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Conservation Agriculture in North-eastern Hill Region of India: Potential and Opportunities for Sustainable Development

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ABSTRACT

Land degradation due to heavy erosion in steep slopes, soil acidity, faulty cultivation practices and poor nutrient management practices are the major challenges in the North Eastern Hill Region (NEHR) of India. Thus, there is an urgent need to adopt conservation effective farming practices to achieve food and nutritional security in one hand and sustain natural resources base on another. The conservation agriculture (CA) approach is one such practice, which has the potential to meet challenges of hill farming while simultaneously achieving food and environmental security, reduce cost of cultivation, enhance cropping intensity, crop diversification and improve soil properties. The NEHR comprises of about 26.3 million hectares (M-ha) geographical area with diverse agro-climatic conditions, ranging from subtropical humid and warm to temperate to alpine climate. The region receives very high rainfall (> 2000 mm annually) and conventional tillage based intensive system is detrimental to upkeep soil and natural resources base in the region. Slash and burn agriculture is still practiced in about 0.76 M-ha area in the region, which further degrades natural resources and contributes to unsustainability. Residue burning/removal, repeated soil tilling, monocropping, low to very low use of organic manure and fertilizers further contribute to soil loss, poor soil properties, low productivity and income. The NEHR requires distinctive approach to obtain solutions of unique and uncommon problems existing in the region. Long-term research data indicated potential of the CA in addressing the concerns of food and environmental security in the NEHR. The major emphasis is on the minimal/no-till cultivation, residue retention and rational crop diversification/rotation. Cover crops, hedgerow/alley crops (leguminous shrubs), intercropping of legumes/cover crops with cereals (rice, maize), mulching, terrace farming, green leaf manuring, integrated application of fertilizer and organic manure, etc., are found to be suitable components of the CA in diverse locations. Significant improvement in soil properties especially water holding capacity, soil organic carbon content and stocks, biological properties, available nutrient content, productivity and income due to adoption of the CA have been observed from different agro-

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ecoregions of NEHR. In-spite of its multiple advantages, the CA practices has not been widely adopted by the farmers in the region mainly due to lack of adequate machinery especially lightweight small machines (for example no-till machine), location-specific technologies (especially for weed management), poor understanding and skills. Large scale research, demonstration and capacity building programme along with adequate policy support is required to promote CA in the region with an ultimate objective of achieving sustainable Development Goal (SDG) of zero hunger, conserve natural resources, biodiversity and climate resilient agriculture.

Key words: Hill agriculture, land degradation, resource conservation, environmental security

Introduction

Widespread land degradation caused by inappropriate agricultural practices has a direct and adverse impact on the environment, food and livelihood security of farmers in the hill and mountain ecosystem of the North Eastern Hill Region (NEHR) of India (Das *et al.*, 2020). Inappropriate agricultural practices, like excessive tillage and use of inappropriate machineries, imbalanced use of inorganic fertilizers, poor irrigation and water management techniques, inadequate crop residue and/or organic carbon inputs and poor crop planning among many others. Agricultural activities and practices can cause land degradation in several 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 extractive 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.

Attempts for developing the conservation agriculture (CA) technologies suitable for the low-input hill agriculture are few. Even though some of the important indigenous resource-conserving technologies is prevalent in the NEHR of India (Comprising of seven states, i.e., Arunachal Pradesh, Manipur, Mizoram, Nagaland, Meghalaya, Sikkim and Tripura with total geographical area of about 18.37 million hectares, M ha), they are confined to their place of origin (Das *et al.*, 2012). An increase in population pressure is also forcing farmers to adopt the intensive method of cultivation. In the rainfed hill zones, marginal mechanization is mainly due to difficult terrains, smallholdings and poor economic condition of the farmers. High rainfall, excessive disturbance to the soil along faulty agricultural practices are resulting in serious land degradation in terms of erosion, nutrient loss etc. Conservation tillage coupled with residue management would reverse the trend of degradation to a great extent as a Mega gram (Mg = 10^6 g) of rice residue can add 6, 2 and 11 kg NPK. Furthermore, crop rotation results in increased SOC content, more so with the inclusion of leguminous crops. Traditionally, the farmers of the NEHR have been practicing some innovative resource conservation measures from ages, for example, the *Apatani* method of rice + fish farming, the *Panikehti* in Nagaland, Sikkim, Manipur and Arunachal Pradesh, the Bamboo drip irrigation in Jaintia Hills, Meghalaya, the Alder-based farming systems of Nagaland, Sikkim, Rotating cowshed in fields practiced in Sikkim, the pond-based farming systems of Tripura, Meghalaya, Manipur and Assam (Das *et al.*, 2012). However, with an increase in population pressure and availability of readymade inputs and high-yielding varieties, these practices started getting declined or mostly remained confined to their place of origin. Because the CA technologies should be socio-economically acceptable and viable to the location-specific situation, we have emphasized on three representative states, namely, Tripura (low altitude), Meghalaya (mid altitude) and Sikkim (high altitude) among NEHR states for assessing opportunities and constraints of the CA in this article.

The Extent of Land Degradation in Hill Ecosystem

Hill and mountainous ecosystems are prone to accelerated water runoff, soil erosion, sedimentation, and non-point source pollution. Restoration of degraded hill lands through eco-friendly conservation measures 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 well-being (Lal, 2015a). Shifting (*Jhum*) cultivation and other extractive practices of hill farming in the NEHR and elsewhere have adversely impacted biodiversity and jeopardized the stability of these fragile environments. Soil loss to the tune of 46 Mg ha^{-1} yr^{-1} has been reported under shifting cultivation in the NEHR (Sharma and Sharma, 2004) as against the country's average soil loss of 16.4 Mg ha^{-1} yr^{-1} (Bhattacharyya *et al*., 2015). A decline in biodiversity also reduces productivity, environmental 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 prerequisite for reversing the degradation trends (Lal, 2015b).

In northeastern region (NER) of India [Comprising of the NEHR and state of Assam (7.84 M ha)], degradation of agricultural lands started with arrival of shifting cultivation in 7000 BC and with an increase in population (about 49 million), the degradation has increased many folds in last few decades in the region. As per NBSSLUP (2004), about 47.5% of the total geographical area of the NER is under various kinds of degradation. Water erosion, water-logging, soil acidity, reduced infiltration, nutrient leaching, burning of vegetation, a decline in vegetation covers and loss of biodiversity are important contributors to land degradation in the region. The transfer of soil and nutrient load along with runoff due to high rainfall and steep topography has much implication for the resource base and environment in the region (Sharma and Sharma, 2004). The extent of soil and nutrient transfer in the region has been estimated to be about 601 tera gram (Tg) of soil and 685.8, 99.8, 511.1, 57.1, 43, 22.6 and 14 thousand tons of N, P, K, Ca, Mg, Mn and Zn, respectively (Sharma and Sharma, 2004). More than 95% of the soils are acidic due to the leaching of salts because of heavy rainfall in the region. Along with the slope cultivation, the intensive tillage and residue burning are major threats to food and environmental security, especially in hill and mountain ecosystems (Das *et al*., 2017a). Excessive tillage disrupts soil aggregates, breaks pore continuity and during heavy rains facilitates dislocation of soil particles and promotes soil and nutrient erosion. The burning of biomass releases carbon monoxide and in-turn CO_2 to the atmosphere. Estimates showed ~10 Mg ha^{-1} dry biomass is burnt under shifting cultivation amounting to the burning of ~9 Tg of biomass annually in the NER (Das *et al*., 2011). Further, rice residue burning has started in stakes like Manipr. Thus, it is necessary to identify and employ efficient technologies to use scarcer natural resources to attain food security and mitigate the impact of climate change. Lal (2015) proposed a model combining various conservation effective practices for restoring hill ecosystems and advancing food security for human wellbeing. The direct cost of soil degradation in India was estimated at INR 448.6 billion with the cost of soil erosion in lost production at INR 361 USD (Sehgal and Abrol, 1994). Per capita annual cost of soil degradation of NEHR states is much higher than other states due to difficult and steep terrains, high rainfall, faulty cultivation practices and anthropogenic activities like road constructions, urbanization, etc. (Ministry of Statistics and Programme Implementation, Govt. of India, 2014). Erosion control, nutrient recycling, increase in carbon pool, biomass production and ecosystem stability have been emphasized for restoring degraded hill ecosystems (Das *et al*., 2018a).

Scope of Conservation Agriculture (CA) in North Eastern Hill Region of India

To keep production systems in different land situations sustainable, the CA-based on minimum (MT)/ no-till (NT) system is an alternative to conciliate agriculture with its environment and overcome the imposed constraints of climate change and low profit in farming. Resource conserving techniques (RCTs) through the adoption of locally available resources encompasses practices that enhance input-use efficiency and provide 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 very high rainfall (> 2000 mm), there is severe water scarcity in the upland from November to April that makes the cultivation of *rabi* crops difficult in the absence of poor soil moisture conservation measures. On the other hand, there is excess moisture in the low-land during the winter season due to seepage from surrounding hillocks. Cultivation of the second crop of rice is not possible due to the early onset of winter and the subsequent problem of spikelet sterility (Das *et al*., 2018a; 2020). There is very heavy soil loss due to runoff owing to high rainfall and faulty land-use practices like shifting cultivation, residue removal/burning, along with the slope cultivation, monocropping and so on (Das *et al*., 2011).

In the region, the farmer’s immediate concern is crop yield improvement, crop diversification, and enhancement of basic income for their livelihoods. The basic social concept of sustainable management of land is based on the balance among the different segments of the society as well as between individual and institutional values. Intensive agriculture and excessive use of external inputs lead to the degradation of soil, water and genetic resources. Widespread soil erosion, nutrient mining, depleting groundwater table and eroding biodiversity are the global concern, which is threatening the food security and livelihood opportunities of farmers, especially those are poor and underprivileged (Lal, 2015a). Therefore, there is an urgent need to reverse the trend of natural resource degradation through adaption of location specific (as per altitude, cropping system, climate, socio-economic conditions, etc.) conservation effective technologies.

Approaches for Rehabilitating Degraded Lands

Reversing degradation trends necessitates the identification and implementation of site-specific strategies with a focus on locally available resources. 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 ultimate aim is to minimize water and nutrients losses out of the ecosystem; create positive ecosystem C, nutrient and water budgets; enhance biodiversity (above and below ground) and strengthen plant-soil interface with minimal soil disturbances (Lal, 2014). The CA is largely accepted as a measure to reverse the trend of natural resource degradation and sequester carbon from the atmosphere. No-till (NT), minimum (MT)/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 suitable for hill ecosystem. Integrated nutrient management (INM) and micro-irrigation with focus on rainwater harvesting are another two important areas, which contribute to natural resources conservation. Tillage, mulch and fertilization also affect CO_2 emission (Tanveer *et al*., 2013). Tillage reduces soil organic matter in all size fractions, but particulate organic matter (POM) is much more readily lost than other fractions. In continuously cultivated soils, the decrease in organic carbon is primarily due to a loss of POM in sandy soils and of clay-associated C in clayey soils (Feller and Beare, 1997).

The approaches of selection of crops and trees and conservation measures to different topo-

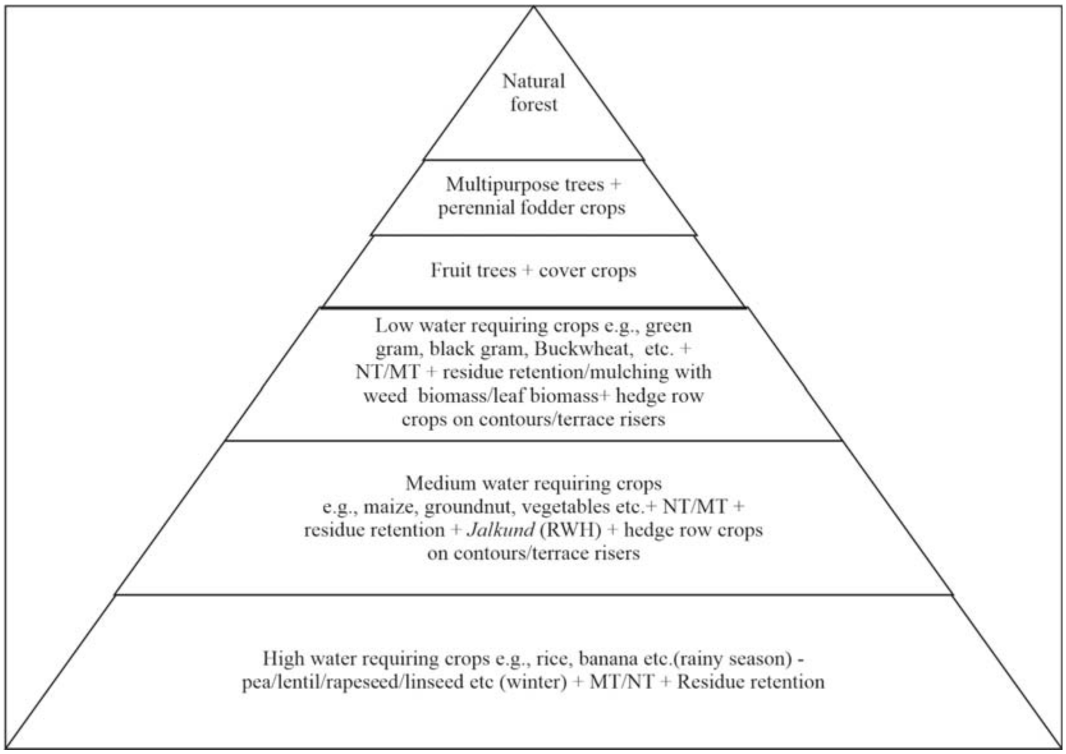

Fig. 1. A framework of crop planning/selection for hilly regions for resource conservation (RWH- Rain water harvesting structures, 250 GSM polyfilm-lined tank, 30,000 to 50,000 L capacity, NT- No-till, MT- Minimum tillage)

sequences are different. A framework of selection of trees, grasses and crops along with conservation measures according to different topo-sequences (hill top, mid-hills, bottom hills) is presented herein for better understanding (Fig. 1). Here, the natural forest has been suggested at the top of the hillocks, while multipurpose trees (MPTs), fruits, perennial fodder grasses have been incorporated in upper steep slopes for resource conservation. Then low, medium and high water requiring crops have been suggested in topo sequence along with conservation measures, like, MT/NT, residue retention, hedge-row species on terrace risers, contours and *jalkund*-a poly-film lined micro rainwater harvesting structure capable of harvesting about 30,000 litre rainwater (Das *et al*., 2018a; Saha *et al*., 2007).

Opportunities of the CA in Meghalaya

About 80% of Meghalaya's population is engaged in agricultural activities for their livelihood. Traditional farming methods like shifting cultivation, bun farming, bamboo drip irrigation etc. are prevalent and practiced by the different indigenous tribal folks of the state. Shifting cultivation and terrace (bun) agriculture are the two popular methods of farming in the state. Coal mining, quarrying, bun cultivation, deforestation, residue burning, etc. are the major causes of land degradation in the state. Cultivation of potato under bun method and along the slopes has resulted in severe degradation in the entire shillong plateau (Das *et al*., 2012). Residue removal/burning, no or poor nutrient replenish-ment and low cropping intensity are the major causes of land degradation in Meghalaya. Monocropping of rice in valleys and ginger, turmeric, maize, etc. in sloping land and uplands are the most prevalent practices in the state. Almost entire farming is rainfed and the use of manure and fertilizer is meager in agriculture. Mechanization is also very limited due to the difficult terrain and small and marginal nature of farmers. There is very good scope for promotion of CA in the state in rice and maize-based system for conserving natural resources and increase productivity and profitability (Das *et al*., 2018a, 2018b)

Case Studies on CA from Meghalaya

Several field studies have been conducted on various aspects of CA in mid–altitude of Meghalaya to standardize the package of practices for crop production using various RCTs (Das *et al*., 2018a, 2018b; Kuotsu *et al*., 2015). The average grain yield of rice was significantly higher under NT (4.79 Mg ha^{-1}) than that of MT (4.49 Mg ha^{-1}) and conventional tillage (CT-4.44 Mg ha^{-1}) from a six-year study at Umiam, Meghalaya. Application of 50% NPK+weed biomass (WB, *Ambrosia* sp)gave significantly higher rice grain yield as compared to 50% NPK or 100% NPK but was statistically at par with 50% NPK + in-situ residue recycling (ISRR, rice straw about 6 Mg ha^{-1}) and 50% NPK+ green leaf manuring (GLM, *Tephrosia* sp). 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 a significant effect on the green pod yield of succeeding pea grown under the NT system. The pooled green pod yield of pea was highest under MT (8.13 Mg ha^{-1}) followed by CT (7.45 Mg ha^{-1}) and lowest was under NT (6.40 Mg 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 under CT (1.04 Mg m^{-3}) was at par with MT (0.99 Mg m^{-3}) but was significantly higher than those recorded under NT (0.96 Mg m^{-3}). The 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*., 2018a).

In flat upland or valley upland, rice is the common crop. Because of water stress, second crop is not grown in rice fallows. In a field study, pea was sown without any tillage (NT) by dibbling after the harvest of rice. At the time of rice harvest, three residue levels (1/3 residue, ½ residue and complete removal of residue) were maintained with the hypothesis that residue kept in the field could maintain soil moisture required for pea. Pea in rice fallow under varying degrees of rice residue retention were sown using a manual dibbler. In rice fallow, better pea performance was found under 75% rice residue retention followed by 50% rice residue retention. In case of complete removal of rice residue, seeds of pea germinated but failed thereafter to grow due to insufficient soil moisture to support crop growth. NT system without crop residue left on the soil surface gave no particular advantage because of the water loss from the surface, as was evident from soil moisture and productivity data (Ghosh *et al.,* 2010). 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 was 70.7, 46.7 and 49% higher compared to CT, respectively. NT along with retention of maize stalks and application of *Ambrosia* spp. mulch @ 5 Mg ha^{-1} 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.*, 2017b). The results of a four years study (Ghosh *et al*., 2010) revealed that maximum grain yield of rice (rainy season) and following crops (wheat, rapeseed and linseed) were recorded under double no-till followed by no-till (for *rabi* crop only) along with residue retention (Table 1).

In another study, the lentil seed yield grown under the NT systems after rice was maximum under 40 cm standing stubble (1.84 Mg ha^{-1}) followed by 20 cm standing stubble (1.60 Mg ha^{-1}) as compared to control (1.36 Mg ha^{-1}). Residue management practices had a significant impact on SOC. The dehydrogenase activity (DHA) and SMBC were significantly affected by rice stubble management practices. Among the different

Table 1. Seed/grain yield (kg ha^{-1}) under different tillage practices (average of 4 years)

Crop	Residue removal and conventional tillage	Residue retention and double no-till	Residue retention and no-till for *rabi* crop	Residue incorporation and minimum tillage	SOC (%)
Rice	3166	4564	4371	4176	1.47
Wheat	2257	3452	3317	2761	2.23
Rapeseed	512	832	775	625	2.51
Linseed	300	479	421	375	2.17

Source: Ghosh *et al*. (2010)

residue management practices, maximum DHA and SMBC were recorded in soils under 40 cm standing stubble (2.09 µg g^{-1} hr^{-1} and 160.41 µg C g^{-1} dry soil) 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 a significant impact on soil physical parameters i.e. ñb, water holding capacity (WHC) and infiltration rate (IR). The 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 compared to 20 cm standing stubble and residue removal in both years (Das *et al*., 2018a). Grain yields of maize and rapeseed under CT have been reported to be similar to those under NT under mid-altitude of Meghalaya. Mulching had a significant effect on the productivity of maize and rapeseed. In-situ retention of maize stalk cover along with mulching with fresh biomass of *Ambrosia* sp. 5 Mg ha^{-1} and poultry manure 5 Mg 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 was enhanced by 30·4% and the mean weight diameter of aggregates by 100% compared with those under control. There was a marked increase in SOC concentration (8·4%), water-stable aggregates (9·3%), mean weight diameter of aggregates (42·6%) and soil microbial biomass carbon (66·8%) under NT concerning the CT. Thus, the NT and mulching are recommended measures for protecting soil and improving its quality in the studied area (Das *et al*., 2017b). In another study on groundnut-rapeseed system, soil profile moisture was significantly higher under residues retention/incorporation and altered land configuration as compared to the farmers' practice (FP). The infiltration rate and hydraulic conductivity under Raised bed (RB) with residue + hedge leaves along with NT were 108% and 46% higher, respectively as compared to FP after two cropping cycle. SMBC was 67% higher under RB with residue + hedge leaves incorporation (381 µg g^{-1} soil and 276 µg g^{-1} soil) compared to FP while, dehydrogenase activity was 135% higher in RB with residue + hedge leaves along with NT (57.8 µg TPF g^{-1} soil 24 hr^{-1}) after groundnut harvest in the second year. In general, weed infestation was higher under NT treatments. The pooled groundnut equivalent yield (GEY) was significantly (p=0.05) highest in RB with residue+hedge leaves incorporation (2,815 kg ha^{-1}) followed by RB with residue incorporation (2,747 kg ha^{-1}) while, minimum GEY was recorded in BBF with residue+hedge leaves under NT. Water use efficiency of rapeseed was maximum in RB with residue+hedge leaves incorporation (4.64 kg ha-mm^{-1}) and the minimum in FP (1.49 kg ha-mm^{-1}). The BBF with residue+hedge leaves (NT) gave the highest B: C ratio (1.58) followed by RB with residue+hedge leaves along with NT (Kuotsu *et al*., 2014).

After harvesting of *kharif* crops (Maize, soybean, groundnut, cowpea, etc), the residues were retained on the surface and rapeseed, French bean and lentil were grown under NT with residual moisture on a sloping land (30-40%

slope). Hedge rows (*Tephrosia* sp.) in alternate terrace risers and toe tranches (25 cm x 15 cm) in the inner side of terraces were made for collecting run-off and increase infiltration. 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 foothills. The rice crop under MT and NT recorded a similar but higher yield than CT. Residue retention and NT resulted about 10% higher soil moisture storage under dry season French bean 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 SOC content (1.80 %) and stock (29.7 Mg ha^{-1}) followed by cover crop-based system (1.61%, 26.8 Mg ha^{-1}) at the end of three cropping cycles in 0-15 cm soil depth (Das *et al.*, 2018a). Cultivation of fodder crops in degraded hilly soils can improve soil quality parameters. The 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 SOC 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 Mg ha^{-1} higher than that under control and inorganic fertilizers, respectively (Das *et al.*, 2016).

Opportunities of the CA in Tripura

Tripura receives >2000 mm of annual rainfall. However, erratic and uneven distribution of rainfall leads to short and long dry spells, which cause moisture stress during cropping season in the coarse-textured (Yadav *et al.*, 2018a). Also, the intense and extreme rainfall events aggravate risks of water runoff and soil erosion, which exacerbate moisture deficit during the growing season (Yadav *et al.*, 2018a). Drought, both agronomic and pedologic, are experienced in one out of three years in the region (Patel *et al.*, 2010), and warrant identification and promotion of conservation-effective practices of crop production (Yadav *et al.*, 2018b). CA plays a vital role in conserving soil and water, enhancing biodiversity, and increasing SOC contents with its four principles: permanent soil cover with crop residues, minimum soil disturbance, crop diversification, and integrated nutrient management (Yadav *et al.*, 2018a). With the system-based approach, the adoption of the CA may improve soil structure, increase SOC, minimize soil erosion risks, conserve soil and water, moderate soil temperature and enhance soil quality and its environmental regulatory capacity (Lal, 2015).

Case Studies from Tripura

A series of field experiments on CA with mulch and different nutrient management for rice and maize have been conducted under both lowland and upland ecology of West Tripura. A field experiment was conducted with two tillage with residue management as the main plot and four type of mulches as the subplot to study the effects of tillage and mulches on weed growth, soil moisture storage, productivity and profitability of upland direct-seeded rice during 2012-13 in Tripura. Tillage treatments included CT-RI: CT with 100% residue incorporation (RI) and NT-RR: NT with 100% residue retention (RR). Mulches included rice straw mulch (SM, 2.5 Mg ha^{-1}), *Gliricidia* mulch (GM, 2.5 Mg ha^{-1}), brown manuring mulch (BM, 2.0 Mg ha^{-1}) and no mulch (NM). The two years results revealed that CT-RI had the highest total weed density (89-168 weeds m^{-2}) and biomass (9.6 to 183 g dry weight m^{-2}) relative to those for the NT-RR (75-161 weed m^{-2} and 8-155 g dry weight m^{-2}). In addition, NT-RR stored (122-172 mm) more soil moisture (0-40 cm soil depth) in comparison to CT-RI treatment (110-161mm). However, NT-RR reduced the cost of cultivation of direct-seeded upland rice by 31.5% compared to CT-RI (INR4

1,677 ha^{-1}, 1 US$=INR 64.5). Thus, the net returns under NT-RR for the direct seeded upland rice were 3 and 7.5 times more than those for the CT-RI in 2012 (INR 5,523 ha^{-1}) and 2013 (INR 1,946 ha^{-1}), respectively (Yadav *et al*., 2018a). Under the same set of treatment combinations after four cropping cycle, it was also observed that the adoption of NT-RR significantly (*p=0.05*) reduced the energy use (16,727 MJ ha^{-1}), carbon footprint (CF) (2,013 kg CO_2 ha^{-1}) and cost of production (INR 54,271 ha^{-1}, 1 US $ = 64.46 INR) over those under CT-RI (27630 MJ ha^{-1}, 2,307 kg CO_2-e ha^{-1}a and INR 76,903 ha^{-1}, respectively). Thus, NT-RR also substantially increased the energy use efficiency, energy productivity, net returns, and reduced CF of the system over those under CT-RI. Various mulching also increased the energy use efficiency, system productivity, and net returns over those under NM (Yadav *et al*., 2018b).

The rice–rice system (RRS) is the most important agricultural production system for lowlands of Tripura, and it provides income, employment, and livelihoods to the farmers Tripura. But, soil degradation, because of the loss of soil carbon (C) and nitrogen (N) pools, is declining the productivity of RRS and threatening food security of the state. Intensive tillage along with improper residues and nutrient management practices are among the reasons of the loss of soil C and N pools and of the decline of rice productivity. Therefore, a 3-year (2013-15) field study was conducted to evaluate the effects of tillage, residues and nutrient management practices on productivity, soil C and N sequestration under RRS in Tripura. The experiment consisted of five combinations of tillage, residue and nutrient management practices *viz.* T_1: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30% residue incorporation (RI) + farm yard manure (FYM) 5 Mg ha^{-1} once in two years in wet season rice (WR) and CT+ 40 kg N and 9 kg P ha^{-1} + 30% RI in dry season rice (DR); T_2: CT+ 80 kg N, 18 kg P and 33.3 kg potassium (K) ha^{-1} (RDF) + 30% RI in WR and CT + RDF + 30 % RI in DR; T_3: Reduce tillage (RT) + 25% N through FYM and 75% N & rest of P & K through inorganic fertilizer (INM) + 30% residue retention (RR) in WR and CT + INM + 30% RI in DR; T_4: RT + 25 % N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg K, 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (IPNM)+ CDM + 30% RR in WR and RT + RDF+ CDM + 30% RR in DR; T_5: No-till (NT) + IPNM+ CDM + 30% RR in WR and NT + RDF+ CDM + 30% RR in DR. Cultivation of WR under RT+ IPNM+ CDM + RR produced significantly higher grain yield (5.1 to 5.2 Mg ha^{-1}) as compared to other treatments. However, the DR transplanted under CT + INM + RI yielded more grain (5.1–5.3 Mg ha^{-1}), straw (7.0–7.2 Mg ha^{-1}), root (1.3–1.4 Mg ha^{-1}) and total biomass (13.4–13.9 Mg ha^{-1}) yield than that from the farmer practice (FP) and other treatment combinations, across the years. The highest system productivity of RRS was recorded under T_3. Therefore, the highest biomass, C and N were also recycled for the same treatment. The soil under T_3 had lower bulk density (ρ_b), the highest soil organic carbon/nitrogen concentration, pool, accumulation, sequestration, carbon retention efficiency, soil microbial biomass carbon and dehydrogenase activities. A total amount of 1.30 Mg C ha^{-1} was accumulated under soils of T_3 over three years. The rate of SOC sequestration ranged from 141.6 kg ha^{-1} yr^{-1} under T_1 to 427.9 kg ha^{-1} yr^{-1} under soils of T_3 under RRS. Thus, adopting RRS under RT/NT with INM/IPNM and effective residue recycling is recommended for enhancing the system productivity and C and N sequestration in paddy soils of Tripura (Yadav *et al*., 2018a,b).

In another study, tillage and land configuration were tested on root growth, soil moisture content, green cob and fodder yield of summer maize in Tripura. The experiment consisted of six combinations of tillage and land configuration practices viz. CT-FB: conventional tillage (CT) with flatbed planting (FB), CT-RF: CT with ridge and furrow planting (RF), CT-RB: CT with raised bed planting (RB), NT-FB: no-till (NT) with FB, NT-RF: NT with RF and NT-RB: NT with RB. The soil moisture content is highest under NT-RB system in all the period of dry spell in all the soil layers. Manipulation of tillage with land configuration had increased the root length density (RLD) and root mass density (RMD) in all the layers of soil in their respective tillage system. NT-RB had significantly more RLD and RMD than all other tillage and land configuration systems. NT-RB produced significantly higher LAI and dry biomass accumulation. NT-RB produced higher green cob, fodder and yield components (number of cobs ha^{-1} and cob weight) (Yadav *et al*., 2018c). Green cobs yield of summer maize by 25.3-27.4% and seed yield of field pea by 17.9-32.2% higher under NT-RF and NT-RB as compared to CT-RF have been observed. *Kharif* maize grown under NT-RF recorded 12.66% less than the CT-RF. The NT-RB recorded maximum system productivity (16.34 and 14.55 maize equivalent yield (MEY) Mg ha-1 in 2012-13 and 2013-14, respectively). However, the CT-RF produced the lowest system productivity (14.37 and 12.86 MEY Mg ha^{-1} in 2012-13 and 2013-14, respectively). The average system productivity was 6.1% higher under NT systems as compared to CT systems. Net returns and B:C ratios showed similar trends as shown by system productivity. The SOC was higher with NT-FB followed by NT-RB. NT-FB recorded 13.2% higher SOC than CT-FB. However, the CT-RB recorded higher soil pH as compared to all other treatments. The available N, P and K was higher with NT systems compared to CT systems. Thus, maize-maize-field pea cropping system under NT-RB have been recommended for higher productivity and profitability and for sustaining soil health (Yadav *et al*., 2015).

Opportunities of the CA in Manipur

Manipur enjoys subtropical to temperate climate with high rainfall. The monocropping and large-scale adoption of major cereal-based crop production systems often resulted in yield stagnation and widen regional yield gaps, low farm income, and inefficient resource use (Heikkinen *et al*., 2013). In Manipur, rice is grown in about 86.22 thousand ha with a production of 0.179 Tg and 2.74 Mg ha^{-1} productivity (Economic Survey Manipur, 2017). Total paddy straw production is estimated to be about 0.628 Tg. Farmers in Manipur, routinely burn their rice straw and stubbles in-situ as a means to clear fields (also roadsides where threshers are installed temporarily) prior to initiating mechanized land preparation or after harvesting causing a range of environmental pollution problems. In a survey covering 360 farmers in both the valley and hilly tracts of Manipur, it was observed that 80 percent from valley and 65 percent from hill farmers burnt their paddy straw and stubbles (Ansari *et al*., 2018). Thus, there is a very good opportunities to adopt CA in rice-fallow system with utilization of in-situ residues management and reduce the environmental pollution. However, rice residue burning is meager in other NEHR states The shifting cultivation or *jhum* (slash and burn agriculture) is an indigenous land use system widely practiced in hills of Manipur (similar to other NEHR), where most of the farmers grow rice, which is not productive and economical. However, the productivity of grown in *jhum* land is very low yield (0.5 to 0.9 Mg ha^{-1}). There is hardly any scope of mechanization in hilly terrain of *jhum* lands where, slope is very steep. Under these circumstances, CA is the most promising options to enhance the cropping intensity and productivity with effective recycling of on- and off farm biomass under both hills and plains of the Manipur state. In Manipur, farmers grow rice in hilly *jhum* areas, which was found less economical than pulses. The net returns obtained by farmers from monocrooping of rice is only about Rs 12,000 to 19,000 ha^{-1} due to low yield in *jhum* areas (Ansari *et al*., 2017). In a participatory demonstration conducted under CA in rice-fallow system of Manipur, it was observed that the mean grain yield of rice (715.5 kg ha^{-1}) was recorded maximum under reduced tillage (RT) followed by NT (639.8 kg ha^{-1}) and minimum yield under CT (504.7 kg ha^{-1}). Consequently, RT enhanced mean net returns by Rs. 27,708 ha^{-1} than NT (Rs. 24,999 ha^{-1}) and CT (Rs. 9777 ha^{-1}), respectively.

Crop diversification in jhum lands for sustainability: Ansari *et al*. (2017) demonstrated the CA based technology with effective recycling of crop residues like pigeon pea (UPAS-120)/ ricebean (Local)/ *rajma* (*Phaseolus vulgaris* L. var. Chitra)-potato, rajma (Chitra)-pea (Rachna), ricebean (Local)-pea (Azad pea), groundnut

(ICGS-76)-lentil (HUL-57). The farmers obtained 1.2 to 1.76 Mg ha^{-1} of pigeonpea, 1.3 to 1.7 Mg ha^{-1} ricebean, 1.4 to 1.9 Mg ha^{-1} rajma, 1.4 to 1.8 Mg ha^{-1} pea a and 0.85 Mg ha^{-1} lentil. The participating farmers especially from *Jhum* cultivated areas received net returns of Rs 56000 to 105000/ha, where, rice mixed farming is dominant with low productivity (0.5 to 0.9 ha^{-1}) and fewer returns. When considering economic returns, the legumes are valuable alternative crops for replacing rice from *jhum* areas. In addition, pulses crop fixed the atmospheric nitrogen in soil, improved soil health, and reduced soil loss, conserved the soil and water and suppressed the weed growth through smothering effects. Pulses production in hill agriculture plays a significant role in nutritional security and is used for various purposes and as well as for second cycle produce in livestock farming (Ansari *et al*., 2017).

The CA under Integrated Farming System in Manipur

Introduction of sustainable integrated farming system (SIFS) may help to safeguard agricultural systems for better livelihood and food security of the farmers with biodiversity value. CA aims at achieving sustainable agriculture and improved livelihoods of farmers through the application of the three basic principles: minimal soil disturbance, permanent soil cover and crop rotations (FAO, 2007). No-till agriculture is considered a revolutionary step in the direction of preventing land degradation and rehabilitation of resilient but fragile lands (Kasam, 2011). Ecological intensification (micro biota) have been reported to enhance under the CA in integrated farming system (Ansari *et al*., 2014). The IFS works on zero waste concepts and all the biomass will be effectively utilized under the IFS due to the adoption of CA. Under IFS a large quantity of biomass recycled in situ and reported to significantly enhance the soil quality attributes (Ansari *et al*., 2013). Biomass retention in hill agriculture effectively reduces soil and nutrient losses and improves fertility (Ansari *et al*., 2014). The NT rapeseed cultivation after harvest of rice has become a popular practice in the Manipur valleys. Many farmers integrates apiculture along with rapeseed in such areas to enhance income and employment (Annual Report, 2013-14; 2019).

Opportunities of CA in Sikkim

Sikkim is a small hilly state having only 12% of the area under cultivation of the total geographical area (7096 sq km). The ecosystem of the state is from tropical (300 m) to the trans-Himalayan region (5000 m) divided into five categories. Out of the total population of 6,07,688 (as per Census 2011) about 65% is still dependent on agriculture for their livelihood. Agriculture is mainly rainfed and mixed type and still at the subsistence level rather than commercial level with irrigated area around 11% only. Farming in Sikkim is done on terraces due to its hilly topography. Farming is a very big challenge in Sikkim due to its hilly geographical structure and different climatic zones in different districts. The agriculture scenario is dominated by soil acidity, excess moisture stress during monsoon season and moisture deficit stress during post-monsoon season, heavy weed infestation, temperature stress during winter, hailstorms in pre-*kharif* (March-May) maize, and incessant rains from May to September that causes leaching of nutrients applied to *kharif* (June-September) crops. The intense rainfall during pre-*kharif* and *kharif* season makes the soil more prone to soil and water erosion in the state. The ecological problems, including degradation of fragile ecosystems of the Himalaya are quite conspicuous. Proximity to the Bay of Bengal and direct exposure to the south-west monsoon makes this region the most humid in the entire Himalayas. An amalgamation of conditions under the influence of heavy rains has generated sandy soils that are moderately to strongly acidic in reaction, low in exchangeable bases and rich in organic matter, high in available zinc, copper, iron and manganese contents and deficient in available boron and molybdenum (Avasthe, 2012). Soil degradation status showed that out of 7,09,600 ha total geographic area about 2,34,401 ha (33.03%) was affected by water erosion causing low, medium, high and very high severity class of degradation. Soils affected by water erosion causing loss of top soils to occupy an area of 2, 28,331 ha (32.18%). Water erosion also resulted in terrain deformation of 6,070 ha (0.85%) (Mishra and Rai, 2013).

Farming systems of the state are mainly traditional and based upon natural resources. Adoption of terrace cultivation, construction of retention walls, mixed cropping, agroforestry, use of farm manure in being practiced in the region (Mishra and Rai, 2013). Soil, water and nutrient conservation practices are having huge potential in mountain farming systems (Sharma *et al*., 2001). The utilization of natural resources in farming systems by the tribals and local communities is based on indigenous and traditional knowledge that helped them to survive under risk and hard-prone conditions (Majumder *et al*., 2010; Das *et al*., 2012). Hence, conservation agriculture can also support the underlying biodiversity for many ecosystem services. CA promotes the concept of enhancing yields and economic profits while ensuring the provision of local and global environmental benefits. The CA has the potential to improve soil health through improvement in water infiltration and reducing erosion, improves soil surface aggregates, reducing soil compaction through the promotion of biological tillage, increases surface soil organic matter and carbon content, moderating soil temperatures and suppressing weeds (Hobbs, 2007). Resource Conserving Technologies using locally available resources encompasses practices that enhance resource or input-use efficiency and provide immediate, identifiable and demonstrable economic benefits. The state of Sikkim started the conversion to organic farming since 2003 and after about twelve years the state was formally declared as organic by 2016. Organic farming has been identified for promoting soil quality even though tillage is used for weed suppression. Adopting NT and other conservation tillage practices can enhance soil quality in cropping systems where synthetic agri-chemicals are relied on for crop nutrition and weed control. Organic farmers are encouraged to adopt conservation tillage, especially if they are located in areas susceptible to erosion. Conservation tillage offers benefits that could improve the soil fertility, soil quality and the environmental impact of organic crop production.

Case studies on CA from Sikkim

Direct seeding involves growing crops without mechanical seedbed preparation and with minimal soil disturbance since the harvest of the previous crop. The term direct seeding is understood in CA systems as synonymous with NT farming, zero tillage, NT, direct drilling. The equipment penetrates the soil cover, opens a seeding slot and places the seed into that slot. Under organic management conditions, land preparation for seeding or planting under NT involves slashing or rolling the weeds, previous crop residues or cover crops, and seeding directly through the mulch. Crop residues are retained either completely or to a suitable amount to guarantee the complete soil cover, and organic sources of fertilizer and amendments are either broadcast on the soil surface or applied during seeding. In a study at ICAR Sikkim Centre on different tillage practices, it was observed that NT planting of vegetable pea immediately after rice harvesting enhances green pod yield (5.89 Mg ha^{-1}) over RT and CT. In the same case significantly higher net returns (96.1x10^{3} Rs.ha^{-1}) and B:C ratio (3.27) was recorded with NT over RT and CT. Energy use efficiency was also significantly higher with NT (6.29%) over RT (4.29%) and CT (3.12%). NT had required 44% and 28.3% less energy as compared to CT and RT, respectively (Singh *et al*., 2015). This increase was due to the 10-12 days early sowing of vegetable pea after rice harvest which provides the congenial condition for plant growth and also to escape the powdery mildew and rust. A short-term positive effect of minimum disturbance has also been observed on SOC and SMBC in the same field under organic management conditions. After two cropping cycle of rice-vegetable pea improved the soil organic carbon content in NT (2.22%) over CT (2.05%) and RT (2.10%). Similarly, SMBC value was also higher under NT (145 mg/g soil) over CT and RT (Singh *et al*., 2015). With respect to production economics, maximum gross returns (96x10^{3} INR ha^{-1} was recorded with RT closely followed by NT and CT. However, maximum values of net returns (67×10^{3} INR ha^{-1}) and B:C ratio (2.34) was recorded with NT over RT and CT. NT was also

Table 2. Comparative energy and economics of no-till verses conventional tillage in organic rice production at Research Farm of ICAR Sikkim Centre

Particulars	No-till	Conventional tillage
Grain yield (Mg ha^{-1})	3.25	3.26
Tilling/dibbling operations	01	04
Time (hrs ha^{-1})	0.00	60.37
Fuel (litres ha^{-1})	0.00	80.60
CO_2 emission (kg ha^{-1})	0.00	208.75
Tillage cost (Rs.ha^{-1})	15,600	20,300
Cost of production (Rs.ha^{-1})	28,900	32,600
Gross returns (Rs.ha^{-1})	95,800	95,500
Net income (Rs.ha^{-1})	66,900	62,900
B:C ratio	2.31	1.93
Energy requirement (GJ ha^{-1})	7.5	11.4
Specific energy (GJ kg^{-1})	0.92	1.42

Source: Singh *et al*. (2015)

found most energy efficient practice and had 33% less energy requirement as compared to CT (Singh *et al*., 2016). NT technology also conserves soil moisture as compared to CT and RT. During the study about 18-20% higher soil moisture was noticed under double no-till practice as compared to the CT. The comparative energy and economics of NT verses conventional tillage in organic rice production at Research Farm of ICAR Sikkim Centre has been given in Table 2.

Although some findings showed that tillage practices had failed to show any significant effect on maize grain yield, however, a significant effect was observed on pod yield of succeeding vegetable pea. Among the tillage practices, the maximum grain yield of maize was recorded with RT (3.90 Mg ha^{-1}) followed by NT (3.88 Mg ha^{-1}). In vegetable pea, a significantly higher pod yield was recorded with NT (5.32 Mg ha^{-1}) and the lowest in CT (4.68 Mg ha^{-1}). With respect to organic nutrient management, the application of 100% recommended dose of N to both the crops in the system, recorded significantly higher grain yield of maize (4.24 Mg ha^{-1}) and vegetable pea (5.45 Mg ha^{-1}) over others (Table 3). This has resulted in 26.4, 10.1 and 5.1% and 20.9, 7.5 and 2.0% increase over control (farmers practice), 50% RDN + maize stalk/pea stover and 75% + maize stalk/pea stover in maize and vegetable yield, respectively (Singh *et al.*, 2016a). Tillage and organic nutrients management practices showed a significant effect on system productivity (SP) and production efficiency (PE) under study. Among the tillage practices, NT recorded a significantly higher value of SP (10.63 Mg ha^{-1}) and PE (29.13 kg ha^{-1} day^{-1}) over other tillage practices. Among the organic nutrients management practices, application of 100% recommended dose of nitrogen recorded significantly higher SP (10.9 Mg ha^{-1}) and PE (29.87 kg ha^{-1} day^{-1}) to control (FP) and 50% recommended dose of nitrogen but remained at par with 75% recommended dose of nitrogen. With regard to system productivity and production efficiency NT along with 100% RDN through organic sources recorded the maximum system productivity (14.0 Mg ha^{-1}) and production efficiency (28.9 kg ha^{-1} day^{-1}) over the other tillage practices with organic sources of nutrients (Singh *et al.*, 2016a).

Maize is the most important *pre–kharif* crop in the region. Farmers of the state leave their land fallow during the *rabi* season due to negligible and scanty rainfall, which is unable to support crop cultivation. Therefore, maize–fallow is the predominant cropping sequence in the rainfed region of Sikkim Himalayas resulting in low cropping intensity (about 118%). Continuous

Table 3. Performance of maize-vegetable pea system as influenced by tillage and organic nutrient management practices

Treatments	Maize grain yield (Mg ha^{-1})	Vegetable pea pod yield (Mg ha^{-1})	System productivity (Mg ha^{-1})	Production efficiency (kg ha^{-1} day^{-1})
Tillage practices				
Conventional tillage (CT)	3.62	4.68	9.37	25.67
Reduced tillage (RT)	3.90	5.11	10.21	27.98
No-till (NT)	3.88	5.32	10.63	29.13
SEm ±	0.07	0.05	0.10	0.27
CD (P=0.05)	NS	0.12	0.24	0.65
Nutrient management practices				
Control (FP)	3.12	4.31	8.62	23.62
100% RDN	4.24	5.45	10.90	29.87
75% RDN + maize stalk/ pea stover	4.02	5.34	10.67	29.24
50% RDN + maize stalk/ pea stover	3.81	5.04	10.09	27.64
SEm ±	0.13	0.14	0.29	0.78
CD (P=0.05)	0.27	0.29	0.59	1.60

RDN: recommended dose of nitrogen
Source: Singh *et al*. (2016a)

degradation of natural resources and the practice of mono–cropping in mountain ecosystems does not sustain farm productivity and food security, especially under organic management. It is assumed that the present and future demand for food can be met through intensive crop production with temporal and spatial increases in productivity and time especially under rainfed ecosystems of the region. Therefore, there is a need to intensify the existing maize–fallow system by including of more crops per unit area. But the intensified production systems require increased use of energy and other production inputs. Hence, selection of appropriate vital crops in maize–based cropping system is required to harness the maximum returns and enhancing the flexibility of cropping under limited moisture supply without considerable modification in farming operations is of paramount importance for self–reliance in food and nutrition. Because of the limited scope for horizontal expansion to augment food production, the alternative is to proceed with vertical growth by increasing the productivity per unit of available land. It is pertinent to focus on the sequential cropping in mono-cropped areas and crop intensification for improved agricultural production. ICAR-NOFRI designed the following diversified/intensified cropping systems with zero irrigation having 200-300% cropping intensity for profit maximization per unit of land and input applied for rainfed ecosystems of Sikkim.

1. Maize (green cobs) -*Pahenlo Dal* - buckwheat/ rapeseed
2. Maize + beans - vegetable pea
3. Maize + beans - rajmash
4. Maize + beans-buckwheat
5. Maize-black gram/green gram/French bean

Even after harvesting maize, heavy rainfall hampers the sowing of pulses due to water logged and higher moisture in soil at the time of sowing and moisture scarcity in later phase of crop growth. Inclusion of short duration pulses like black gram, *rajmash* and pea may be the options for enhancing the cropping intensity up to 200%t in the state. ICAR Sikkim centre identified maize – black gram, maize + bean – rajmash and maize + bean – pea in those areas where irrigation facilities are not available. Similarly, more tillage operations are affected by the farmers for sowing of *rajmash* which requires more window period.

However, NT and or RT technology makes cultivation more farmer-friendly and saves time and input as well as produces healthy crops. Hence, to reduce the labour cost and time for preparation of land form sowing after harvest of maize, NT techniques for sowing of black gram and *rajmash* immediately after harvesting of maize has been standardized. After harvesting of maize field is cleaned by removing all the debries remained on surface. Application of FYM or mixed compost @ 5 Mg ha^{-1} has been recommended before sowing followed by goat manure/poultry manure @ 1-2 Mg ha^{-1} as basal dose to overcome micronutrient deficiencies. Sowing is done by opening a narrow slit (5-8 cm depth) for placement of seed at 30-40 cm row to row and 10-15 cm plant to plant distance. The results of the study recorded 17.8% higher *rajmash* yield under NT practice over CT. Similarly, the black gram yield was also was higher under NT planting (0.98 Mg ha^{-1}) over CT.

In-situ moisture conservation practice seems to be the only way to enhance the productivity and sustainability in the state for the cultivation of a second crop during post or pre-monsoon season in maize based systems. In order to meet the demand of pulses in the state, short duration pulse crop *rajmash* variety which does fit in maize-fallow under rainfed condition is of high demand by the farmers in the state. Short-duration *rajmash* variety can escapes the drought during early winter season may enhance the cropping intensity after harvest of maize crop in the state. Retention of 30% maize stover as a mulch along with use of localy available biomass was found effective for conservation of soil moisture and growing pulses in *rabi* season in Sikkim condition. In the study, Raj-2 recorded significantly higher grain yield (1.73 Mg ha^{-1}) over Raj-1, SKR-57 and Tripura Raj Sel-1 but remained at par with Raj-3 and Raj-4 (Annual Report, 2016).

Farm Mechanization for Conservation Agriculture in Hills

Fragmented small holdings are mostly prevalent in hilly tracts of NEHR of India. Farm mechanization has a great role in CA. Machines like happy seeder, laser leveler, seed drills etc. are popular for sowing of NT wheat after in states like Punjab, Haryana and Western Uttar Pradesh. These machines not only help in timely sowing of wheat in rice fallow but minimizing the need for rice straw burning and GHGs admission. Farm mechanization is also very much needed in hills for reducing the drudgery, timely completion of agricultural practices and popularization of CA (Jat *et al.*, 2013). As compared to the plain land of India, mechanization for agricultural activities is very limited in hills. As majority agricultural lands of hills are sloping, small in size, undulating topography and remotely situated, big tractor mounted implements are neither practical nor feaible. Lack of location specific farm machinery manufacturing units, skilled person, poor facilities for services & maintenance etc. also restricts the use of farm machinery for CA in hill ecosystem. Despite the limitations, there is enormous scope for farm machinery especially for CA practices in hills like developing small water harvesting structures, land configuration like terracing, raised and sunken bed development, contour trenching and introducing small scale agro-based industries based on post-harvest engineering principles. Implements like -3 row no-till planter, two wheel mini tractor drawn tiller, cono-weeder, row maker, knapsack sprayer or model irrigation systems (drip or sprinklers) has considerable future potential in hills for enhancing resource use efficiency under CA system (Sims and Kienzle, 2015). Terraced farming is very popular in Sikkim, Nagaland and Mizoram. In the region the share of manual and animal drawn implements to the total energy input is 25-30%. Hence, power assisted small and medium light weight farm machinery *viz.*, power tillers equipped with zero-till drill may be very popular amongst the farming community of NEHR to reduce the drudgery and enhanced the energy use efficiency. Mechanically powered light weight mulcher cum zero-till crop planter developed by College of Agricultural Engineering and Post-Harvest Technology, Gangtok Sikkim was found very much suitable for the terrace farming in Sikkim (Yadav *et al.*, 2016). The planter was tested in clay soil with actual field capacity of 0.043 ha h^{-1} at 1.21 km h^{-1} with 89% field efficiency (Yadav *et al.*, 2016).

Water Resource Management for Life Saving Irrigation in Hills

In spite of the abundant water resources, the ratio of irrigated area to net sown area varies from meager 5% in Assam to 28% in Arunachal Pradesh with the average for region as a whole at 10.6%. There is extreme water scarcity during the post and pre– rainy season leading to low cropping intensity and productivity (Das *et al.*, 2014). Although the region receives substantial rainfall during April to November, virtually no rainfall is received during November to March (Das *et al.*, 2018a,b). Hence, development of water harvesting structure is essential in the hills for supply of water in the winter season for livestocks and crops. Due to lack of water harvesting structures/irrigation facilities in hills, the farmers mostly grow only one crop in a year leading to low cropping intensity and limited income. Although crops like lentil, mustard etc. can be grown with limited moisture; one or two supplemental life saving irrigation at the time of flower initiation/ pod formation stage increases the yield. Thus, the strategy is to conserve as much rainwater as possible and to harvest the surplus water for life saving irrigation and also for enhancing the cropping intensity and to maximize returns. Construction of small earthen dam for water storage and silt retention at lower areas of the watershed helps to use stored water for supplemental irrigation to winter crops and one pre-sowing irrigation to summer crops, besides additional production of fishes. A rain water harvesting structure like farm pond (valleys) or *jalkund* (uplands, sloping lands) is recommended in hills for life saving irrigation and aquaculture (Das *et al.*, 2019). However, conserving water in hills is very challenging due to high infiltration and seepage loss. Lining '*jalkund*' with polyfilm lining (250 GSM) having storage capacity of 30,000-45,000 liters water is recommended for the region for promoting diversified farming activities (Das *et al.*, 2017d). Thus, two major approaches recommended for the NEHR are farm pond development for valleys and *jalkund* (a micro rain water harvesting structure of 5m × 4 m × 1.5 m dimension and lined with PVC- agri-film such as silpaulin 250 GSM) for hills and sloping lands. Adoption of integrated watershed development approach with emphasis on Roof water harvesting, farm ponds, check dam, spring water management, terracing, jalkunds, tube wells etc are having great potential for promoting water resource development and irrigation in the region (Das *et al.*, 2014). Land configuration like raised and sunken beds and in-situ retention of crop residues have been found to conserve rain water and increase water productivity (Das *et al.*, 2015). Adoption of NT along with retention of standing stubbles of previous rainy season rice (20-40 cm) or maize (0.75 -100 cm) conserves carry over soil moisture and enhances crop and water productivity of dry seaon crops (Das *et al.*, 2020; Ngangom *et al.*, 2020). Apart from enhancing the availability of water by various methods, increasing the water use efficiency and water productivity should be the focus by arresting various kinds of losses associated with utilization of water. The benefits could be still higher if improved irrigation techniques like drip and sprinklers are used for the use of harvested water. Growing vegetables during winter months using drip irrigation system is estimated to save 40% water (Karlberg *et al.*, 2007). The gravity fed drip irrigation system (GDIS) is very much suited to the hilly terrain of the region, where irrigation can be provided with this mechanism without any external power requirement. It is suitably for small farms especially 1.0-1.5 acre size. Bamboo drip irrigation is traditionally being used by some tribal farmers of Meghalaya and has very good scope for providing life saving irrigation in hills especially for the crops like betel, pepper, areacanut and high value vegetables (Das *et al.*, 2012). In a study at Manipur hills (Chandel district), establishment of *jalkund* reported to facilitate cultivation of tomato, cabbage, cauliflower and other high value crops in winter as against fallow with no jalkund. On an average, the cost of per liter harvested water was computed at Rs. 0.067 per liter considering 3 years life span of lining material. The effort played a significant role in doubling the cropping intensity (200%) as compared to monocropping before establishment of jalkund (Ansari *et al*., 2016).

Dissemination of the CA Technologies in Farmers Fields

The technologies on CA approach in rice and maize-based cropping systems (15 demonstrations), and raised and sunken bed (RSB) technology for crop diversification (10 demonstrations) for higher productivity were demonstrated in a participatory mode in the farmers field in Meghalaya. The results indicated that productivity enhancement with rice-pea sequence under conservation tillage was 229% compared to farmers' practice of rice monocropping. The rice equivalent yield (REY) recorded with rice-pea sequence was 10715 kg ha^{-1}. Similarly, maize-French bean under conservation tillage gave 168% higher maize equivalent yield compared to monocropping of maize. Adoption of the RSB system resulted in maximum enhancement in system productivity (348%) compared to monocropping of rice (farmers' practice) under conventional tillage practice in lowland (Das *et al*., 2017c). The maximum enhancement in net return was observed with RSB (487%) followed by maize-French bean under CA (465%) over respective farmers' practices. Adoption of various conservation measures and crop diversification enhanced water use efficiency (WUE) by 12% with maize-rapeseed system under CA. The WUE achieved with rice-pea system under CA (19.69 kg ha^{-1} mm^{-1}) was much higher compared to 5.99 to 7.79 kg ha^{-1} mm^{-1} under monocropping of rice and 6.23 kg ha^{-1} mm^{-1} under monocropping of maize under farmers' practice. The water productivity of rice- pea system was Rs. 9.57 m^{-3} water compared to Rs. 2.66 m^{-3} water under farmers' practice (Das *et al*., 2014).

Capsicum is a popular and widely grown vegetable crop in NEHR. It is high value crop and is generally cultivated in upland and garden lands. However, its cultivation in rice fallow area can enhance farmers' income substantially. Generally, capsicum is cultivated in well-pulverized field with medium tilth. Similar to pea cultivation, there is no need to cultivate the whole field for capsicum cultivation. 20-30 standing stubble was maintained like NT pea cultivation in rice fallow fields. However, the root zone needs to be opened for placing manure and fertilizer and transplanting capsicum seedlings. Thus, pits of about 30 cm diameter with 20 cm depth was dug out in rice field. Farmyard manure (5 Mg ha^{-1}) and DAP (50 kg ha^{-1}) was placed in the pit and well mixed with the soil. Adequate drainage of water was provided to make the land suitable for capsicum cultivation and also to protect crop from waterlogging in case of winter/pre-*kharif* rains. One month old seedlings were transplanted in the pits and watering was done immediately using a rose can. Some farmers cultivated capsicum in temporary raised beds. After rice harvest, raisedbeds of about 1 m width , 5-8 m length and about 30 cm height were made by cutting and filling method. 3 rows of capsicum with plant to plant spacing of 45 cm to 60 cm was practiced by the farmers. FYM /fertilizers are applied to the pit and then a month old seedlings is transplanted to the pit, which is then covered with soil: FYM mixture. Light irrigation was given after transplanting depending on the soil moisture and weather conditions. Intercultural operations like weeding, hoeing, pruning etc. were done for better crop growth. In case of dry fields, watering was done with rose cans at 3-5 days interval. Results revealed that capsicum productivity in farmers field ranged from 4.5 to 7.3 Mg ha^{-1} under raised beds and 3.3 to 7.5 Mg ha^{-1} under pit method. The net return ha^{-1} under two methods were Rs. 1,46, 540 under raised beds and Rs. 2,07370 ha^{-1} under pit method and the B:C ratio were 3.02:1 and 3.86:1, respectively (Rajkhowa *et al*., 2016). The NT Rapeseed after maize fallow resulted in almost 30% higher yield than those of CT practice in farmers field of Meghalaya. NT French bean after maize is also giving encouraging results in terms of higher productivity and income of farmers (Das *et al*., 2018a). Under National Agricultural Innovation Project, Component-3 a total of 915 beneficiaries covering 576 ha area demonstration on NT rapeseed in rice fallow was undertaken during 2008 to 2014 in Tamenglong District, Manipur, where farmers earned an additional average net income of Rs. 15,000 ha^{-1} under NT rapeseed after rainy season rice (Singh *et al.*, 2012).

Constraints for the Adoption of the CA in NEHR of India

- The most important factor in the adoption of the CA is convincing farmers about tillage. It is very often difficult to convince farmers that successful cultivation is possible even with reduced-tillage or without tillage is a major hurdle in promoting CA on a large scale in the region.
- Lack of appropriate seeders/equipment/ machineries especially for small and medium-scale farmers and hill farmers. Significant efforts have been made in developing and promoting machinery for seeding wheat in NT systems but hill region-specific mechanization is still lacking to implement the CA especially in hill agriculture. There is urgent need for developing lightweight portable weeding and seeding machinery for hill ecosystem and the development of eco-friendly and efficient weed management practices for the promotion of the CA in hill ecosystems (Das *et al.*, 2018a).
- Burning of crop residues in rice fields for timely sowing of the next crop, clearing fields and other reasons are major concerns especially in states like Manipur where rice threshing through mechanical threshers is gaining popularity due to time and labour saving. It is estimated that out of 628.31 Mg $annum^{-1}$ paddy straw production, approximately 463.7 Mg is burnt per annum (295.10 and 168.6 thousand Mg from valley and hill, respectively) in Manipur (Ansari *et al.*, 2018).
- Biomass burning in NEHR on under *jhum* farming [10 Mg ha^{-1} (Das *et al.*, 2011)] is a prevalent practice and the major challenge is to convince the farmers for recycling biomass and CA.
- Competing demand for crop residues for other sectors such as fodder, biofuel, etc. also is a challenge for residue retention.
- Lack of knowledge about the potential of CA to agriculture leaders, extension functionaries, NGOs, FPOs, Farmers Club and farmers.
- With the promotion of organic farming and farmers' reluctance of using herbicides, weed management is a real challenge in the region. Inadequate availability of manual labour and involvement of high costs further exacerbates the situation.
- Lack of irrigation facilities during dry season restricts popularization of CA/NT practices in NEHR to great extent.
- Lack of adequate skill and training is another important constraint for the popularization of CA in the NEHR.

Conclusions

The hill and mountain ecosystems need to be protected, rehabilitated and developed similar to other ecosystem or economy. It is proven that several conservation effective techniques, *viz.*, minimum disturbance of soil through the adoption of RT and/or NT farming practices for winter crops, crop diversification, cover crop, *in-situ* moisture conservation practices through locally available biomass and substitution of bulky organic nutrient sources by incorporation of at least 30% of the crop residues in-situ may be the solution for sustaining agricultural productivity and conserve natural resources (soil, water and biodiversity) by the resources poor farmers of the region. Similarly, inclusion of short-duration crops specially legumes (as cover crops/economic crop) in cereal based cropping system is also recommended for the region to sustain the soil health and enhancing cropping intensity. There is an urgent need to develop/promote light weight and small size conservation agriculture machineries like NT seed dril, planter, weeder etc for the hills to enhance efficiency, income and reduce drudgery. For the promotion of the CA practices across diverse hill and mountain agro-ecologies, appropriate policy and institutional and technical support would be a prerequisite. Many CA practices like rainwater harvesting structures, machinery for seeding, etc. are capital intensive, which resource-poor farmers in hills may not be able to afford and hence need to be supported. Initial incentives, to procure appropriate machinery and to offset any economic loss due to residue retention or production loss, are also important to motivate farmers to follow CA.

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