments and cannot be described as natural, they do represent a move away from the markedly artificial systems of monoculture production towards mimicking aspects of natural ecosystem, with an emphasis on species diversities and resource conservation (Anderson and Sinclair, 1993). The aim of agroforestry practices is to maximize the positive consequences, thus enhancing productivity and conserving resources. The capacity of trees to grow under difficult climate and soil conditions, coupled with their potential for soil conservation, gives agroforestry a potential in the main types of marginal and slopping lands with soil productivity constraints. The agroforestry systems comprises Agrisilivicultural systems (improved fallow species in shifting agriculture (*jhum*), hedgerow intercropping (alley cropping), multispecies tree gardens, multipurpose trees/shrubs on farmlands, plantation and other crops, shade trees for commercial plantation crops, soil conservation hedges, and etc.), Agrisilvipastoral systems (tree-livestock-crop mix ground, home garden, woody hedgerows for browse, green manure, soil conservation etc., integrated production of crops, animals ,fuelwood, poles, etc.), Silvipostoral systems (multipurpose fodder trees on or around farmlands, living fences of fodder hedges and shrubs, trees and shrubs on pastures, integrated production of animals and wood products, etc.), aquaculture with trees, multipurpose tree lots, etc. (Nair, 1985). Toky and Ramakrishna (1983 a, b) studied the changes with time in above ground biomass production, accumulation of nutrients in aerial shoots; ecosystem and litter fall at the lower elevation of Meghalaya. They found steady increase of biomass production, net primary production, accumulation of nutrients in aerial shoots and litter fall (Table 3). The 5 years of shifting cultivation cycle (abundant period) generated very low level of soil fertility and build up started beyond it to a minimum of 10 years. Almost similar pattern was seen at higher elevations but production was low (Mishra and Ramakrishnan, 1983). Loss of organic matter in burning has several consequences on microenvironmental conditions of the soil,

Table 3. Rates of biomass accumulation, net primary production (accumulation in boles, branches and litter fall), nutrient in biomass, and nutrient deposited by litter fall

Attributes	Fallow periods, years				
	1	5	10	15	20
Standing biomass (t/ha)	5.0	23.0	57.5	103.7	147.6
Net primary production (t/ha)	5	8	14	17	18
Nutrients in living aerial shoots, kg/ha					
N	31	143	193	339	489
P	5	20	25	44	64
K	35	189	543	977	1379
Ca	14	79	164	284	440
Mg	15	65	89	154	226
Total ecosystem nutrients (0-40 cm soil depth), kg/ha					
N	9810	11250	12460	10910	11010
P	20	30	50	60	90
K	1030	760	810	2160	1530
Ca	1370	880	1210	1380	1530
Mg	1320	1150	820	1360	1440
Amount of nutrients recycled through litter fall, kg/ha					
N	13	210	620	1020	1680
P	1	13	330	615	1060
K	8	150	510	810	1380
Ca	9	155	555	600	1000
Mg	6	130	390	450	720

particularly soil surface. Burning results the reduction of soil porosity, aeration, water holding capacity, infiltration and surface moisture with an increase of erosion and nutrients loss through increasing intensity of runoff (Ahn, 1975, Jha *et al*., 1979). Misra and Saha (2003) reported that minimum erodibity factor (08) and dispersion ratio (0.112) were observed in conserve forest and increased with increasing cropping intensity of shifting agriculture. The planting of woody fallows for 2-3 years may be capable of larger biomass accumulation and larger quantity of N to provide residual yield effect to 2-3 subsequent crops without loss of soil quality.

In the present context of increasing land use pressure, farmers are not getting the benefits of long fallow periods, that allow recovery of secondary forests and rejuvenation of exhausted soils. Badly fields are abundant to imperata grass [*Imperata cylindrical* (L) Raeuschel], which is unproductive for cattle grazing as well as for regeneration of soil fertility. Even sloppy land under agriculture without conservation measures badly affected degradation processes. Agroforestry systems can repair degraded soils, improving both soil fertility and biodiversity.

From the management point of view, the agroecological objective is to provide balanced environments, sustainable yields, biologically mediated soil fertility and natural pest regulation through the design of diversified agroecosystems and the use of low-input technologies (Gleissman, 1998). It is necessary to initiate synergisms which subsidize agroecosystems processes by providing ecological services such as the activation of soil biology, the recycling of nutrients, the enhancement of beneficial orthopods and antagonists, and so on. The agroforestry systems exploit the complementarities and synergisms that result from the various combinations of crops, tree and animals in spatial and temporal arrangements (Altieri, 1994). The agroforestry approaches can contribute towards the ecological functions of soils by the following ways(Young, 2003):

- find ways of making the use of marginal lands;
- reclaim and restore degraded lands;
- improve germplasm to produce plant varieties which are adapted to soil constraints;
- maintaining soil organic matter and biological activity, with benefit 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 can not otherwise be remedied; and
- improve water-use efficiency.

In this way the aim of agroforestry is to maximize the positive consequences in order to enhance and conserve the resources.

Role of agroforestry in soil quality/heath

Compared to natural, a managed agricultural ecosystem has greater amounts of nutrient flowing in and out, less capacity for nutrient storage, and less nutrient recycling. 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 (Young, 2003). The processes by which trees maintain or improve soil fertility are given below:

1. Photosynthetic fixation of carbon and its transfer to the soil via litter and root decay,
2. Nitrogen fixation by all leguminous trees and in few non-leguminous species (e.g., Alder and Casuarinas),
3. Improved nutrient retrieval by tree roots, including through mycorrhiza and from lower horizon,
4. Providing favourable conditions for the input of nutrients from rainfall and dust
5. Control of erosion by combination of cover and barrier effect, especially the former,
6. Root uptake of nutrients that would otherwise have been lost by leaching,
7. Soils under trees have favourable structure and water holding capacity, through organic matter maintenance and root action,
8. Provision of a range of qualities of plant litter, woody, and herbaceous,
9. Growth promoting substances,
10. The potential through management of pruning and relative synchronizatoion of timing of release to nutrients from litter with demand for their uptake by crops, and
11. Effects of tree shading on microclimate.

Control of soil erosion: On the basis of land capability classification, most of the hill sloppy lands of NEH are only suitable either for forestry or agroforestry. Soil erosion caused by runoff water on hill slopes without vegetative cover is the main cause of land degradation and ultimately resulting low productivity of soil. In the past the state governments have constructed terraces to settle the *jhumias* in isolation without further agricultural improvements. Very little success was achieved, many problems arose: the maintenance of soil fertility, excessive cost of the maintenance of mechanical structures, socially unacceptable to prohibit shifting cultivation (*jhum*) on sloppy lands, and compulsory means could not be forced (Patiram and Bhadauria, 1994).

Erosion is now accepted as one of the main causes of soil degradation, including of physical, chemical and biological properties, all of which require attention. Mechanical means of soil erosion control measures are not cost effective and also cannot be well maintained; there is a greater interest in biological means of conservation. There is greater emphasis on the effects of soil cover as a means of controlling erosion, as compared with checking runoff. It is accepted that we cannot stop the cultivation on sloppy lands in this region. The inclusion of trees in soil conservation and erosion control is one of the most widely acclaimed and compelling reasons for including trees on farmlands prone to erosion hazards. The beneficial effects of trees in these regards extend beyond the immediate farmland under consideration, to impart stability to the ecosystem and reducing the rate of siltation of downstream aquatic system, dams and reservoirs.

Among the spatial zonal practices, the most effective means of erosion control is hedgerow intercropping or barrier hedges. The barrier hedges are contour aligned hedgerows planted specifically for erosion control on sloppy lands. It checks soil erosion through the cover effect, where hedge pruning are laid along cropped alleys. They reduce runoff, increase infiltration and reduce soil loss through their barrier effect. They maintain the soil organic matter through decay of pruning and root residues. The contour aligned hedgerows ultimately lead to development of terraces through accumulation of soil upslope of hedgerows and stabilized the risers by stems and roots. The grass barrier strips with planted trees can give additional benefits of fruit, fodder or fuel wood, according to farmer choice. In this humid to moist subhumid hilly climate, densely planted combinations of agricultural plantation crops with multipurpose trees appear to control erosion effectively on at least moderate slopes. In Mizoram, Thansanga (1997) developed the new contour farming system alternative to shifting cultivation involving planting of grasses preferably fodder with strong root formation at the lower edge of the trench line supported by various species preferably leguminous ones. The higher ridge of slope use for horticulture and forestry and contour farming was practiced between the made contour trenching. It was found that whatever soil loss at the time of cultural operation get deposited in contour trench, and erosive crops like sweet potatoes, ginger etc. could safely be cultivated in this system without loss of top soil within the permissible soil loss (0.4 –15 t/ha). This system in time may replace the shifting cultivation by conserving soil and water to realize the paramount importance of permanent cultivation.

Dense ground forest vegetation (grass, cardamom, herbs, shrubs) under large cardamom plantation with shade trees on hill slopes more than 35% in Sikkim, arrests the flow of water, reduce the soil erosion and soil remains almost undisturbed (Patiram *et al*., 1996). As a result large cardamom agroforestry resembles natural forest ecosystem. Although the loss of runoff from highly sloppy lands of cardamom fields has been observed higher than the terraced field of maize crop, yet the loss of soil considerably reduced (Table 4). This result clearly revealed that even on such type of topography large cardamom with trees, the runoff contains almost clear water without suspended soil particle.

Table 4. Runoff and soil loss under different land use systems of Sikkim (Sharma *et al*., 1992)

Land use	Runoff (L/ha)	Soil loss (kg/ha)
Agricultural field of maize	6427	122
Large cardamom plantation	6989	66
Natural forest	5581	12
Barren land	8097	166

Recycling of nutrients: The maintenance of soil fertility is much less a problem with trees than with arable food-crops in addition to provide timber, fuel, fodder or other tree products, or shade. Competition and facilitation most often occur together. Trees may compete with a crop for light, leading to reduced crop yield through shading, whilst at the same time increasing soil organic matter and hence soil moisture content, and the availability of nutrients for the crop through leaf litter. Nutrients enter the ecosystem with the rain, deposition of dust and aerosol, (in case of nitrogen) by fixation of microorganisms above and below ground, and weathering of the underlying rocks. The major above ground pool of nutrients is the canopy and there is a flow of nutrients from this to the ground floor in small and large litter fall and in trough fall and stem flow of rainwater, which usually becomes enriched by nutrients from leaves and bark (Anderson and Sinclair, 1993). Singh and Ramakrishnan (1982) estimated the nutrient flow through incident rainfall, trough fall and stem flow through a 50 years stand of forest in sub-tropical humid climate of Meghalaya, and total amount of nutrients contributed given in Table 5. It can be seen from the table, the total amount of nutrients (kg/ha/yr) through trough fall contributed 98% of all the nutrients, because of larger quantity of water passing through this compartment. More amounts of the Ca and Mg contributed by trough fall as compared to N, P, and Mg.

Table 5. Nutrient return through stem flow, trough fall and rainwater at Lailad forests

Source	Nutrients (kg/ha/yr) added				
	N	**P**	**K**	**Ca**	**Mg**
1. Stem flow	0,17	0.02	0.71	0.84	0.10
2. Trough fall	8.39	0.89	31.28	35.19	5.03
3. Total	9.56	0.91	31.99	35.93	5.13
4. Rainfall	4.33	0.43	7.80	9.96	4.77
Contribution of 1+2 (3-4)	5.23	0.48	24.19	24.97	0.63

As nutrient demand declines with age, gradual increase in nutrients in soil can occur as tree demands progressively fall below the rate of soil nutrient supply. The particular tree species adapted to particular soil conditions, the decomposition of litter leads with to the release of nutrients in a form available to plants; the rate of decomposition are controlled by climate and resource quality so that the efficiency of nutrient transfer will depend on the timing of release in relation to the maximum crop growth and plant nutrient demand. The Himalayan alder (*Alnus nepalensis*) is a native species of this hill region and has the immense importance in terms of rapid colonization on landslide-affected/prone sites. It stabilizes the steep slopes, nurse tree in age-old traditional cardamom plantations and agricultural field (jhum as well as terraced agriculture) in Nagaland. It has the capacity to fix substantial amount of atmospheric nitrogen, augments the soil fertility in both natural and its based agroforestry systems. Annual inputs of nutrients to the forest floor are mainly contributed by litter fall of leaf, twigs, catkins and residues left after under planted crops. The total amount of nutrients to forest floor from *Alnus* and cardamom are given in table 6. Forest floor biomass and its nutrient contents increased from the 5-year to a highest value at the 15 year and declined to a lowest value at the 40-year old stand. Both N and P concentration of the foliage decreased almost to one-fourth in the 40-year old *Alnus* stand to that of 5-year old stand.

Table 6. Floor-litter biomass and nutrient content in the age series of *Alnus*- cardamom plantation stands (Sharma, 1995)

Stand age (years)	Floor litter (t/ha)	Nutrient recycled (kg/ha)	
		Nitrogen	**Phosphorus**
5	18.51± 0.25	240.63±18.19(2.5)	13.14±2.45(2.5)
10	23.16 ± 2.06	305.71±10.73(2.6)	22.00±5.77(3.9)
15	34.91± 1.24	429.39±11.52(2.7)	33.10±4.89(4.5)
20	28.05± 1.44	339.41±12.42(3.2)	26.96±1.23(4.4)
30	28.05± 1.44	327.65±13.49(3.4)	18.20±1.90(3.6)
40	14.67± 1.04	176.04±14.00(3.0)	11.88±2.68(3.4)

In parentheses the turn over time (year) are given

In the large cardamom plantation substantial amount of N is extracted out from the system due to thinning of *Alnus* and extraction of fuel-wood that cause lowering of N storage in the older stands. Average annual N fixation in *Alnus nepalensis* was reported in the tune of 117-155 kg/ha and being the highest in the youngest stand (Sharma and Ambast, 1988, Sharma, 1995). Sharma (1995) suggested that the adoption of replanting after 20 years for both *Alnus* and cardamom would be highly beneficial and sustainable on the basis of nutrient use efficiency, nutrient dynamics and cycling of this agroforestry system. This system also maintains higher amount of soil organic matter content, total nitrogen as well as N-mineralization rate as compared to other agroforestry systems (Table 7). The N_2-fixing species conserves less nutrient compared to non-N_2-fixing species and hence, contribute more of these elements in their litter which results greater cycling (Sharma *et al.,* 1994, 1995). This provides better production potential for associate crops in the stands with N-fixers (Sharma *et al*., 1997).

Table 7. Soil organic carbon, nitrogen and N-mineralization rate in different agroforestry Systems (Sharma *et al*., 1992)

Agroforestry systems	**Org. C (%)**	**Nitrogen (%)**	**N-mineralization rate (ug N/g /14 days**
Albizzia + cropland	1.13 ± 0.03	0.25 ± 0.02	19.0 ± 6.7
Non-N-fixing trees+ cropland	0.90 ± 0.07	0.20 ± 0.01	8.0 ± 2.8
Alnus + large cardamom	2.01 ± 0.10	0.30 ± 0.02	35.5 ± 4.0
Natural forest + large cardamom	3.56 ± 0.46	0.51 ± 0.03	54.0 ± 8.9

At higher altitude of Meghalaya, potato is taken under pine tree (Pinus kesiya) utilizing its litter fall, twigs and branches under the *bun* system of cultivation. The amount of nutrients recycled through this tree in this system of agroforestry is given in table 8.

Table 8. Recycling of nutrients (kg/ha) through litter fall and forest floor in a 22-year-old pine (*Pinus kesiya*) (Das and Ramakrishnan, 1985)

Nutrient	**Litter fall**	**Forest floor**
N	64.7	276.9
P	15.4	38.3
K	40.1	55.4
Ca	492	87.5
Mg	24.2	40.7

The effects of long-term (7 years) cultivation of crops under different agroforestry systems as compared to trees alone are given in table 9. It can be seen from the table 9; the total content of N was higher in soil tree stand as compared to agroforestry systems in top soil (0-15 cm). It has increased more than 100% in alder, 80-100% in Albizia, 54-63% in mandarin and only 36-54% in cherry-systems. The C: N ratio was narrow in alder and Albizia N- fixing trees (6.9-8.0) as compared to non N-fixing trees (8.4-9.6) and was also comparatively narrow in sole tree stand. There was too much retrieval of exchangeable Ca, Mg, K and available P in both the system forms the subsurface through roots and recycled by litter fall, and were high in agroforestry systems caused by its additional input through fertilize (Table 9).

Table 9. Nutrients build up in top soil (0-15 cm) in the sole tree stand and under agroforestry systems (Dhyani, 1998)

Agroforestry systems	Total N (%)	C/N	Exchangeable nutrients (me/100 g)			Avail. P (ppm)
			Ca^{2+}	Mg^{2+}	K^{+}	
Tree only						
Alder	0.25	6.9	3.10	2.28	0.34	9.4
Albizia	0.22	7.6	3.26	4.58	0.35	11.1
Cherry	0.17	8.4	2.3	2.14	0.21	8.5
Mandarin	0.18	8.7	2.84	2.30	0.27	8.8
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
Mean	0.19	8.6	2.51	2.46	0.29	11.67
Sd (±)	0.04	1.61	0.83	1.28	0.08	3.39
CV (%)	23.2	18.63	33.23	51.90	27.02	31.80

In Sikkim, farmers over cropped mandarin based agroforstry systems of crop production of interest against a standard, taken to be the performance of monoculture. The major intercrops are ginger, ginger+maize, maize-finger millet, maize-urd or mustard, vegetables (especially beans), maize-buckwheat and maize-cassava, etc. Farmers are more organic manure conscious. The rate of organic manure application depends on intercrops to be taken. As the age of orchards increases, the intercropped intensively with ginger+maize to compensate loss occurs through decline in mandarin productivity. This agroforestry system has resulted build up of organic matter, available P and K (Table 10) 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.

Table 10. Soil fertility builds up in mandarin orchards of Sikkim (Upadhyaya *et al*., 1994)

Fertility indices	Orchard age (years)		
	Below 20	20-40	Above 40
pH	5.80±0.20	5.80±0.10	5.80±0.10
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	166.6±50.0	204.1±28.6	234.6±40.8

Biological properties: 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. 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 fauna cover a range soil functions beyond that of soil microbial community. The microfauna (protozoa, nematodes, and rotifers < 100 μm diameter) function as secondary consumers, feeding largely on bacteria and fungi, thereby speeding the turnover of microbial biomass and their associated nutrients (Anderson, 1988). The mesofauna (Collembola and the Enchytraeidae 100-200 μm) are omnivore of microflora and fauna, as well as other mesofauna, thus directly and indirectly speed organic matter turnover by fragmenting plant residues. Macrofauna are greater than 200 μm and include ants and termites as well as soil engineer earthworm. Ants and termites have the profound effects on soil structure, but earthworms are found everywhere and are indicator of positive soil quality symbols of a healthy living soil. 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 of natural regrowth and planted fallows in Nigeria are given in table 11. It can be see 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 and cassava. The population of microarthopods was positively related to lignin content of the leaf litter.

Table 11. Effect of fallows on population of soil microarthopods over the years (May to March) in southwestern Nigeria (Adejuyigbe *et al*., 1999)

Microarthopods	**No. of population/m^2**				
	Continuous				
	Natural regrowth	**Leucaena**	**Acacia**	**Senna**	**cropping**
Soil mites (Acari)					
Oribatids	7218	6662	8394	12014	2569
Actinedids	1216	1183	1568	1718	467
Gamacids	3525	2568	3754	3966	1174
Springtails (Collembola)	2483	1697	3098	3701	724
Others	248	104	207	659	43
Total	18591	15911	22621	27004	7952

When earthworms digest organic-matter-rich soil the solubility of plant nutrients increases. The influence of soil fauna, particularly earthworms, termites and ants on the physical, chemical and biological properties of soil has been observed by Saharan and Singh (1988). 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, Wilkinson, 1975).

Maintenance of organic matter: Soil organic matter replenishment is the cornerstone to regenerating soil health and increasing soil organic matter is a goal of most agroforestry systems. Soil organic matter influences many soil properties including infiltration rate, bulk density, aggregate stability, cation exchange capacity, nitrogen availability, and a number of key soil quality parameters (Patiram, 2003). Sharma (1995) observed an increase of soil organic matter, different forms of the N and P up to 15 years old large cardamom plantation, thereafter, the decrease associated with decline in the litter accumulation and productivity in 20, 30, and 40-years plantation stand (Table 12).

Table 12. Soil organic matter, different form of nitrogen and phosphorus in the different of *Alnus*-cardamom plantation

Indices	**Stand age (years)**					
	5	**10**	**15**	**20**	**30**	**40**
SOM (t/ha)	145±9	152±5	200±11	158±9	169±15	143±10
Total N (t/ha)	8.4±2.1	8.7±1.8	9.9±1.7	11.7±2.9	9.8±1.9	8.9±2.1
Inorganic N (kg/ha)	90±8	93±15	95±17	101±11	82±6	78±5
NAI (kg/ha)	21.9±4.2	30.8±5.0	38.0±9.4	28.9±8.0	26.6±7.4	17.5±4.1
Total P (kg/ha)	2285±105	2312±110	2554±121	2457±139	2255±129	2192±136
Inorganic P (kg/ha)	110±19	117±14	162±20	126±21	120±19	107±25
Avail. P (kg/ha)	135±17	137±19	182±26	147±16	143±16	130±13

SOM = soil organic matter and NAI = nitrogen availability index.

Dhyani (1998) also observed an increase of soil organic matter different agroforestry systems at mid altitude of Meghalaya after 5 years of tree planting, thereafter decreased after 7 years on sloppy lands.

Soil physical properties: The water stability of soil aggregates is paramount in the restoration of soil structure to destructive forces. Structural stability increases with increasing organic matter content, which in turn is correlated with increased biotic activity. Soil microbial and megafaunal (earthworms) population improve water infiltration by altering soil physical structure. Bacteria produce thread-like polysaccharide adhesive and fungi produce thread-like hyphae that bind soil particles into stable aggregates and reduce potential soil losses by erosion (Gupta and Germida, 1988). The decaying tree roots, exudates, persistent of root channels, and root-associated fungi network also enhance the aggregate formation. The structural stability increases with increase in organic matter content, which in turn correlated with increased biotic activity. The lining of earthworm channels by slime, and of the root channels by mucigel, may make an important contribution to their stability and persistence (Oades, 1993). The overall effect of different agroforstry systems on soil hydrological behaviour and aggregates are given in table 13. It can be visualized from the table that the decrease of bulk density in natural forest, multistoried agroforestry and silvi-horti-pastoral systems related to the relatively higher content of organic carbon. Micro and micro aggregate percentage, mean weight diameter (MWD), maximum reduction in transmission pores (.50μm) were almost in the order of natural forest>multistoried agroforestry systems>silvi-horti-pastora>arboretum> Khasi mandarin> Assam lemon. Structural stability refers to the ability of soil aggregates to withstand the destructive forces of changing water content and the influence of rainfall on bare surfaces. Dispersion ratio, erosion index, and erosion ratio were high in Khasi mandarin and Assam lemon. It has been also observed that moisture content during dry period increased with increasing soil depth in all agroforestry systems and reverse in the rainy season. On the basis of this studies, two conclusions can be withdrawn; (1) management of different agroforestry systems to develop optimum soil physical condition for production of agricultural crops is unlikely to be achieved by tree cover alone, but will also require that the soil be managed in such a way to mimic almost the natural forest vegetation, and (2) the multistoried agroforestry and silvi-horti-pastoral systems appear to be most congenial for hill resource (soil) conservation.

Summary

Agroforestry is an ecologically based, natural resources management system that sustains production and benefits all those who use the land by integrating trees on farms and in the agricultural land scape. In addition to provide timber, fodder, fuelwood, medicines, etc., it conserves soil and enhances 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.

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Table 5. Effect of multiple tree species on chemical properties of soils

Multi-purpose tree species	pH	Organic C (%)	Fulvic C (%)	Humic C (%)	Exch. cations (me/100 g) Ca	Mg	K	Bray's P_2 (mg/kg)	Exch. Al (me/100 g)	Available B (mg/kg)
Indian alder	4.7(4.6)	2.13(1.61)	0.34(0.31)	0.78(0.53)	0.4(0.6)	1.4(0.4)	0.14(0.10)	6.0(0.4)	2.16(2.28)	0.95(0.44)
Tree bean	5.0(4.7)	1.60(1.40)	0.77(0.49)	0.84(0.43)	2.0(0.4)	1.2(0.6)	0.26(0.16)	1.8(0.1)	2.09(2.35)	0.98(0.88)
Champak	4.9(4.8)	1.80(1.43)	0.46(0.68)	0.62(0.0.27)	1.7(0.5)	0.7(1.6)	0.12(0.16)	3.2(0.5)	1.71(2.22)	0.55(0.88)
Albizia	4.7(4.7)	1.83(1.77)	0.68(1.23)	0.53(0.56)	0.6(0.4)	1.5(0.6)	0.19(0.12)	5.4(0.5)	1.78(2.41)	1.41(1.54)
Japanese cedar	4.9(4.7)	2.07(1.61)	0.68(0.55)	0.68(0.31)	1.6(0.4)	0.4(0.8)	0.18(0.15)	2.0(0.5)	1.46(1.90)	0.66(1.52)
Himalaya cypress	5.0(5.0)	1.86(2.16)	0.55(0.55)	0.93(0.62)	0.7(0.6)	1.1(0.6)	0.18(0.13)	2.6(1.2)	1.90(1.90)	0.73(2.16)
Bastard cedar	4.8(4.7)	2.01(1.34)	0.62(0.43)	0.71(0.53)	0.6(0.7)	1.6(0.7)	0.19(0.13)	2.3(0.3)	2.09(2.22)	1.96(2.24)
Himalayan wild cherry	4.7((4.7)	2.1391.52)	0.80(0.55)	0.78(0.53)	1.0(0.3)	1.6(0.4)	0.26(0.16)	7.7((0.8)	2.54(2.22)	0.88(1.87)
Khasi pine	4.7(4.8)	1.77(1.10)	0.52(0.60)	0.75(0.27)	0.7(0.5)	0.3(0.7)	0.16(0.13)	7.4(0.04)	2.54(2.22)	2.24(1.36)
Mean	4.84(4.74)	1.91(1.55)	0.60(0.60)	0.73(0.45)	1.1(0.5)	1.1(0.7)	0.19(0.14)	4.2(0.5)	2.00(2.30)	1.151.43)
Sd(±)	0.12(0.11)	0.17(0.28)	0.140.24	0.11(0.13)	0.5(0.1)	0.5(0.3)	0.04(0.02)	2.2(0.3)	0.30(0.02)	0.56(0.58)
CV (%)	2.52(2.38)	8.90(18.15)	23.45(40.00)	15.33(28.21)	51.6(46.4)	43.8(46.4)	22.6(14.7)	52.2(67.8)	15.1(15.3)	48.7(40.3)
Initial	4.9(4.8)	1.77(0.88)	0.46(0.22)	0.90(0.58)	1.20(0.20)	1.00(0.80)	0.17(0.13)	1.2(0.2)	1.65(2.03)	0.901.54

Table 13 . Effect of different agroforestry system on soil physical properties (Saha and Mishra, 2003)

Systems	B.D. (Mg/m^{-3})	MWD (mm)	Aggregate size (cm) >0.25	<0.25	Pore size distribution (%) >50µm	0.5-50µm	< 0.5µm	K ($m/sX10^{-4}$)	Dispersion ratio	Erosion ratio	Erosion index	Erodibility factor
Arboretum	1.13	2.42	53.91	6.16	18.66	40.00	41.34	0.50	4.10	3.95	2.19	0.20
Khasi mandarin	1.19	2.42	51.48	5.81	16.12	43.64	40.24	0.38	4.80	4.46	2.47	0.31
Assam lemon	1.19	1.97	50.94	5.22	19.51	38.50	41.99	0.53	4.50	4.26	2.39	0.30
Silvi-horti-pastoral	0.98	2.43	55.06	6.25	21.94	34.95	43.11	0.72	3.30	3.07	1.63	0.26
Multistoried AFS	0.97	2.65	56.32	6.37	20.08	27.95	52.37	0.77	3.90	3.06	1.84	0.18
Natural forest	0.94	3.13	60.78	6.37	30.12	11.95	57.93	1.84	2.50	2.10	1.13	0.05

B.D. = bulk density; MWD = mean weight diameter; and K = hydraulic conductivity

Table 1. Wasteland/Degraded land in NEH (sq. km) (Wasteland Atlas of India, 2000)

Degraded land	Arunachal Pradesh	Assam hills*	Manipur	Meghalaya	Mizoram	Nagaland	Sikkim	Tripura	Darjeeling hill (W.B.)
1.Land with /without scrub	3326.17	0	1.32	4190.63	0	1596.46	1073.11	286.87	14.40
2.Shifting cultivation	3088.08	8046.75	12014.06	2086.77	3761.25	5224.65	0	400.88	-
3.Degraded forest	1416.67	578.44	608.64	3612.11	310.45	1582.99	1060.57	588.18	44.60
4.Degraded pasture	2134.99	0	0	0	0	0	0	0	0.67
5. Others**	8360.34	54.50	324.60	14.87	0	0	1435.9	0.11	10.92
6.Total degraded land	18326.25	8679.69	12948.62	9904.38	4071.68	8404.10	3569.58	1276.03	69.62
7. % of Total Geog. area	21.88	56.65	58.00	44.16	19.31	50.69	50.30	12.17	2.21
8. Total Geog. area	83,743	15,322	22,327	22,429	21,081	16,579	7,096	10.486	3149

* = North Cachar and Karbi Anglong hill districts of Assam

** = Includes areas of waterlogged, plantation, sand inland, mining, barren rocky, steep sloping, and snow/glacier