Conservation Agriculture for Managing Degraded Lands and Advancing Food Security in North Eastern Region of India

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Abstract

Hill and mountainous landscape and physiography are prone to accelerated water runoff, soil erosion, sedimentation, and non-point source pollution. Ecological restoration of degraded hill lands would trigger the process of soil/terrestrial C sequestration, improvements in productivity and use efficiency of inputs, mitigation and adaptation of climate change, provisioning of essential ecosystem services, increase in biodiversity by restoration of wildlife habitat, and increase in human wellbeing. The North Eastern Region (NER) of India (26.2 M ha geographical area), comprises the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, lies between 22^{0}05' and 29^{0}30' N latitudes and 87^{0}55' and 97^{0}24' E longitudes. The region is characterized by diverse agro-climatic and geographical situations. On steep slope, because of continuous removal of topsoil, organic matter status is poor to medium. In this region, around 56% of the area is under low altitude, 33% mid altitude and the rest under high altitude. Reversing degradation trends necessitates identification and implementation of site-specific strategies. Choice of strategies depends on biophysical (climate, geology, soil type, drainage patterns, vegetation, land use) and human factors (demography, infrastructure, land tenure, access to credit and market). There is an urgent need to formulate a regional program in a mission mode approach engaging all the stakeholders to disseminate CA approaches for food and environmental security in the region. Need based technical support, farm mechanization, credit facilities and other inputs should be made available to the farmers to achieve desired goal of food security and environmental sustainability.

Keywords: Conservation agriculture, degraded land, environmental sustainability, food security

1. Introduction

With the current trends of greater agricultural intensification in richer nations and greater intensification in poorer nations to continue, about 1 billion ha of land would be cleared globally by 2050, with CO_2-C equivalent greenhouse gas emissions reaching ~3 giga tonne (Gt)/ year and N use ~250 mt/ year. In contrast, if 2050 crop demand is met by moderate intensification focused on existing croplands of poor yielding nations, adaptation and transfer of improved and high yielding technologies to these croplands, and further global technological improvements, land clearing of only ~0.2 billion ha is forecasted, greenhouse gas emissions of ~1 Gt/year, and global N use of ~225 Mt/year (Tillman et al., 2011). Thus, conservation effective management practices could substantially advance food security with minimal environmental impacts.

Continuous and intensive tillage practices lead to loss of soil carbon and it has been estimated that globally 60–90 peta gram (Pg) of soil organic carbon (SOC) was lost during the last several decades (Lal, 1999). Adoption of traditional management practices including deep tillage and inversion combined with the removal of crop residues has resulted in SOC depletion which has exacerbated soil degradation and diminished the physical, chemical and biological properties of the soil (Lal, 2014). Intensive cropping over the years encourages oxidative losses of C due to continuous soil disturbance, while cropping results in large scale addition of C to the soil through addition of crop residues which either results in net addition or depletion of soil C stocks. The finite and fragile soil resources, especially of the ecologically sensitive eco-regions of hill lands, must be used, improved and restored through adoption of restorative land uses and recommended best management practices. Soil must never be taken for granted because "soil is life and life is soil" (Lal, 2015). There is urgent need for revisiting agronomic management in conventional crop production systems with an overall strategy of: (i) producing more food with reduced risks and costs, (ii) increasing input use-efficiency, viz. land, labour, water, nutrients, and pesticides, (iii) improving and sustaining quality of natural resource base, and (iv) mitigating emissions and greater resilience to changing climates (Sharma and Singh, 2014).

Food grain production of India has increased from 50 Mt to over 272 Mt in 2016, over the last five decades. This however, had further consequences, including loss of plant biodiversity and environmental pollution. Widespread land degradation caused by inappropriate agricultural practices has a direct and adverse impact on the environment, food and livelihood security of farmers. Inappropriate agricultural practices include excessive tillage and use of heavy machinery, excessive and imbalanced use of inorganic fertilizers, poor irrigation and water management techniques, pesticides overuse, inadequate crop residue and/or organic carbon inputs and poor crop planning. Agricultural activities and practices can cause land degradation in a number of ways depending on land use, crops grown and management practices adopted. Some of the common causes of land degradation by agriculture include cultivation in fragile deserts and marginal sloping lands without any conservation measures, land clearing and deforestation, depletion of soil nutrients due to poor farming practices, overgrazing, excessive irrigation, over drafting (the process of extracting groundwater beyond the safe yield of the aquifer), commercial development and land pollution through industrial waste disposal to arable lands. Land degradation in India is estimated to be occurring on 147 million hectares (M ha) of land, including 94 M ha from water erosion, 16 M ha from acidification, 14 M ha from flooding, 9 M ha from wind erosion, 6 M ha from salinity, and 7 M ha from a combination of factors. Natural causes include earthquakes, tsunamis, droughts, avalanches, landslides, volcanic eruptions, floods, tornadoes, and wildfires. Human-induced degradation results from land clearing and deforestation, inappropriate agricultural practices, improper management of industrial effluents and wastes, over-grazing, careless management of forests, surface mining, urban sprawl, and commercial/ industrial development. Social causes of soil degradation in India are land shortage, decline in per capita land availability, economic pressure on land, land tenancy, poverty, and population increase (Bhattacharyya et al., 2015).

Due to growing resource degradation problems worldwide, conservation agriculture (CA) has emerged as an alternative strategy to sustain agricultural production. It is a concept for resource saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while promoting the environmental balance. Conservation agriculture is based on enhancing natural biological processes above and below the ground. Intervention such as mechanical soil tillage are reduced to an absolute minimum and use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level.

About 155 m ha is covered under CA worldwide and USA, Brazil, Canada cover most of the area. In India, about about 3 m ha area is under CA in rice –wheat system, mainly in Indo-Gangetic Plains (Sharma and Singh, 2014). Zero tillage, minimum tillage, Furrow Irrigated Raised Bed (FIRB), laser leveling, incorporation/retention of crop residues etc. are major CA technology promoted in India. This has been possible mainly due to the development of the new generation machineries like zero till drills, rotary disk drills, happy seeders, laser levelers etc. But all these developments have been mainly in the irrigated belts of Northern India. On the other hand there are meager attempts for developing conservation agriculture technologies suitable for the low input hill agriculture. Even though some of the indigenous resource conserving technologies are prevalent in the North Eastern Hill (NEH) Region, they are confined to their place of origin. Increase in population pressure also forcing farmers to go for intensive method of cultivations. In the rainfed hill zones, mechanization is meager mainly due to difficult terrains, small holdings and poor economic condition of the farmers. High rainfall, excessive disturbance to the soil along with faulty agricultural practices are resulting serious land degradation in terms of erosion, nutrient loss etc. Reduced tillage coupled with residue management would reverse the trend of degradation to a great extent. A ton of rice residue contains 6, 2 and 11 kg NPK. Crop rotations results in increased SOC content, more so with introduction of leguminous crops.

2. Land Degradation in Hill Eco-system

Hill and mountainous landscape and physiography are prone to accelerated water runoff, soil erosion, sedimentation, and non-point source pollution. Ecological restoration of degraded hill lands would trigger the process of soil/terrestrial C sequestration, improvements in productivity and use efficiency of inputs, mitigation and adaptation of climate change, provisioning of essential ecosystem services, increase in biodiversity by restoration of wildlife habitat, and increase in human wellbeing (Lal, 2015). Jhum (shifting) cultivation and other extractive practices of hill farming in NEH and elsewhere have adversely impacted biodiversity and jeopardized the stability of ecosystems in these fragile environments. Soil loss to the tune of 46 t/ha/year have been reported under shifting cultivated area (Sharma and Prasad, 1995) as against country's average of 16.4 t/ha/year (Bhattacharyya et al., 2015). Decline in biodiversity also reduces productivity, environment quality, and human wellbeing. Indeed, biodiversity plays a critical role in ecosystem productivity and ecological stability (Hautier et al., 2015), which must be enhanced. Thus, re-wilding of marginal/depleted hill lands would be an essential pre-requisite to reversing the degradation trends (Lal et al., 2015).

Intensive tillage, residue burning and along the slope cultivation are the major threats to environment and food security specially in hill and mountain ecosystem. Excessive tillage disrupts soil structure, breaks pore continuity and during heavy rains facilitates dislocation of soil particles and promotes soil and nutrient erosion. Burning of biomass releases carbon monoxide and in-turn CO_2 to the atmosphere. It is estimated that about 10 t/ha dry biomass is burnt amounting to burning of about 9 million tones biomass annually in north eastern Region (Das et al., 2011). Thus, it is warranted to identify and employ efficient technologies to use scarcer natural resources to attain food security and mitigate impact of climate change. Lal (2015) proposed a model for restoring hill ecosystems and advancing food security for human wellbeing. Total direct cost of soil degradation was estimated at INR 448.6 billion with cost of soil erosion in lost production at INR 361 USD (Sehgal and Abrol ,1994). Annual per capita cost of soil degradation of Himalayan states are much higher than other states due to steep topography, high rainfall, cultivation practices and anthropogenic activities like road constructions, urbanization etc. (Indian Ministry of Statistics and Programme Implementation 2014; Mythili and Goedecke, 2016). Erosion control, nutrient recycling, increase in carbon pool, biomass production and ecosystem stability have been emphasized for restoring degraded hill ecosystems.

3. Scope of Conservation Agriculture in North Eastern Region of India

The North Eastern Region (NER) of India (26.2 M ha geographical area), comprises the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, lies between $22^{0}05'$ and $29^{0}30'$ N latitudes and $87^{0}55'$ and $97^{0}24'$ E longitudes. The region is characterized by diverse agro-climatic and geographical situations. On steep slope, because of continuous removal of topsoil, organic matter status is poor to medium. In this region, around 56% of the area is under low altitude, 33% mid altitude and the rest under high altitude. Traditionally, farmers both at upland terrace and valley land follow mono-cropping practice in rainfed agriculture, where rice is the major crop occupying more than 80 % of the cultivated area followed by maize. Farming in rainfed North-East India is complex-diverse-riskprone (CDR) type (Bhatt and Bujarbaruah, 2005). Intensive natural resources mining and continuous degradation of natural resources (soil, water, vegetation) under conventional agriculture practices will not ensure farm productivity and food security for the coming years. In order to keep production system in different land situations sustainable, CA based on minimum/ no-till system is an alternative to conciliate agriculture with its environment and overcome the imposed constraints of the climate change and continuous inputs cost. Resource Conserving Techniques (RCTs) using locally available resources encompasses practices that enhance resources or input-use efficiency and provide immediate, identifiable and demonstrable economic benefits such as reduction in production costs, saving in water, fuel, labour requirements, and timely establishment of crops resulting in improved yields (Ghosh et al., 2010).

Even though the region receives high rainfall (2450 mm), there is severe water scarcity in upland during November to April that makes cultivation of rabi crops difficult in the absence of soil moisture conservation measures. On the other hand, there is excess moisture in low land due to seepage from surrounding hillocks. Cultivation of a second crop of rice is not possible due to early onset of winter and subsequent problem of spikelet sterility.

In the region, the farmer's immediate concern is crop yield improvement, diversity of crops, and enhancement of basic income for their livelihoods. The basic social concept of sustainable management of land is based on balance among the different segments of the society as well as a balance between individual and institutional values. Intensive agriculture and excessive use of external inputs lead to degradation of soil, water and genetic resources. Wide spread soil erosion, nutrient mining, depleting ground water table and eroding biodiversity are the global concern which are threatening the food security and livelihood opportunities of farmers, especially the poor and underprivileged. About 10 million hectares of good quality land is lost annually for agricultural uses due to soil degradation which adversely affects agricultural production and profitability. Therefore, there is urgent need to reverse the trend of natural resource degradation.

4. Rehabilitating Degraded Lands

Reversing degradation trends necessitates identification and implementation of site-specific strategies. Choice of strategies depends on biophysical (climate, geology, soil type, drainage patterns, vegetation, land use) and human factors (demography, infrastructure, land tenure, access to credit and market). The objectives are to minimize losses of water and nutrients out of the ecosystem; create positive ecosystem C, nutrient and water budgets; enhance biodiversity (above and below ground); strengthen plant-soil feedback, and minimize soil disturbances (Lal, 2014). Some strategies to reclaim drastically disturbed lands include mechanical land forming to create gentle slope gradients and increasing micro-relief. Increasing SOC pool, by recycling biomass/biosolid carbon (e.g., compost, manure, mulch, sludge, grey/black water after treatment) is always useful to set-in-motion the restorative process. Enhancing available water capacity, deceasing bulk density (ρb) and soil strength, improving availability of essential nutrients (N, P, K, Zn, B, Cu) and improving bio-turbation are generic options of rehabilitating degraded lands.

Conservation agriculture (CA) is largely accepted as a measure to reverse the trend of natural resource degradation and sequester carbon from atmosphere. No-till, minimum/ reduced tillage (RT), Furrow Irrigated Raised Bed (FIRB), laser leveling, incorporation/retention of crop residues & mulches, maintaining cover crops, fodder crops & grasses, crop rotation, agro-forestry, biochar application etc. are the major CA based technologies. Tillage, mulch and fertilization also affect CO_2 emission (Tanveer et al., 2013). Tillage reduces SOM in all size fractions, but particulate organic matter (POM) is much more readily lost than other fractions. In continuously cultivated soils the decrease in SOC is primarily due to a loss of POM in sandy soils and of clay-associated C in clayey soils (Feller and Beare, 1997). Although agricultural soils can also emit CO_2 to the atmosphere, adoption of best soil and cropping management practices improved the ability of agricultural soils to remove more carbon from the atmosphere than they release to it. The correlation between CO_2 loss and tillage intensity is well established and a shift from CT to CA, along with effective nitrogen management, provides an effective option to help offset emissions of the main GHGs (CO_2, CH_4, N_2O). In time such a shift also promotes carbon sequestration in the soil profile, including below the ploughed layer, and helps to restore a degraded agro-ecosystem to a sustainable one. High root biomass generation, constant addition of organic matter to the soil through decaying of large volume of dead roots and high return of leftover surface plant residue lead to improvement in C-status of the soil. Ghosh et al. (2010) reported that double NT practice in rice-based system was cost-effective, restored SOC , favoured biological activity, conserved water and produced better yield, which were 70.75, 46.7 and 49% higher compared to conventional tillage. NT along with retention of maize stalks and application of *Ambrosia* spp. mulch @ 5 t/ha resulted in maximum improvement in soil quality parameters and enhanced yield of rapeseed in maize-rapeseed cropping system in the Eastern Himalayas (Das et al., 2014). Cultivation of fodder crops in degraded hilly soils can improve soil quality parameters. Addition of organic amendment can further improve soil quality. In a study conducted in a degraded land at mid altitude of Meghalaya, the SOC stock (0-15 cm) after third year was 5.4 to 7.5% higher under forages and 2.3 to 10.4% higher under fertilizer types compared to the antecedent stock. Among forages, the highest SOC stock was observed under napier followed by that under Congo signal grass. Among the fertilizers, the maximum SOC stock was observed under organic followed by that under inorganic fertilizers. The SOC stock in the third year under organic fertilizer was 8.1 and 2.1 t/ha higher than that under control and inorganic fertilizers, respectively (Das et al., 2016).

5. Some Case Studies from North Eastern Hill Region of India

The average grain yield of rice was significantly higher under NT (4.79 t ha^{-1}) than that of MT (4.49 t ha^{-1}) and CT (4.44 t ha^{-1}) from a six year study at Umiam, Meghalaya. Application of 50% NPK+ weed biomass (WB) gave significantly higher rice grain yield as compared to 50% NPK or 100% NPK but was statistically at par with 50% NPK+ insitu rice residue retention (ISRR) and 50% NPK+ green leaf manure (GLM). The average rice grain yield under 50 % NPK+WB were 16.7 % and 9.10% higher than that of under 50% NPK and 100% NPK, respectively. The residual effect of tillage and nutrient management (NM) practices applied to rice had significant effect on green pod yield of succeeding pea grown under NT system. The pooled green pod yield of pea was highest under MT (8.13 t ha^{-1}) followed by CT (7.45 t ha^{-1}) and lowest was under NT (6.40 t ha^{-1}). In comparison with the initial baseline, there was a marked improvement in physico-chemical and biological properties of soil after three years (after harvest of pea crop). The bulk density (ρb) under CT (1.04 t m^{-3}) was at par with MT (0.99 t m^{-3}) but was significantly higher than those recorded under NT (0.96 t m^{-1}). Among the residual effect of NM practices in rice, 50% NPK recorded significantly higher ρb and lower was under 50% NPK+GLM. Soil under NT had significantly higher available nutrients (N, P_2O_5, K_2O), SOC and soil microbial biomass carbon (SMBC) concentration than those under CT. The available N, SOC and SMBC of soils were recorded significantly higher under 50% NPK + GLM as compared to 50% NPK alone at 0-15 cm soil depth (Das et al., 2017).

In another study, the lentil seed yield grown under NT systems after rice was maximum under 40 cm standing stubble (1.84 t ha^{-1}) followed by 20 cm standing stubble (1.60 t ha^{-1}) as compared to control (1.36 t ha^{-1}). Soil chemical properties like SOC was higher in IPL 406 (2.41%) than DPL 81 (2.31%). Residue management practices had significant impact on SOC. The dehydrogenase activity (DHA) and SMBC were significantly affected by rice stubble management practices. Among the different residue management practices, maximum DHA and SMBC was recorded in soils under 40 cm standing stubble (2.09 µg g^{-1} hr^{-1} and 160.41 µg C g^{-1} dry soil 2) followed by 20 cm standing stubble as compared to residue removal. These might be due to the enhancement of the pool sizes of microbial biomass. Rice residue management practices had significant impact on soil physical parameters i.e. ρb, water holding capacity (WHC) and infiltration rate (IR). Least ρb was recorded with 40 cm standing stubble followed by 20 cm standing stubble and residue removal at 0-15 cm soil depth. The 40 cm standing stubble recoded higher WHC and IR as compare to 20 cm standing stubble and residue removal in both the years (Das et al., 2017).

Grain yields of maize and rapeseed under CT were similar to those under NT. Mulching had a significant effect on the productivity of maize and rapeseed. Institute retention of maize stalk cover along with mulching with fresh biomass of *Ambrosia* sp. 5 t ha^{-1} and poultry manure 5 t ha^{-1} (MSAPM) produced significantly ($p = 0{\cdot}05$) higher yield of maize and rapeseed than that of other treatments. The SOC concentration in soils under MSAPM enhanced by 30·4% and mean weight diameter by 100% under compared with those under control. There was marked increase in SOC concentration (8·4%), water stable aggregates (9·3%), mean weight diameter (42·6%) and soil microbial biomass carbon (66·8%) under NT, with respect to CT. Thus, NT and mulching are recommended measures for protecting soil and improving its quality in the studied area (Das et al., 2014).

A land use model (0.53 ha, 30-40% slope) involving natural forest, fodder crops, leguminous cover crops, intercropping of maize + legume, residue management, conservation tillage, micro rain water harvesting structure (5x4x1.5 m^3) etc. were implemented for climate resilient agriculture in hills. Hedge rows (*Tephrosia* sp.) in alternate terrace risers and toe tranches (25 x15 cm^2) in the inner side of terraces were made for collecting run-off and increase infiltration. After harvest of kharif crops, the residues were retained on the surface and toria, French bean and lentil were grown under NT with residual moisture. The cropping sequence followed beginning with the top to bottom hill slopes were natural pine forest with catch pits - fodder crops - cover crops - maize + legume intercropping - rice based system at the foot hills. The highest fodder and legume (cover crop) grain yields were recorded with guinea grass (91.5 t ha^{-1}) and groundnut (2.5 t ha^{-1}), respectively. Among different maize + legume intercropping systems, maize + groundnut system recorded the highest maize equivalent yield (5.6 t ha^{-1}). The rice crop under minimum tillage and NT recorded similar but higher yield than conventional tillage. Residue retention and NT resulted about 10% higher soil moisture stock in dry season frenchbean crop compared to residue removal and CT. The productivity of succeeding French bean/rapeseed crop after legume/maize + legume intercropping system under NT and residue retention were significantly higher compared to farmer's practice of residue removal/CT. Among the different cropping systems, fodder crop based system recorded maximum soil organic carbon (1.80%) and SOC stock (29.7 t ha^{-1}) followed by cover crop based system (1.61%, 26.8 t ha^{-1}) at the end of three cropping cycles in 0-15 cm soil depth. On an average, the above model enhanced SOC stock by 10% and reduced soil loss substantially over farmers' practice (Das et al., 2017).

6. Conclusion

The studies conducted over last one decade provided sufficient evidence that CA led practices has ample opportunity in the degraded hill ecosystem of north east India to reverse the trend of land degradation, conserve natural resources, enhance input use efficiency and simultaneously advance food security in the region. There is an urgent need to formulate a regional program in a mission mode approach engaging all the stakeholders to disseminate CA approaches for food and environmental security in the region. Need based technical support, farm mechanization, credit facilities and other inputs should be made available to the farmers to achieve desired goal of food security and environmental sustainability.

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