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SOIL RESILIENCE IN NORTH EASTERN HILLS

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ABSTRACT

Soil resilience (restoration) is the ability of soil to restore its quality after disturbance and ultimately affects the health/quality of soil. The sustainability depends on resilience and resistance of soil by the management practices followed over time. The soils of north eastern hill states are suffering from various types of degradation (i.e., loss of quality and resilience), mainly caused by over exploitation of forest for timber, fuel and fodder surrounding human settlements, shifting agriculture (jhum) on hill slopes, improper land use practices, population explosion including livestock, infrastructure development and mining activities. These practices result in poor soil quality/health and loss of soil productivity for sustaining agricultural productivity and hill agro-ecosystem. The paper attempts at resilience of soil through the practices of preventing soil erosion, replenishment of nutrient removal from crops harvested animals by judicious use of organics, inorganic fertilizers and amendments to correct soil acidity associated problems, regenerative shifting agriculture, agroforestry and sequestering soil organic matter.`

INTRODUCTION

The suitability of soil for sustaining plant growth and biological activity is a function of physical, chemical and microbial properties of soils, many of which are related to organic matter content of the soil. Soil degradation is the principal component of soil quality/health deterioration, due to adverse changes in pedosphere. There is a strong link among the soil degradation, environmental quality, food security and nutrition. Soil resilience has been introduced into soil science recently, mainly to address soil ecology and sustainable land-use issues (Blum, 1994). Resilience has been defined as the capacity of a system to continue to function without change through a disturbance, and is proportional to the rcoveries of the functional integrity following a disturbance (Pimm, 1984). Holling and Meffe (1996) defined soil resilience in terms of equilibrium and ecosystem resilience. The 'equilibrium resilience' concentrates on stability near equlibrium steady state and rate of return to equilibrium and disturbance is the measure of resilience. The 'ecosystem resilience' is the magnitude of disturbance that can be absorbed or accommodated before system changes its structure. Soil of the pedosphere, is in dynamic equilibrium with the biosphere, hydrosphere, atmosphere, and lithosphere. The adverse effects of inherent constraints of north eastern hills (NEH) on productivity and environment are exacerbated by land misuse, soil mismanagement and subsistence farming by resource poor farmers. The occurrence of widespread soil degradation is attributed to cultivation of marginal lands (steep slope, shallow soils) in high rainfall area. Transport of sediments and organic matter from the cultivated steep lands has been a major cause of the degradation of soil health. The soils of NEH are suffering from various kinds of health degradation and ultimately affecting the soil quality/health and its productivity.

SOIL RESILIENCE AND SOIL QUALITY

Resilience is one of the most important critical issues to be addressed whwn assessing soil quality, yet it is also the most difficult to predict. Soil resilience, soil's ability to restore its quality following a perturbation, depends on inherent soil properties and the net balance between soil formative and degradative processes (Lal, 1994) as per equation - $Sr = Sa + f(Sn - Sd +/- Im)dt$ where Sr is the soil resilience, Sa is the antecedent soil condition, Sn is the rate of new soil formation, Sd is the rate of degradation/depletion, Im is the management inputs and t is the time. The magnitude and sign of the term (Sn - Sd +/- Im) are critical in determining soil resilience. The above equation can be applied to specific soil properties e.g., rooting, depth, top soil thickness, soil organic matter, available nutrients and water etc. as long as the time-dependent relationship of that property is known. Soil resilience affects soil quality by mitigating the adverse effects on predominant degradative processes. Soil resilience has profound influence on soil quality in terms of the degree of change in soil functions as a result of disturbance. At the time disturbance, soil quality becomes the function of soil resilience, and soil resilience is the component of soil quality after disturbance. Thus sustainability depends on soil resilience and resistance of the system. The improper management and misuse of soil over the time can result in reduction of soil quality as result of the degradation or loss of soil resistance/resilience.

Mausbach and Tugel (1995) defined soil quality as the function of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Soil health (condition) is the ability of soil to perform according to its potential. Soil quality is a measure of the condition of soil relative to the requirement of one or more species and /or to any human need or purpose (Johnson et al, 1997). Soil quality and health changes over time due to human use and management or to usual natural events. Appropriate use of indicators (Doran et al, 1996) will depend to a large extent on how well the relevance indicators is interpreted with respect to consideration of ecosystem as given below:

Physical	:	Texure, depth of soil, topsoil, rooting, infiltration and soil bulk density (SBD) and water holding capacity (water retention characteristics)
Chemical	:	Soil organic matter (OM), pH, electrical conductivity and extractable N,P and K.
Biological	:	Microbial biomass C and N, potentially mineralizable N (anaerobic incubation), soil respiration, water content and temperature.

Arshad and Coen (1992) recommended that qualitative information should be an essential part of the soil quality-monitoring programme and can be estimated by calibrating qualitative observations against measured value.

SOIL QUALITY OF NEH REGION

Shifting cultivation, valley rice-based cropping, horticulture and mixed farming (agriculture and livestock) are the main use of land for agricultural production in NEH region comprising the states of Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. Soil degradation is the reverse of soil health/quality, resulting persistent decrease of soil potential productivity and loss of environmental regulatory capacity. The land has been degraded mainly due to over exploitation of forest for fuel, timber and fodder surrounding human settlement, shifting cultivation (*jhum*) with 3 - 5 years abundant cycle on hill slopes, improper land-use practices, population explosion including livestock, infrastructure development and mining activities (Patiram, 2000), which ultimately resulted the poor soil quality and waste land. The continuous short cycle of shifting cultivation disturbed the soil quality parameters and soil lost the resistance for resilience as a result of water erosion, least production of biomass to recover the losses of nutrients during cropping period and soil biodiversity.

Soil erosion through running water is the main agent of land degradation devoid of vegetative cover (Table 1). The loss of top fertile soil from the limited cultivated lands caused many farmers to abandon their traditionally cultivated land and to move on to other marginal lands. Erosion adversely affects crop production by reducing the availability of water, nutrients and OM of the topsoil by restricting rooting depth. The reduction in plant canopy cover due to exposure of infertile subsoil or rocks leads to increase water erosion and further accentuates the problem. The deterioration of soil quality/health is the joint result of the loss of soil fertility, biological degradation (Decline of OM, biomass C and decrease in activity and diversity of soil fauna), increase in erodibility and exposure of compact sub-soil of poor physico-chemical properties.

Majority of the soils has edaphically inferior subsoil and shallow effective rooting depth. The loss of surface layer cannot be compensated for by additional inputs. The rate of soil formation is difficult to measure because it depends on many interacting factors, such as parent material, climate, vegetation and soil disturbance. Under tropical and humid climatic condition, Hudson (1995) estimated the rate of soil formation to be about 2.5 cm in 30 years. Sometimes, this amount of soil loss occurs in the region in one year on sloppy lands with improper cultivation practices.

SOIL RESILIENCE FOR SUSTAINED PRODUCTIVITY

Sustainable management of natural resources involves the concept of using, improving and restoring " the productive capacity and life support processes of soil - the most basic of all natural resources". Sustainable practices are those that maintain the function of a resource for use by current generation and preserve the resource for potential use by future generation (Wienhold et al, 2000). Composition of sustainable land management according to Smyth and Dumanski (1995) include Productivity (maintain and enhance production), security (reduce level of production uncertainty), protection (conserves soil resources), viability (maintain economic viability) and acceptability (be socially acceptable).

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, soil pH, rooting depth, soil biodiversity, soil fauna activity and microbial activity. The soil quality and its productive capacity must be enhanced beyond preservation through building measures. Roose (1996) opined that if the six rules (control of runoff in erosion scoured soil, deep tillage for compacted soil, ploughing a stabilizer capable of stabilizing the macropores in the profile, introduction microflora and mesofauna in depleted or stripped surface horizon, liming in acidic soil to a pH value over 5 and correction of soil mineral deficiencies) for restoring soil fertility are respected, it would take one to five years to bring life and productivity back to totally degraded and abandoned soils.

There is strong relationship between soil quality and conservation farming for sustainable agriculture. The practices include preventing soil erosion and enhancing the development of rooting depth, replacing nutrients harvested in crops and animals through judicious use of mineral fertilizers and organic amendments and effective nutrient cycling practices, encouraging biological activity of soil fauna and improving soil organic matter (SOM) content. The soil resilience to maintain the quality/health of NEH region for food security and hill ecosystem equilibrium can be achieved by adopting following location specific practices.

Control of soil erosion by runoff water : Soil and crop management is crucial factors that regulate risk of soil erosion and determine erosion-induced changes in soil quality. Nutrient use efficiency drastically decreases with increase in soil erosion. The following equation can reflect erosion- induced changes in quality index (Lal, 1999b) : $Sq = f(AWC, CEC, SOC, Rd)$ where, Sq is the soil quality index, AWC is the available water capacity and Rd is the effective rooting depth. The basic aim of runoff water management and soil conservation include (i) prevention of soil detachment by raindrop impact, (ii) improvement of the structural stability of the soil surface, (iii) enhancement of soil water retention and transmission properties, and (iv) reduction of the runoff rate and its velocity by providing appropriate surface drainage systems for safe disposal of water and more time to infiltrate (Hudson, 1995). Establishment of a permanent vegetative covers and development of stable soil structures can successfully reduce soil erosion on highly erodible lands. The engineering approaches include check dam, level bench terraces, stone terracing, contour drains, counter bunds, stream channeling etc. Terracing with variable grade diversions, used in combination with grassed waterways, is one of the most successful engineering means of reducing runoff. The terrace risers can be planted with local grasses to protect the loss and produce fodder for cattle. Mechanical methods are only acceptable farmers where these are the part of traditional culture and biological approaches are more effective when used with mechanical control measures. Biological approaches include vegetative barrier on field boundaries, contour bunds and ridge, appropriate agroforestry practices, vegetative filter strips, live checks etc. to promote in situ soil and moisture conservation.

Amelioration of soil acidity and fertilization : The quality/health of our soil resources is a primary indicator of sustainability of our land management practices. An agricultural ecosystem differs from a natural one in that plant nutrients are constantly removed. So the quantity of nutrients removed in production plus those lost in other ways (e.g., leaching, runoff, and gaseous losses) must be replaced if the agricultural system is to be sustainable. Nutrient balances result from the combination of five basic inputs (fertilizer, manure, deposition, N-fixation and sedimentation) and outputs (harvested produce, crop residues, leaching, gaseous losses and erosion) (Stoorvogel and Smaling, 1990). Inorganic fertilizers are most accessible restorative option for degraded soils, although only partially effective in mitigating yield losses. The soils of NEH region are rich in total N due to presence of high amount of organic matter at higher altitude and decrease of temperature slows down the decomposition of organic matter. Almost all the soils are acidic in reaction due to leaching of bases from exchange complex under the prevailing high rainfall and hilly topography. As such soils of NEH region are rich in total P stock (organic and inorganic). Acid soil and low temperature especially at higher altitude retards the mineralization of organic P into inorganic P, which in turn, minimizes the soil availability of P to crops (Patiram, 1990), and and also present in such forms that render it to maintain the sufficient concentration in soil solution for the plants. The availability of potassium varies from low to medium category. The soil status of micronutrient cations are sufficient excepting the deficiency of Zn, B and Mo may occur on light textured leached acidic soils caused by excessive rainfall.

In this region, most of the farmers are marginal and poor and their subsistence agriculture without fertilizers and manures result in mining of soil reserves of nutrients, poor soil quality and yield. The loss of plant nutrients and fertility depletion reduces the amount of biomass produced, loss of SOM and associated microbial processes. Low-input agriculture is sustainable if the balance between the export and supplies of nutrients is in equilibrium. The application of liming materials has been recognized as a suitable management practice for the efficient utilization of native nutrients, elimination of soil acidity and judicious use of added fertilizers to realise the yield potential of crops. The field experiments conducted on acid soils of this region, revealed that the optimum yield of crops could be obtained by applying lime stone either 0.25 LR (lime requirement) or 1 - 2.5 equivalent soil exchangeable aluminum (Patiram et al, 1994). It has also been found that the application of FYM and lime on acidic P-deficient soil can give the optimum productivity of crops without application of phosphates fertilizer (Table 2).

Organic recycling of nutrients creates good condition of soil biota for soil quality and high production. In the traditional system of crop production in the humid hills of the region was totally based on organic/regenerative/low-input/biodynamic systems, such as slash-and-burn agriculture, nutrient cycling through animal manure, forest litter, available grasses and weeds on farms etc. Integrated plant nutrient supply

(IPNS) is a step towards biological approach to soil fertility by integrating the use of minerals, fertilizers, organics, bio-fertilizers and recycling urban wastes, rural wastes, industrial wastes and farm wastes to increase crop production and at the same time sustain the soil fertility.

Agroforestry : Agroforestry is the deliberate integration of woody perennials (trees, shrubs, palms, bamboo etc.) with the crops and/or animals on the same land management unit. Spatial association of trees and crops include hedgerow intercropping (alley cropping), trees on boundaries, trees in crop land and live fences. The temporal sequences or rotations of trees and crops include improved fallow. Young (1989) reported a number of hypothetical benefits from trees in association with crops. In addition to supplying nutrients to crops, the litter and pruning from trees may play a role in detoxification of soil aluminum and enhancement of soil biological activity.

Regenerative shifting (jhum) agriculture : The shifting cultivators depend on the nutrient released after slash and burn of the dried biomass for a year or two, thereafter land is left to restore the soil health on the growth of natural vegetation. Earlier, this system was sufficient to restore the soil fertility, where shifting cultivation cycle was 15 - 20years and now the cycle has become short (3-5 years) resulting poorer soil fertility recovery with reduced crop yield. The shortening of fallow periods under shifting cultivation combined with little or no use of fertilizers and manure, has had negative consequences on agricultural productivity, soil quality and agro-ecosystem integrity. Frequent burning is reducing the quality of seeds, sprouts and vegetative propagules available for fallow recolonization, ultimately reducing the rate of biomass and nutrient accumulation by secondary vegetation. Regenerative agriculture is one of the important ways to resilience or restore the degradation of natural resource base and soil quality towards their natural state through making maximum use of the internal resources available around and/ on farm (Rodale, 1995). Regenerative agricultural technologies for sustainable development of mountain areas in respect of soil, water and nutrient management must integrate socio-economic issues and biophysical process. Productive cultivation systems are urgently needed if the forest remnants and their natural biodiversity are to be protected and shifting cultivators are to be afforded a better standard of living.Planted woody leguminous fallow of 2-3 years have shown potential for soil quality improvement cause by larger quantity of nitrogen accumulation to provide residual yield effect to 2-3 years subsequent crops (Szott et al, 1999). Tree food crops and agroforestry practices depending on location specific availability in the hills offer the best possible measure for restoring the productivity of severely eroded soils. The trees and shrubs are useful for ecological objectives. The humid climate of NEH region is very much favourable for agriculture production based on biomass without degradation of soil health. The cultivation of bamboo and rattans on jhum land can provide the income to the people as a raw material for paper industries located in this region and for cottage industries, respectively in addition to protecting the degraded sloppy land.

The introduction of plantation and horticultural crops like rubber, coffee, tea, black pepper, cashew, banana, citrus sp., pineapple etc. on the sloppy jhum land are the promising alternatives. During the establishment of the plantation crops, immediate plan for resettlement of cultivators on permanent settled terraced cultivation and sufficient employment to families to be assured in the programme to meet their household demands. There is also another alternative for stall-fed dairy-based farming nearby roads to restore the deteriorating hills and wasteland. In this system soil quality gets improved through recycling of animal excreta and least disturbance of the system.

Organic matter sequestering : Soil organic matter (SOM) influences the wide range of physical, chemical and biological properties of soils and is considered as the most important indicator of soil quality. Soil microbes regulate the many ecosystem processes and biophysical integration of organic matter with solid, liquid and gaseous phases. The SOM is closely linked with soil quality and soil productivity. In NEH region, nutrients through organic manures are transferred in large amounts to cash crops via livestock, especially ginger, potato, and vegetable cultivation. The application of organic manure eliminates the aluminum toxicity in acidic soils by farming organo-Al complexes and favours the increase of soil pH, OC, available nutrients and soil CEC (Patiram and Singh, 1993). In addition to improving the soil health, organic matter can reduce the pest and disease by increasing species diversity for favour of natural enemies; promote fungi population that can control nematodes; absorb and inactivate pesticides, and provide alternative food for marginal pests and decrease their severity (Edwards, 1990). Sharma et al (1998) found that continuous application of FYM + NPK increased the soil organic carbon 50% over the initial value after 20 years with higher microbial biomass-C, bacterial and fungal population by creating more favourable good soil health in acid sub-humid temperate agro-climate of Western Himalayas. Young (1989) evaluated indicative plant biomass requirements for the maintenance of SOM balance (Table 3) and suggested that agroforestry had the exciting prospects to lead to a steady state SOM in the tropics. In brief, the balance of SOM can be achieved by :

- Increasing biomass production per unit cropped area by eliminating major soil inherent constraints;
- Recycling of more biomass to the cropped area by mixed farming, crop rotations, BNF species, improved species and crop/tree association which favour a quick establishment of dense and deep root system;
- Control of soil erosion and enhancing human accumulation;
- Vegetative barriers and non-structural soil erosion control measures;
- Use of selected and alternative crops, grasses, shrubs and trees, especially those tolerant to soil acidity associated stress environment; and
- Restoration of highly degraded lands suffering from water erosion, physical and chemical degradation processes through agroforestry, horticulture, pasture, plantation crops etc.

In NEH region, the soils which are highly resistant to soil erosion following heavy rainfall, may lose the resistance when rainfall is combined with jhum or hill agriculture along slopes. Soil erosion is the major cause of soil quality deterioration and loss of resilience will remain for generation to come. There is a need to develop necessary database to establish the relationship of productivity, soil quality and environment of this fragile humid hill eco-zone to soils, land-use and management practices. We must emphasize the maintenance of SOM - a good indicator of soil quality and its resilience through different management practices and acceptable to farmers of different agro-climatic zones for their specific requirements.

REFERENCES

Arshad M A and Coen G M. (1992). *Amer. J. Altern. Agric.* **7**:12-16.

Blum W E H. (1994). *Proc. 5th World Congr. Soil Sci.* pp 233-237.

Doran J W, Jones A J, Arshad M A and Gilley J E. (1999). Proc. Soil Quality and Soil Erosion. R Lal (ed). pp. 17-36. Soil and Water Cosv. Soc., Iowa.

Edwards C A. (1990). In: Sustanable Agrl. System. C A Edwards, R Lal, P Madden, R H miller and G House (eds). pp. 249-264. Soil and Water Conv. Soc., Iowa.

Holling C S and Meffe G K. (1996). Conserv. Biol. 10:328-337.

Hudson N W. (1995). Soil conservation, 3rd Edn. ISU Press, Ames.

Johnson D L, Amrose S H, Bassett T J, Bover M L, Grumnaey D E, Issacson A E, Johnson D N, Lamb P, Saul M and Winter Nelson A E. (1997). *J. Environ. Qual.* **26**:581-589.

Lal R. (1995). Global soil erosion by water and carbon dynamics. In: Soil and Global Change. R Lal, J M Kimble, E Livine and B A Stewart (eds). pp. 131-141. CRC Press, Boca Raton, Florida.

Patiram, Rai R N and Prasad R N. (1990). *J. Indian Soc. Soil Sci.* **38:**237-242.
Patiram and Singh K A. (1993). *J. Indian Soc. Soil Sci.* **41:**430-433.
Patiram. (1994). *Indian Farming.* May,20.
Patiram. 2001. Proc. Nat. Seminar Water and Land Mangt for Soci Economic Upliftment of NE Region, Guwahati. Pp. 11-19.
Pimme S L. (1984). *Nature.* **307:**321-326.
Maubach M and Tugel A. (1995). White Paper, Natural Resource Conservation Service.
Rodale R. (1995). *New Farm Magazine Regenerative Agriculture.* May-June. pp. 6-8.
Sanchez P A. (1976). Properties and Management of Soil in the Tropics. John Willey & Sons, New York.
Sharma S P, Sharma J and Subehia S K. (1998). Proc. Long Term Fertility Mangt through Integrated Plant Nutrient Supply. IISS, Bhopal. pp. 125-138.
Smyth A J and Dumanski J J. (1999). *Can. J. Soil Sci.* **75:**401-406.
Stoorvogel J J and Smaling F M A. (1990). Assessment of soil nutrient depletion in sub-saharan Africa. The Winand Staring Center Report. 28.137 p.
Szott L T, Palm C A and Buresh R J. (1999). *Agrof. Syst.* **47:**163-196.
Wienhold B J, Power J F and Doran J W. (2000). *Soil Sci.* **165:**13-30.
Young Y. (1989). Agroforestry for Soil Conservation Science and Practice of Agroforestry. ICRAF-CAB International, Wallingford, UK. 275p

Table 1. Soil degradation status in north eastern hill states of India (lakh ha)

States	Degraded land due to		Total problem area	Area treated till 1996-97
	Erosion	Special problems		
Arunachal Pradesh	24.44	2.10	26.54	15.86
Manipur	3.74	3.60	7.34	1.40
Meghalaya	8.37	2.65	11.02	1.35
Mizoram	4.21	1.89	6.10	0.40
Nagaland	4.05	6.33	10.38	1.43
Sikkim	3.03	-	3.03	2.72
Tripura	1.67	1.12	2.79	2.32
Total NEH states	49.51	17.69	67.20	-
% of geographical area	26.94	9.63	36.57	=

Source: Ministry of Agriculture, Directorate of Economics and Statistics, New Delhi

Table 2. Effect of phosphorus and amendments on the productivity of crops (pooled mean of 12 years)

Treatment	Crop yield (q/ha)		
	Maize	Soybean	Rice
Control	1.68	2.55	7.10
20 t FYM/ha	32.85	14.30	22.65
2 t lime/ha	7.00	5.60	12.10
20 t FYM + 2 t lime/ha	40.35	17.10	25.48
26 kg P2O5/ha as RP	5.40	5.90	13.96
5 + 20 t FYM/ha	35.40	15.80	24.95
5 + 2 t lime/ha	13.40	7.10	16.20
5 + 2 t lime + 20 t FYM/ha	40.40	17.95	27.50
26 kg P2O5/ha as SSP	20.70	10.10	18.60
9 + 20 t FYM/ha	42.35	17.10	28.80
9 + 2 t lime/ha	29.90	12.80	21.77
9 + 2 t lime + 20 t FYM/ha	45.90	19.90	29.50

Table 3. Indicative plant biomass requirements for maintenance of soil organic matter (Young, 1989)

Climatic zone	Initial top soil carbon (kgC/ha)	Topsoil carbon (%) (	Oxidation loss (kgC/ha/y)	Erosion loss (kgC/ha/y)	Required addition to soil humus (kgC/ha/y)	Required plant residues to soil (kg DM/ha/yr)	
						Above ground	Roots
Humid	30,000	2.0	1,200	400	1,600	8,400	5,800
Sub-humid	15,000	1.0	600	200	800	4,200	2,900
Semi-arid	7,500	0.5	300	100	400	2,100	1,400