Can agroforestry be a resource conservation tool to maintain soil health in the fragile ecosystem of north-east India?

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Abstract: *In the north-eastern regions of India, shifting cultivation is traditional and a dominant land use practice, leading to heavy soil erosion and severe degradation of biodiversity. Agroforestry systems (AFS), which have great potential for crop and livestock production, are the best alternative to overcome the adverse effects of shifting cultivation. Agroforestry is an ecologically based, natural resource management system that sustains production and benefits all those who use the land by integrating trees on farms and in the agricultural landscape. In addition to timber, fodder, fuelwood, medicines, etc, it conserves natural resources. In this paper, the authors discuss the role of promising agroforestry systems and various multipurpose trees (MPTs) in the conservation of natural resources. These systems improved soil physical health through checking soil erosion and run-off, maintained soil organic matter, enhanced soil chemical and biological properties, added nitrogen input by trees and shrubs, and helped in the mining of minerals from lower horizons by roots and their recycling through litter fall on the ground. Of the systems studied, multistoreyed AFS [alder + tea + black pepper + annual agricultural crops], silvi-horti-pastoral [alder + pineapple + fodder grasses] and natural forest systems with suitable soil conservation measures are the most viable alternatives for natural resource management and could sustain long-term soil productivity in the highly degraded soil of this region.*

Keywords: *agroforestry; soil health; resource conservation; north-east India*

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The north-eastern hill (NEH) regions of India, comprising the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, are characterized by fragility, marginality, inaccessibility, cultural heterogeneity, ethnicity and rich biodiversity. Shifting cultivation, also known as *Jhum* cultivation, is the most traditional and dominant land use system in this region. The society is agrarian and depends on agriculture and allied sectors for its livelihood, as there are no major industries except in the state of Assam. Thus, any attempt to reduce poverty in this region would have to be based on system-wide and eco-regional planning of the development of the agriculture sector.

Shifting cultivation and its impact on land degradation

Shifting cultivation in its more traditional and cultural integrated form is an ecological and economically viable system of agriculture as long as population densities are low and *jhum* cycles (*jhum* is a traditional cyclical practice involving tree clearance, burning, crop production and contour bunding) are long enough to maintain soil fertility (Anonymous, 1992). Shifting cultivation has become unsustainable today primarily due to the increase in population that led to increased food demand. The *Jhuming* cycle in this area, which historically extended to 20–30 years, has now been reduced to 3–6 years (Borthakur, 1992). At present, it is estimated that the number of people practising shifting cultivation is around 367,000 tribal families and the area affected by this practice involves 385,400 hectares annually (Patiram and Verma, 2001). The overall scenario of shifting cultivation in this region is presented in Table 1. On average, 3,869 square km are put under shifting cultivation every year. The significance of this system of farming in the present day has much to do with the maladies associated with it. Degradation of land resources is a serious problem in the NEH region. Hilly topography, high rainfall, primitive types of agriculture, excessive exploitation of forest wealth including deforestation, urbanization, faster population growth and pressure on land, etc are mainly responsible for this degradation in the region. Land degradation affects about 36.64% of the total geographical area, which is almost double the national average of 20.17% (Anonymous, 2000). Water erosion, reduced infiltration, acidification, nutrient leaching, burning of vegetation, decline in vegetative cover and biodiversity are important contributors to this in the NEH region (Table 2). The annual loss of topsoil is much higher (46 tonnes/ha) than the all-India permissible limit of 16 tonnes/ha. Similarly, due to lack of proper water harvesting measures, only 0.88 M ha m water are of use for crop cultivation out of 42.5 M ha m total water resources available in this region. Resource degradation, low productivity, a tendency to encourage large family size and little or no scope for the adoption of modern agricultural technology are some of the drawbacks in this system. Taking into account all these factors, it has never been easy to develop a viable and widely acceptable land use model that can replace shifting cultivation. However, efforts have been made to develop alternative land use models for shifting cultivation, and analyses of the soil characteristics have been conducted to find out how these models could improve the ecological imbalance for sustainable crop production.

Modified land use systems: agroforestry

The agroforestry system (AFS) has today become an established approach to integrated land management, not only for renewable resource production, but also for ecological considerations. It represents the integration of agriculture and forestry to increase the productivity and sustainability of the farming system. Differential rhizospheric effects brought about by growing trees and grasses simultaneously or sequentially improve soil physical properties, biological fluxes and the nutrient

Table 1. Area under shifting cultivation in NEH region (area in 1,000 ha; families in thousands).

State	Area under shifting cultivation	Area sown at one point in time	Column 3 as % of column 2	Total families involved	Area (ha/family)	Fallow period (years)
Arunachal Pradesh	210.0	70.0	33.3	54.00	1.30	3–10
Assam	139.2	69.6	50.0	58.00	1.20	2–10
Manipur	360.0	90.0	25.0	70.00	1.28	4–7
Meghalaya	265.0	53.0	20.0	52.29	1.01	5–7
Mizoram	189.0	63.0	33.3	50.00	1.26	3–4
Nagaland	191.3	19.0	9.9	111.046	0.17	5–8
Tripura	111.5	22.3	20.0	43.00	0.46	5–9
Total	1,466.0	386.9	31.05	444.336	0.87	

Table 2. Extent of land degradation in the north-eastern region (10^4 km^2).

State	Degraded land due to		Total degraded land	% of total geographical area
	Erosion	Other problems		
Arunachal Pradesh	2.444	0.210	2.654	31.6
Assam	2.690	0.309	2.999	38.2
Manipur	0.374	0.360	0.734	32.6
Meghalaya	0.837	0.265	1.102	49.1
Mizoram	0.421	0.189	0.610	27.9
Nagaland	0.405	0.633	1.038	62.1
Sikkim	0.303	–	0.303	42.4
Tripura	0.167	0.112	0.279	26.8
Total	7.641	2.078	9.719	37.1

Table 3. Potential agroforestry systems (AFS) in NEH region.

State	Promising AFS
Arunachal Pradesh	Agri-horti-silviculture AFS, multistoreyed AFS/home garden, agri-silviculture AFS, horti-pastoral AFS
Assam	Agri-silviculture AFS, silvi-pastoral AFS, multistoreyed AFS/home garden, agri-horticulture AFS, agro-aquaculture AFS
Manipur	Multistoreyed AFS/home garden, agri-horticulture AFS, sericulture-based AFS, agri-silviculture AFS, agro-aquaculture AFS
Meghalaya	Agri-horti-silvi-pastoral AFS, multistoreyed AFS/home garden, horti-pastoral AFS, agro-aquaculture AFS
Mizoram	Agri-silviculture AFS, horti-pastoral AFS, multistoreyed AFS/home garden
Nagaland	Agri-silviculture AFS, agri-horticulture AFS, multistoreyed AFS/home garden
Sikkim	Agri-horticulture AFS, agri-silviculture AFS, silvi-pastoral AFS
Tripura	Multistoreyed AFS/home garden, agri-silviculture AFS, silvi-horti-pastoral AFS, agro-aquaculture

pool (Young, 1989). According to one estimate, 7.85 M ha of the region are degraded and need rehabilitation through various agroforestry models. Various potential indigenous tree/shrub species and bamboo species could be included in afforestation programmes.

Agroforestry land use systems and their interactions with other farm resources are important from the perspectives of productivity, profitability, sustainability and socioeconomic factors in the region. Agroforestry strengthened with subsidiary sources of income such as animal husbandry, poultry or pig keeping, fisheries, apiculture or sericulture provides opportunities for optimum realization of potentials through recycling of wastes and converting them into economic products. Thus agroforestry is an alternative land use system with respect to food security, employment generation and maintenance of soil fertility, whilst at the same time playing a vital role in the management of soil and water resources in the north-east of the country.

Potential state agroforestry systems

The region is a repository of floral and faunal diversity. Local people have screened many tree/shrub species for multiple uses in farming. In this way, agroforestry models have been developed based on the indigenous knowledge system and consequently the needs of the people. Some of the important agroforestry systems (AFS) are mentioned in Table 3.

Examples of annual agricultural crops grown in different systems are turmeric (*Curcuma longa* L.), colocasia (*Colocasia esculenta*), paddy (*Oryza sativa*), ginger (*Zingiber officinale*), maize (*Zea mays*), soybean (*Glycine max*), groundnut (*Arachis hypogaea*), etc. Horticultural crops include *Khasi* mandarin (*Citrus reticulata*), Assam lemon (*Citrus lemon*), pineapple (*Ananas squennsa*), etc. The fodder species are stylo (*Stylosanthes guyanensis*), guinea (*Panicum maxicum*), setaria (*Setaria sphacelata*) and local grass (*Imperata cylindrica*). The tree species in various systems include alder (*Alnus nepalensis*), tree bean (*Parkia roxburghii*), champak (*Michelia oblonga*), gamhar (*Gmelina arborea*), makari-sal (*Schima wallichii*), jarul (*Lagerstroemia speciosa*), bamboo (*Bambusa pallida*) and *khasi* pine (*Pinus kesiya*).

Characteristics of multipurpose trees (MPTs) for agroforestry

The multipurpose tree species (MPTs) form an integral component of different agroforestry interventions in crop sustainability. The MPTs, besides furnishing multiple outputs such as fuel, fodder, timber and other miscellaneous products, help in the improvement of soil health and other ecological conditions. Screening of MPTs is an important prerequisite for determining the suitability of agroforestry models for various agroecological regions. The desirable characteristics of MPTs that suit agroforestry are:

- adaptability to local climatic conditions;
- straight canopy architecture so that the tree canopy can allow maximum sunlight to reach the understorey crops;
- ability to resprout quickly after pruning, coppicing and pollarding;
- good leaf litter, making nutrients available to the crop at the appropriate time;
- sparse and shallow lateral root systems;
- ability to fix atmospheric nitrogen;
- potential to help in nutrient investment in soil through higher organic carbon, nitrogen, phosphorus and potassium content;
- fast decomposition of leaf litter and rapid nutrient release pattern from decaying litter; and
- no allelopathic effect on associated crops.

MPTs and soil hydro-physical behaviour

The effects of five multipurpose tree species on soil physical behaviour were studied. Multipurpose tree species with greater surface cover, constant leaf litter fall and extensive root systems (Table 4) increased soil organic carbon, helped with better soil aggregation, improved water transmissivity and infiltrability, and in turn reduced soil erosion. All the MPTs significantly improved soil hydro-physical characteristics (Table 5), particularly by decreasing bulk density and erosion ratio by 15.9 and 39.5% respectively and increasing soil organic C by 96.2%, porosity by 10.9%, aggregate stability by 24.0% and available soil moisture by 33.2% (Saha *et al*, 2007). Such improvements in soil hydro-physical properties in tree-based systems have a direct bearing on long-term sustainability, productivity and soil quality in hilly ecosystems. Inclusion of these tree species is a viable option for eco-restoration and maintenance of soil resources and could sustain long-term soil productivity and improve the food security of the poor tribal farmers of north-east India under the humid subtropical climate of the north-eastern Himalayan region, where erosion is a major land degradative process.

Table 4. Growth, litter production and fine root biomass of MPTs.

MPTs	Diameter at breast height (cm)	Annual litter production (g m^{-2})	Time required for decomposition (days)	Total fine root biomass (g m^{-2})
Pinus kesiya	23.32	621.5	718	496.75
Alnus nepalensis	21.20	473.75	350	435.50
Parkia roxburghii	27.95	341.75	385	415.50
Michelia oblonga	27.45	512.25	390	462.00
Gmelina arboria	31.52	431.75	360	419.00

Table 5. Effect of various MPTs on soil physical properties.

MPTs	Organic C (g kg^{-1})	Aggregate stability (%)	Available water (m^3 m^{-3})	Infiltration rate (mm h^{-1})	Erosion ratio
Pinus kesiya	35.4	75.6	0.220	8.04	0.20
Alnus nepalensis	32.2	72.1	0.201	7.28	0.23
Parkia roxburghii	23.1	63.4	0.192	4.85	0.30
Michelia oblonga	33.6	73.2	0.210	6.10	0.22
Gmelina arboria	28.6	67.9	0.183	5.36	0.24
Control (no tree)	15.6	56.8	0.151	3.84	0.39

Agroforestry and soil resource management

Compared with natural systems, a managed agricultural ecosystem has greater amounts of nutrient recycling in and out of the soil. The trees are able to maintain or improve soil health, which is evident from the high fertility status and closed nutrient cycling under natural forest. The processes by which trees improve soil fertility are as follows:

- photosynthetic fixation of carbon and its transfer to the soil via litter and root decay;
- nitrogen fixation by all leguminous trees and also by a few non-leguminous species (for example, alder and casuarinas);
- improved nutrient retrieval by tree roots, including mycorrhiza from lower horizons;
- erosion control by a combination of cover and barrier effects;
- efficient uptake of nutrients that would otherwise be lost by leaching;
- soils under trees have a favourable structure and water-holding capacity through organic matter maintenance and root action;
- exudation of growth-promoting substance; and
- pruning of trees synchronizes the time of release of nutrients from litter with crop demand.

All the AFSs mentioned in Table 6 have high organic C content, ranging from 12.3 to 27.0 g kg^{-1} in surface soil through heavy litter fall and subsequent decomposition. About 20–25% of the total living biomass of trees prevails in the roots and there is constant addition of organic matter to the soil through decaying dead roots, which leads to improvements in the C status of the soil (Armson, 1971; Balkrishnan and Toky, 1993). Better soil aggregation under natural forest, multistoreyed AFSs and silvi-horti-pastoral systems maintaining intensive vegetative cover throughout the year could be ascribed to the effect of the higher percentage of organic matter, clay content and the high amount of Al and Fe oxides in soil (Saha *et al*, 2003). Soil biota influence soil properties through the formation of stable aggregates, development of organo-mineral complexes by improving the macroporosity and continuity of pores from the surface to the subsoil; they also increase water transmission and reduce run-off (Lal and Hawksworth, 1991).

The moisture distribution pattern of the soil profile under various AFSs during dry spells – that is, in the months of December and January – revealed that the moisture content increased with increasing soil depth in all AFSs. Maximum moisture content at each depth of soil profile was recorded in natural forest, followed by multistoreyed AFS (Saha *et al*, 2004). Significant variation in available water capacity may be attributed to the differences in quantity, the nature of colloidal materials present, pH and pore size distribution among the various systems. Within an established tree-based cropping system, macropores dominate the pore space and facilitate rapid movement of water through the soil profile (Humbel, 1975). Soils under trees generally have better physical condition, including higher water-holding capacity combined with good permeability and drainage and greater erosion resistance.

The low erosion ratio values in silvi-horti-pastoral and multistoreyed AFSs (3.07 and 3.06 respectively) showed that these systems were most suitable for soil and water conservation in hilly ecosystems (Saha *et al*, 2005). This could be ascribed to the effect of heavy litter fall, which may have increased the cohesiveness in the soil after decomposition and also tight binding of the soil in lower horizons by deep root systems. It has been established that for all types of soil groups, grass cover is at least five times more effective than bare soil in the control of soil water loss. Since vegetative barriers are economical to

Table 6. Effect of different agroforestry systems on soil and moisture conservation.

Agroforestry systems	Bulk density ($Mg\ m^{-3}$)	Organic C ($g\ kg^{-1}$)	Mean weight diameter (mm)	Erosion ratio	Available water (%, v/v)
Silvi-horti-pastoral	0.98	22.5	2.43	3.07	24.23
Multistoreyed AFS	0.97	24.6	2.65	3.06	25.30
Natural forest	0.94	27.0	3.13	2.10	26.94

Table 7. Effect of different agroforestry systems on soil fertility.

Agroforestry systems	pH	Available N (ppm)	Available P (ppm)	Exchangeable Ca [cmol (p^+)/kg]	Exchangeable Mg [cmol (p^+)/kg]
Silvi-horti-pastoral	4.25	199.40	0.94	0.31	0.48
Multistoreyed AFS	4.61	216.90	3.36	0.65	0.71
Natural forest	4.62	167.20	0.63	0.26	0.16

establish, easy to maintain and provide direct benefits including fodder, they could be a boon to marginal and small farmers for sustainable crop production.

Agroforestry and soil fertility

The effect of different agroforestry systems on soil fertility status is presented in Table 7. In all the AFSs, there was a 1.17 to 1.65-fold increase in organic carbon compared with the initial status of organic carbon in the surface soil. The silvi-horti-pastoral system contributed the maximum amount of organic carbon to the soil, which was largely dependent on the nature of the vegetation. Adoption of different cropping patterns in various AFSs markedly influenced the exchangeable Ca and Mg content in the soil. Maximum accumulation of these cations was recorded under multistoreyed AFSs. Similarly, the higher availability of N and P contents under multistoreyed AFS confirms that this system becomes a viable alternative to shifting cultivation from the point of view of fertility when combined with judicious use of fertilizers and manures (Majumdar *et al*, 2002).

Agroforestry and sustainability

Besides maintaining the quality of the resource base (soil and water), the trees contribute to the vitality of the entire agroecosystem, which is best ensured when soil and water are well managed. Since renewable plant diversity and recycled nutrients in a self-contained hill farming system are the basis of soil fertility management and of the natural biological protection of plants, system pollution by eco-malignant pesticides is avoided. Thus, a forest or assemblage of trees provides a base for ecologically sound and environmentally safe agriculture.

Conclusion

The holistic approach involving regenerative agricultural technologies of integrated farming systems is a prerequisite for the sustainable development of hilly areas, soil conservation, hydrological stability and higher productivity. In this regard, the multistoreyed agroforestry and silvi-horti-pastoral systems are the most sustainable practices for resource conservation in the hilly ecosystems of the north-east region, as these systems not only help to strengthen soil physical health, but also enhance moisture retention and release the capacity for sustainable crop production in humid tropical climates.

Future priority areas for hill agriculture

Future priorities should include the following:

(1) identification of agroforestry practices for resource conservation and their optimization to increase economic returns and sustainable traditional practices;
(2) integrated farming system approaches at the watershed to restore highly degraded land through agroforestry, horticulture and pasture plantation crops;
(3) development of economically feasible technologies for enhancement of the hydro-physical, chemical and microbiological condition of soil to suit the land use for site-specific crop production at different elevations of the hills of NEH; and
(4) promotion of 'option enhancement' via the differential use of components of crop–tree–animal–fish systems, by means of which individual households can modify and diversify their production options for nutritional and food security.

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