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Bio-restoration of degraded lands under the sub-tropical North Eastern Himalayan region of India

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ABSTRACT

Soil quality fatigue is the combined result of soil physical, chemical, biological degradation (decline of organic matter, biomass C, decrease in activity and diversity of soil fauna), increase in erodibility, acidity, and salinity, and exposure of compact subsoil of poor physicochemical properties. North Eastern Region (NER) of India (geographical area of about 26.3 m ha) is characterized by high rainfall (> 2000 mm annual rainfall) of uneven distribution, severe water scarcity especially during post rainy season, soil acidity or Al^{+3} toxicity, heavy soil and nutrient losses through erosion. In the North Eastern Region, degradation of soil and environment is on alarming stage. Excessive deforestation coupled with shifting cultivation (slash and burn primitive agriculture) and other faulty agricultural practices have resulted in remarkable soil loss and poor soil physical health in this region. As the region is characterized by high rainfall and slopping hills and valleys, engineering means of terracing, bunding *etc.* for soil and water conservation may further accelerate the soil loses by erosion leading to land degradation. Bio restoration technique would not only help in conserving the productive soil, by reducing the soil erosion and restoring the soil C and nutrients but would also enhance the productivity and fertility of highly degraded soils. Considering the present level of resource mining, bio-based resource conservation techniques like zero tillage or minimum tillage, hedge crop, mulching, cover cropping along with use of biofertilizers and organic manure needs due attention for building up of organic matter and soil health of degraded soils of the region.

1. Introduction

Climate change deforestation, poor farming practices, overgrazing, inappropriate irrigation, urban sprawl, commercial development, soil pollution are the main causes of the land degradation. Over exploitation of forests and grass lands in the region has been previously documented by many researchers (Saha *et al.,* 2012; Lenka *et al.,* 2012). The problem of land degradation has cascading effect on land and crop productivity and the basic land chunk through multi-factor deficiencies on the one hand and the ever growing demand for food, fodder, fiber, fuel, many non-farm lands uses on the other hand. Soil degradation refers to the decline in soil's inherent capacity to produce economic goods and perform ecologic functions (Saha *et al.,* 2012). It is the net product of active soil restorative and degradative processes governed by natural and anthropogenic factors. The extent of soil degradation cruxes on susceptibility of soils to degradative processes, land use, impacted duration of land use, and the management practices. This forces the researchers to analyze the role of soil organic matter (SOM) dynamics and carbon (C) sequestration capacity under different ecosystems to attain desire quality soils (Lal, 2004).

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Soil quality is the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promotes plant and animal health and thus, has a profound effect on the health and productivity of a given ecosystem and the environment related to it (Choudhury *et al.,* 2015).

1.1 Extent of soil degradation in NER

North-Eastern region (NER) of Indian Himalayas comprises eight states (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura) spread over 26.3 million hectares (M ha) or ~8% of total geographical area of India (329 M ha). It lies between 22°05′ and 29°30′ N latitudes and 87°55′ and 97°24′ E longitudes and home of 45.5 million people (Nath *et al.,* 2015). The land of the region is characterized as hilly terrains with steep slope therefore high vulnerable to agricultural activities. Hence, soil degradation is a serious problem in the region, and it is also an important issue in the world. The extent of land degradation in NER varies across the states of the region depending upon geological formations, topographical features, soil characteristics, climatic conditions, land use practices *etc.* However, in totality NER receives a very high amount of annual rainfall ranging from 1500–12,000 mm. The hilly and sloppy soils of region are prone to erosion by water and other means causes soil, C, nutrient losses. In addition, human-mediated escalation of land degradation has been caused by cleaning of vegetation, buildings and road construction, excessive mining, and construction of hydro-power projects. The extent of soil degradation in North East Region (NER) of India, as estimated by ICAR-NBSS&LUP and Indian Council of Agricultural Research (ICAR) is given in Table

1.2 Causes of soil degradation in NER

The region is agglomeration of diverse geographical and agro-climatic conditions. The region has 54.1% area under forest, 16.6% under crops and rest of the area is either under non-agricultural activities or not available for agriculture. The area under agriculture crops is low due the geo-physiographic features of the region. A major land mass (~15%) falls under sloppy, undulating, eroded and unproductive land (Saha *et al.*, 2012). Continuous attenuation of natural vegetation, due to expansion of agriculture land, urbanization, shifting cultivation, timber and firewood collections is posture more serious problem on poor soil health of region. Major causes of soil degradation in region are listed in are given Figure 1.

Figure 1. Major causes of soil degradation in NER, India

Table 1. The extent of land degradation (Million ha) in North East Region (NER) of India

State	Water Erosion	Water Logging	Soil Acidity	Complex Problem	Total Degraded Area	% of Degraded Area to Total geographical area (TGA)
Arunachal Pradesh	2.4	0.2	2.0	0	4.6	53.8
Assam	0.7	0	0.6	0.9	2.2	28.2
Manipur	0.1	0	1.1	0.7	1.9	89.2
Meghalaya	0.1	0	1.0	0	1.2	53.9
Nagaland	0.4	0	0.1	0.5	1.0	60.0
Sikkim	0.2	0	0.1	0	0.3	33.0
Tripura	0.1	0.2	0.2	0.1	0.6	59.9
NER	4.0	0.4	5.1	2.2	11.8	
India	93.7	14.3	16.0	7.4	146.8	

Data source: NBSS&LUP-ICAR (2005) on 1:250,000 scale.

1.3 Erosion by water

Due to faulty land uses and intense rainfall water-induced soil erosion is major cause of land degradation in NER-India. The Eastern Himalayan Region is more susceptible to soil erosion because of its physiography and high precipitation. Further, encroachment of forest land by road and hydro-power construction, mining and unscientific agricultural activities also aggravated the soil degradation in the region (Sharma, 2004; Lenka *et al.*, 2012). Further, shifting cultivation especially on very steep slopes leads to accelerated erosion (Mandal and Sharda, 2013). Soil crusting and poor ground coverage accelerates the process of soil erosion and causes very high soil loss during cultivation after slashing and burning of forest (150 Mg/ha/year). On average, ~50 ton soil per ha is lost due to biomass removal/burning from soil surface and successive ploughing in steep slopes (Baishya and Sarkar, 2015). The removal of top soil leads to soil fertility degradation which cannot be easily built up. Therefore, depletion of SOC, available N, P and exchangeable cations are the common features in these soils (Das *et al.,* 2009).

2. Shifting Cultivation

Shifting cultivation popularly known as *jhum*, an old age and very destructive and unsustainable agricultural production system in the region. It involves slashing and burning of the native vegetation and cultivate plots of land in the virgin forest until the yields of the crops fall below subsistence level (Nath *et al.,* 2016). This practice in NER represents one of the predominant land uses system and covering an area of 0.88 million hectares (mha). After that farmers abandon the land to natural fallow and move to a new area. After few years the cultivators come back to same site and repeat the process, until soil fertility apparently exhausted. Due to increase in population pressure, demand for food and fuel are increasing leading to pressure on land in one hand and reduction in agricultural land availability due to increase other uses of land such as construction, infrastructure *etc.* As a result, the *jhum* cycle of 10-15 years in past is reduced to 3-5 years at present. Furthermore, indiscriminate felling of trees on the hill slopes brought an unsustainable eco-imbalance. The hill tops are the main source of water conservation; deforestation of this hill top led to the elimination of water source. This, in fact, ended in the loss of top soil. Erosion of soil in the catchment area resulted in silting of the reservoirs. Shifting cultivation along with excessive deforestation has caused soil loss to the extent of >200 t/ha/year in area, which has poor soil physical and biological conditions. Among the agriculture practices in the region, shifting cultivation cause the maximum soil loss about 30–170 t/ha/year followed by repeated tillage based production system about 5–68 t/ha/year (Saha *et al.*, 2012). However, increasing population pressure has further reduced the *jhum* cycle and has been the cause of soil and environmental degradation in the region. The most common adverse impact of shifting cultivation on soil health is represented by the figure 2. Hence, this alarming situation needs to be attempted on top priority to maintain the ecological balance and fodder, food, fuel requirements, *etc.* of the region. The calendar of shifting cultivation system is given in Table 2.

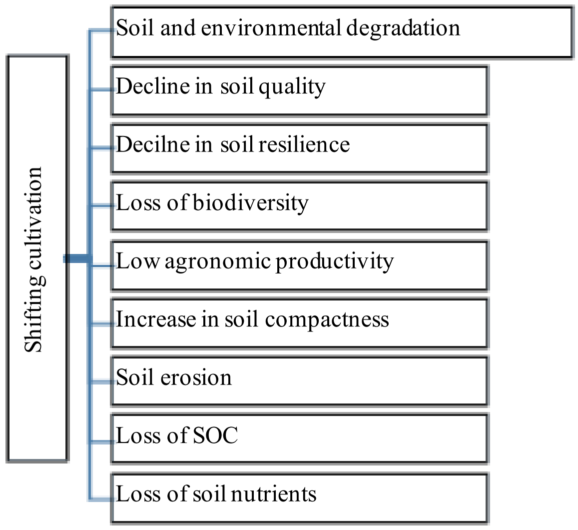

Figure 2. Impact of shifting cultivation on soil and environment

3. Deforestation

Snowballing population needs more space for habitation resulted in heavy and indiscriminate deforestation in NER is not only leading to land degradation but also contributing to food and environmental insecurity. India State of Forest Report (2015) stated that a net decline of 628 km^2 in the forest cover since 2013 in the North East is more than a cause for worry. The main reason for this decrease is attributed to the biotic pressure and shifting cultivation in the region. Among the North Eastern States, Mizoram has recorded the highest decrease in forest of 307 km^2, followed by Nagaland 78 km^2. The 80% of forest of the region is un-classified and mostly administrative by Autonomous District Councils of states. Only 10% of the forest is own by Govt., therefore region has poor access to certified seed and planting materials (Bhatt *et al.*, 2016). This dearth of quality planting material has constrained the regeneration of forests to a great extent in the fragile ecosystem of NER. Soil health and forest resource are closely interlinked, hence, rapid depleting forest resources retarded the soil productivity (Bhatt *et al.*, 2016). Further, burning of vegetation by forest fire and decline in biodiversity are exaggerated the process of soil degradation.

Table 2. Soil erosion calendar of shifting cultivation system

Month	Agricultural operation	Erosion problem	Soil erosion (Mg/ha)	
January to April	Field selection, forest/vegetation cutting, burning and cleaning of hill slopes	Loose soil displacement to down hills and rolling down of earthworm casting and other organic materials and wash due to rains.	0.0	22.4.
May	Sowing	Substantial soil wash, drilling at foot hills on silt deposits	0.2	61.9
June	Weeding	Heavy wash-down of soil aggregates	0.2	45.4
July	Weeding/harvesting begins	Heavy wash of soil aggregates, crop root get exposed	1.8	21.9
August	Harvesting and occasional Weeding	Soil washing continues	1.0	29.6
September	Harvesting	Moss appears, sloughing soil erosion	0.1	13.8
October	Harvesting	Considerably reduction in Soil erosion	0.0	2.7
November	Harvesting	Negligible erosion, moss turns blackish	0.00	0.00
December	Harvesting/threshing/carry harvest back to home	No erosion	0.00	0.00
Year	Direct seeding/planting on steep slope	Heavy soil wash	3.30	201.4

Source: Yadav *et al* 2006

4. Soil acidity and decline of soil fertility

Acid soils occupy nearly 21.2 M ha (~81% of geographical area) in the region and majority of these soils (16.2 M ha) has pH < 5.5 (Sharma *et al.,* 2006). Productivity of these soils are mostly constrained by the adverse effects of aluminium (Al), deficiency of phosphorus (P) and zinc (Zn) and impaired biological activity (Das *et al.,* 2016a). The major cause of decline of soil fertility in the region is soil erosion. Declining SOM, soil biological activity, deterioration of soil physical properties and increase in unavailability of major nutrients (NPK) and onset of micronutrient deficiencies aggravated the land degradation. The amount of soil and nutrient losses by water erosion causing environmental degradation in the region was assessed about ~601 Mt of soil, and 685.8, 99.8, 511.1, 22.6, 14.0, 57.1, and 43.0 thousand tons of N, P, K, Mn, Zn, Ca, and Mg, respectively (Singh and Singh, 1981).

5. Faulty land use practices on hill slopes

The resource degradation process in the region is closely linked up with the land use system. Forestry is the ruling land use system in the region followed by agriculture, horticulture, animal husbandry and non-agricultural uses, respectively. Most of the land use systems practices in the region are hazardous to resources and are not favorable to the sustainable agriculture development. Cultivation of horticultural/agricultural/vegetable crops along the hill slopes without appropriate soil and water conservation resulted in very high soil erosion. The soil erosion varied with the extent of disturbances caused to the soil surface. Colocasia, tapioca, sweet potato, turmeric and ginger are the crops, which resulted in movement of soil to the foot hills during the process of harvesting (Table 3).

Table 3. Land use practice and soil erosion on hill slopes

Land use/practice	Soil loss (t/ha/yr.)	Authority
Pineapple along the slope	24-62.6	Ghosh (1976)
Bun" system for raising tuber crops	40-50	Singh (1970)

Decline of soil organic carbon

Faulty land use systems accelerate the soil organic matter (SOM) decomposition and it affects the carbon cycle because of the imbalance between carbon emissions and sequestration (Chaudhury *et al.,* 2015). SOC is influenced by dynamic interaction of climate, vegetation, soil type, topography, soil texture, soil aggregations, and land use (Barua & Haque, 2013; Jaiarree *et al.,* 2014). However, in the recent past, rapid land use–land cover change as a result of large-scale deforestation, transformation of natural forests to temporary agriculture through various production practices, plantations and other forms are mostly resulting in colossal loss of phytomass in the region. Shifting cultivation alone is burning phytomass of more than 8·5 million tons annually. Reports showed that the conversion of primary or secondary forests to crop lands and perennial crops/plantations in the tropics always results in 25–30% loss of SOC stock (Don *et al.,* 2011). In burning of vegetation in the Mediterranean hill slopes, similar to shifting cultivation practices of the NER, surface SOC stock was reduced by 41·8% (Novara *et al.,* 2011).

Synthesis of available literatures suggest that cultivation practices in hill slopes under an agriculture system always degrade soil structure, reduce the aggregate stability and make the soils more prone to soil erosion (Chaudhury *et al.,* 2015).

6. Strategies for bio-restoration of degraded soils in NER, India

It is obvious that contending the degradation of precious natural resources and investing in their conservation for future generation will be a major real task for promoting sustainable development and nature protection. The application of modern techniques and development of new methodologies to cope with the widespread problem of soil degradation has become imperative to protect cultivable and uncultivable lands from the ravages of erosion, enhance and restore soil productivity, reverse degradative trends and restore degraded soil. The restoration of degraded soil of NER is necessary to sufficient food and dignified life to the people of the region. As the region is characterized by sloppy hills and valley, therefore construction of terracing, bunding *etc.* by engineering means may further accelerate the soil lose by erosion and due to heavy rainfall and caused the soil degradation. Use of bio-based technique/strategies may conserve the soil, reduce the soil erosion and restore the soil C and nutrient lost previously. The most important bio-restoration strategies for degraded soil are given in Figure 3.

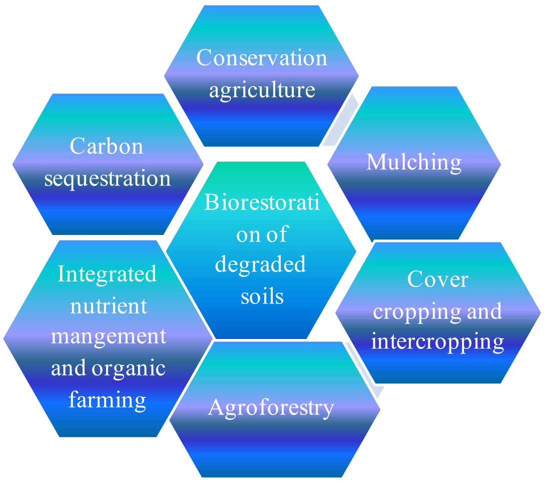

Figure 3. Important strategies for bio-restoration of degraded land

6.1 Conservation Agriculture

Conservation agriculture (CA) involve minimum soil disturbance, providing a soil cover through crop residues or other cover crops, and crop rotations for achieving higher productivity and minimize adverse environmental impacts (Das *et al.,* 2013). In the conventional systems (involving intensive tillage), there is a gradual decline in SOM through accelerated oxidation and burning of crop residues causing pollution, greenhouse gases emission, and loss of valuable plant nutrients. Aggressive seed-bed preparation leads to declining soil fertility and biodiversity. When the crop residues are retained on soil surface in combination with no-till (NT)/zero till (ZT) lead to improved soil quality and overall resource enhancement. Therefore, CA may lead to sustainable improvements in the efficient use of water and nutrients by improving nutrient balances and availability, infiltration and retention by soils reducing water losses due to evaporation, and improving the quality and availability of ground and surface water (Das *et al.,* 2013). CA couple with application of organic matter (OM) through weed biomass, farm yard manure (FYM) and poultry manure (PM) can increase SOC concentration and restore the degraded soil in high rainfall region of the North East India (Das *et al.,* 2014a). Increase in SOC concentration also improved soil physico-chemical and biological qualities of soils (Das *et al.,* 2014a). Use of NT system significantly improved soil hydro-physical characteristics and biological activity, specifically increasing the SOC concentration by 8·4%, WSA by 9·3%, MWD by 42·6% and SMBC by 66·8% in comparison to CT after a 4-year period (Das *et al.,* 2014a). Such improvement in soil properties has a direct bearing on long-term sustainability and soil quality in complex, diverse, risk-prone and fragile hilly ecosystems.

Soil degradation can also be reversed with an appropriate combination of technologies (application of organic amendments with minimum tillage (MT) and use of buffer strips). For example, Himalayan valley had 4% slope, MT + crop residue decreased runoff by 40% and 11% and soil loss by 69% and 28% compared to cultivated fallow and conventional tillage (CT), respectively (Sharma *et al.,* 2013). NT with crop residues retention initiates processes that lead to improved soil quality and overall enhancement of resource-use efficiency. Higher SOC and total N contents under NT and residue retention in rice–pea (*Pisum sativum*) (Ghosh *et al.,* 2010), rice–lentil (*Lens culinaris*), (Das *et al.,* 2014b) maize–rapeseed (*Brassica campestris* var. toria), (Das *et al.,* 2011) and maize–French bean (*Phaseolus vulgaris*) (Das *et al.*, 2014c) have been reported from the diverse ecosystems of the NER. Increase in SOC and soil nutrient status due to residue management under groundnut (*Arachis hypogaea*)–rapeseed system is also reported (Kuotsu *et al.,* 2014).

6.2 Mulching

Under fragile Himalayan ecosystem soil resources of NER are very prone to degradation. The practice of mulching has been widely used as a management tool in many ancient civilizations. Residue mulching can play a pivotal role in protecting and improving soil quality. It is a common practice for conserving soil moisture, reducing soil erosion and enhancing the SOC (Das *et al.,* 2015). Generally, crop residues, forest litter and weed biomass are used as mulch in the region. Mulching has a buffering effect and it dampens the influence of negative environmental factors on soil (Bristow and Abrecht, 1989). The magnitude of the buffering effect depends on the quality, quantity and durability of the mulch material. Mulches improve the physical condition and fertility of the soil, check runoff and soil erosion, increase infiltration (Ghosh *et al.,* 2006), help in maintaining soil temperature, impede movement of water vapour (evaporation) from soil to air, check weed growth and thereby, reduce transpiration loss of water (Blevins and Frye, 1993), develop high humidity within the residue mulch (Phillips, 1984) and reduce the kinetic energy of impacting rain drops on the soil surface and thus, reduce soil compaction and aggregate disintegration and restore the degraded soil (Mbagwu, 1991).

6.3 Intercropping and cover cropping

Agronomical practices like use of cover crops, mixed/inter/strip cropping, crop rotation and green manuring are vital practices mostly used for carbon sequestration and improvement of soil physical, chemical and biological properties of a degraded land. Growing soybean (*Glycine max*)/groundnut (*Arachis hypogaea*) /cowpea (*Vigna radiata*) with maize (*Zea mays*) is a common example of intercropping in the region (Ghosh *et al.,* 2011). Strip cropping is a combination of contouring and crop rotation in which alternate strips of row crops and soil conserving crops are grown on the same slope, perpendicular to the water flow in hilly regions, respectively. Intercropping cowpea with maize (2 rows of cowpea with 1 row of maize) decreased runoff by 10% and soil loss by 28% compared to pure stand of maize (Singh *et al.*, 1992). Rice and maize based intercropping systems such as rice+groundnut/soybean in 3:1 row ratio and maize +groundnut/soybean in 1:1 row ratio reduced the runoff and soil loss significantly compared with maize and rice along the slope (Pattanaik *et al.,* 2016).

6.4 Integrated farming system

Eight micro watershed based alternative integrated farming systems were developed by Indian Council of Agricultural Research, Research Complex for North Eastern Hill Region, Umiam, in 1983 to replace the shifting cultivation in the region. Soil physicochemical properties were assessed after 20 years. The maximum accumulation of exchangeable Ca^{2+} was observed under cropping system and exchangeable K under agri-hortisilvi-pastoral system (Saha *et al.*, 2012). There was a substantial buildup of available N in soils under all eight systems. The rise in available P in agricultural livestock-based system could be due to heavy and continuous dressing of cow dung litter for a long period. Available K increased in all systems except that in the livestock-based farming system. The overall fertility buildup followed the trend of agriculture >agri-horti-silvi-pastoral > livestock-based farming system. The improvement in overall soil fertility due to various farming systems over shifting cultivation-based land use has been reported (Das *et al.,* 2016).

6.5 Agroforestry systems (AFS)

In hill ecosystems, AFSs play an important role in sustainability, resource conservation, and food security. Multistoried AFSs/home gardens are the classic example of agro forestry. Agri-horticulture, agri-silviculture, agrihorti-silvi-pasture, agri-pisciculuture, and multitier systems are some of the important AFSs in the NER (Das *et al.,* 2016). Tree species (*e.g. A. nepalensis* and *P. kesiya*) have favorable effects on soil physical properties, particularly on soil bulk density, moisture content, and mean weight diameter of soil aggregates (Das *et al.,* 2016). About 33%, 50%, and 76% increase in soil available N, P, and K content, respectively, has been observed under *A. nepalensis* as compared to control. *A. nepalensis* and *Michelia oblonga* considerably favored the accumulation of SOC and available nutrients compared to other tree species under mid hill condition of Meghalaya (Ramesh *et al.,* 2013). The Agri-horti-silvi -pastoral land use model increased organic C by ~45%, mean weight diameter of soil aggregates by 29%, and in-situ soil moisture content by 21%, and decreased clay dispersion by 53%, soil loss by ~99%, and soil erosion ratio by 45.9% under moderate to steep slopes. Multipurpose trees (MPTs) like *Michelia oblonga* were identified as a better bio-ameliorant for these soils because continuous leaf litter and root exudates improved soil physical behaviour and SOC (Ghosh *et al.,* 2009).

6.6 Hedgerow or alley crops

Growing hedge row leguminous shrub species helps in conserving soil and water in sloping lands and improve soil health. The hedge rows are grown around the farm boundaries also along the contours in sloping lands at adequate spacing as per the slope and crops to be grown. In 30-40% slopes, the hedge rows may be grown at a spacing of 5-6 m and cultivation can be done of interspaces. In long run this will help in development of natural terraces due to removal and deposition of soils in contours. Growing hedgerow crops especially leguminous species on the boundaries not only protects the field from outside contamination, but also provides a very good source of plant nutrients and feed for cattle (Das and Ghosh, 2012). Six different hedgerow species (*Cajanus cajan*, *Crotolaria tetragona*, *Desmodium rensonii*, *Flemingia macrophylla*, *Indigo feratinctoria,* and *Tehphrosia candida*) have been tested for soil fertility build-up and soil maintenance in the mid hills of Meghalaya, north-east India (Laxminarayana *et al.,* 2006). Each species was planted in the contour bunds on the upland terraces with an inter-terrace spacing of 5 m. Two years after planting, soil samples were collected from the contours of each species at different soil depths. The results revealed that hedgerow species had a significant effect on soil chemical properties. Almost all the species improved the available NPK status and organic carbon content of the soil compared with initial and control. *C. Tetragonoloba* can add as much as five tons of fresh leaves/ha/year. On average, the pruning of N-fixing hedgerow species can add 20–80, 3–14 and 8–38 kg of N, P and K per ha respectively per year (Bhatt and Bujarbaruah, 2006). Addition of leaf biomass from hedgerow species also improves the fertility of soil and lowers soil acidity. The pruning of these species can also be used for mulching, which helps conserve moisture and on decomposition supplies additional nutrients to the plants (Das and Ghost, 2012).

6.6 Role of nitrogen-fixing tree species

In north-east India, nitrogen deficiency is a major constraint for increasing and sustaining productivity because land use in the hills is hazardous and adds to the process of depletion (Das and Ghost, 2012). Off-late organic farming is promoted in the region by the Governments and use of fertilizer is discouraged. Under such condition Nitrogen-fixing trees and shrubs can play a vital role in maintaining soil fertility by reducing land degradation and generating N rich leaf biomass. These species include *Acacia, Albania, Lanus, Calendar, Casuarinas, Dalbergia, Gliricidia, Leucaena, Prosopis, Robinia, Sesbania, Crotolaria, Desmodium, Flemingia, Indigofera, Tephrosia* (Dhyani and Chauhan, 1990). These trees fix atmospheric nitrogen as a result of their symbiotic association with rhizobium in case of legumes and in some *Ulmaceae* and *Actinomycetes*, genus *Frankia* in case of other trees. Three genera of *Rhizobia*, namely *Rhizobium*, *Bradyrhizobium,* and *Azorhizobium*, are involved in N fixation in nitrogen fixing trees (NFTs) (Das and Ghosh, 2012). The microbial symbiont infects the roots of nitrogen-fixing trees and stimulates the tree to form nodules. Within the nodule, the symbiont multiplies and fixes atmospheric nitrogen. Das *et al.* 2008 reported that continuous application of leguminous tree leaves (10 t/ha on fresh weight basis) in lowland rice fields helped to sustain soil and crop productivity.

6.7 Vegetative barriers and natural grasses

Biological methods of soil and water conservation, especially grass/vegetation covers are not only cost-effective but very suitable for hilly ecosystems. Inclusion of permanent pastoral grasses for soil quality management is very pertinent under humid conditions of fragile hill ecosystems (Saha *et al.,* 2012). Perennial grasses provide year-round ground cover, which reduces run-off and soil erosion from sloping land (Ghosh *et al.,* 2009). Perennial grass cover improves physico-chemical properties of the soil by adding OM (Bonnin and Lal, 2014). The contribution of SOM from grasses can increase water stable aggregates (WSA), mean weight diameter (MWD), and soil moisture retention (Ekwue, 1990). Larger root mass, root exudates, and the presence of fungal hyphae in soils under grasses improve the stability of macro-aggregates (Tisdall and Oades, 1982). Diverse range of perennial forages *viz.* broom grass (*Thysanolaena maxima*), congo signal grass (*Brachieria rosenesis*), napier grass (*Pennisetum typhoides* x *P. purpureum*), guinea grass (*Panicum maximum*), setaria (*Setaria sphacelata*), *etc.* are very much suitable for cultivation on degraded soils of the NEH region (Das *et al.,* 2016b). Cultivation of forages in degraded and sloping lands not only rehabilitates the degraded soils by improving physico-chemical properties but also supplies green palatable fodders to livestocks (Ghosh *et al.,* 2009). Forages have strong root systems compared to field crops (such as rice, maize *etc.*) protect soil and improve aggregation. A geospatial study in NEH region of India covering about 10.1 M ha, reported high SOC concentration from grassland and second only to forest land use. The SOC stock under perennial grassland was 47 Mg/ha. 23 Mg/ha under degraded and abandoned *jhum* land (Choudhury *et al.,* 2013). ICAR Tripura centre working on soil and water conservation since inception. The centre identified Hybrid Napier one of the potential biological measure for bund stabilization and controlling soil erosion.

The planting of stem cutting of Napier on bund, make the bund more stable and check the overflow of water/runoff and enhanced the water stagnation time, which ultimately lead the more amount of water infiltration in soil. This is well proven technology of ICAR Tripura centre is available for soil and water conservation as well as augmenting the fodder production of state (Figure 4).

Figure 4. Use of Hybrid Napier for conservation of soil and water (ICAR NEH Tripura Centre)

6.8 Integrated nutrient management and organic farming

The use of N, P, and K fertilizer in the NER is only 13.4%, 11.1%, and 11.1%, respectively, of the crop removal, indicating a perpetual depletion and low productivity. In most cases, only N fertilizer is applied and P and K are neglected. In case of Manipur state of NER, the ratio of N/P/K application is 76.9:7.5:1, respectively. Integrated use of chemical fertilizers of 60 kg N/ha along with 5 Mg/ha farmyard manure (FYM) with the seed inoculation of *Azotobacter* can enhance rice yield, nutrient uptake, and N buildup in soils (Majumdar *et al.*, 2004). Similarly, conjoint application of single super phosphate and *Rhizobium* in black gram recorded 69.1% increase in nodulation over control in acidic soils of Tripura. Patel *et al.* 2014 reported integrated nutrient systems as organic amendment resulted in maximum improvement in soil organic carbon (SOC), available P and potassium (K), soil microbial biomass carbon and water holding capacity and was similar to those under FYM. The SOC concentration under INS (23.6 g/kg), FYM (23.3 g/kg) and vermicompost (22.3 g/kg) after five years of organic farming were 31.0, 29.4 and 23.8% higher than the initial and 26.2, 24.6 and 19.3% higher than those under control, respectively.

The fertilizer consumption is less than 12 kg/ha (excluding Manipur and Tripura) in the NER. The total potential for nutrient supply through crop residues in the region has been estimated as 9.86, 2.12, and 35.5 Mg of N, P, and K, respectively, thus creating on an average 2.46 kg N, 0.53 kg P_2O_5, and 8.87 K_2O/ha. Thus, a good quantity of potash can be added through crop residues (Das *et al.*, 2016a). Growing leguminous shrubs such as *Crotalaria juncea* and *Tephrosia purpurea* around the farm fences can produce 5–6 Mg/ha green leaf manure containing 2.4–2.7% N, 0.3–0.6% P, and 0.8–2.0% K (Das *et al.*, 2016a). It is an added advantage that every family maintains some cattle, and thus, the NER has about 13 million cattle population. Patel *et al.* 2014 while working at Meghalya reported that the application of recommended dose of N through FYM or FYM + vermicompost is equally effective as organic amendment and their continuous application improved soil health and productivity of rice, pea, lentil, carrot (*Daucus carota*), French bean, tomato (*Solanum lycopersicum*), potato (*Solunum tuberosum*), and okra (*Abelmoschus esculentus*). Similarly, Das *et al.* 2015 stated that organic manure has the potential to improve quality of degraded soils. They have reported the higher levels of total SOC, total N, soluble P, microbial activity and soil microbial biomass carbon (SMBC) under organic management condition as compared to mineral fertilizers.

6.9 Crop residue management

Improvement in soil conditions mediated very effectively through residues, stubbles and weed biomass recycling in the soil system (Das *et al.,* 2008). Recycling of residues and plant biomass in the soil is the one of the best alternative practices for replenishing the depleted soil fertility, improving the physico-chemical properties of the soil and ultimately crop yield (Das *et al.,* 2010). Incorporation of crop residues not only improved the crop yield but also increased the nutrient uptake besides improving the physico-chemical and biological properties of the degraded soil (Karchoo and Dixit 2005). Water infiltration rate (11.2 mm/h) and hydraulic conductivity (6.98 mm/h) in soil under raised bed with residue + hedge leaves mulching (NT) were significantly higher than that under conventional practice (7.65 mm/h and 3.35 mm/h) after two cropping cycles (Kuotsu *et al.,* 2014). Improvement of soil microbial biomass carbon (381 mg/g soil) and dehydrogenase activities (57.8 mg TPF/g soil/24 h) as compared to conventional farming practice were also reported due residue addition (Kuotsu *et al.,* 2014).

6.10 Carbon sequestration

Insubstantial hilly ecosystem of NER of India, interaction of land use change and SOC holds significance in sustaining land productivity and restoring degraded soils. SOC is one of the most important indicators of land productivity because it influences soil processes responsible for enhancing productivity and sustainability of agricultural ecosystems (Stevenson & Cole, 1999).

Phytomass on decomposition is an important source to enrich soil with organic C and improves aggregation (Choudhury *et al.,* 2013). The SOM pool is the backbone in supplying essential nutrition to support marginal input and low productive rainfed agricultural production system of NEHR (Ghosh *et al.,* 2009). The impact of climate change, particularly rainfall and temperature pattern, on phytomass production, food and environmental security of the region largely depends on SOM pools. SOC concentration in the surface soils (0–30 cm) of NER varies widely from 0·85 to 3·56% (Bhattacharyya *et al.,* 2008). Choudhury *et al.* (2013) also reported SOC stock of 20–40Mg/ha in the surface soils of the region. In the studied soils of different land-use systems of Lembucherra, Tripura, the SOC concentrations ranged from 8.6 to 16.4 g/kg at 0–15 cm and from 7.4 to 15.2 g/kg at 15–30 cm layers. Among all the land uses, SOC stock was the maximum under bamboo (*Bambusa spp.*) plantations followed by that in *Tephrosia purpurea* alley cropping and duck based farming system. Soils under mango (*Mangifera indica*) and arecanut had the lowest SOC stock (Das *et al.,* 2016a). In addition, Agroforestry systems, perennial forage crops, crop residue recycling, conservation agriculture and hedge row species (Figure5) sequestrate the C sequestration in degraded soil and improve its soil health has been reported under the NER (Das *et al.,* 2016a).

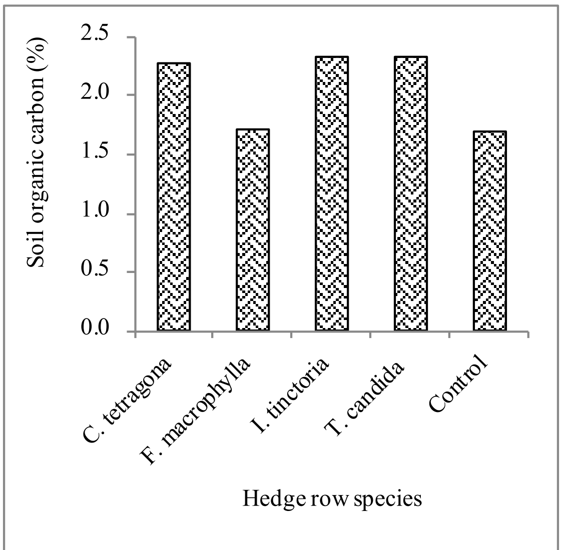

Figure 5. Effect of hedge row species on soil organic carbon (Das and Ghosh, 2012)

7. Conclusion

North Eastern Region is a natural hub of biomass, vegetation diversity and soil organic carbon hence, bio-based management strategies can play an indispensible role restoring the degraded of soils of the region. Since the region is a mix of hills and valleys with steep slopes, the problems of soil degradation is more severe due to soil erosion, loss of soil C, shifting cultivation and soil acidity. Thus, biological approaches with integrated natural resource management for restoring Soil C and nutrient in there antecedent level and improve further. The most suitable bio-based strategies for the region comprises conservation agriculture, mulching, inter and cover cropping, use of vegetative barriers and grasses, integrated nutrient management, integrated farming systems, agroforestry systems and most important technologies which enhanced the rate of C sequestration in the region.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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