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Land and water conservation technologies for building carbon positive villages in India

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Abstract

Continuous and unabated land degradation in India is a threat to agricultural sustainability while increasing temperatures, changing rainfall patterns and precipitation intensification are going to further aggravate degradation in future. The timely adoption of integrated land and water conservation technologies minimises erosion and provides significant adaptation and mitigation co-benefits. The objectives of this study were to assess the mitigation potential of soil and water conservation technologies and also the feasibility of making villages carbon positive. The extent of minimisation of soil loss due to soil conservation technologies ranges from 0.10 to 21.65 Mg ha^{-1} yr^{-1}, while carbon emissions minimised range from 0.73 to 158.77 kg ha^{-1} yr^{-1}. Emission minimisation from various water management technologies in rice ranges from 73.0 to 507.9 kg CO_2 equivalents ha^{-1} yr^{-1}. Agroforestry practices can sequester 8.64 to 52.77 Mg CO_2 ha^{-1} yr^{-1} besides enhancing system productivity, arresting soil erosion and carbon loss through erosion. Integration of multiple technologies in a farming system further enhances the adaptation and mitigation benefits. Adoption of conservation technologies resulted in a net carbon balance of 0.05–1.23 CO_2 Mg ha^{-1} yr^{-1} in 9 villages in India, indicating net positive carbon balance due to reduction of greenhouse gas emissions and carbon sequestration. Building carbon positive villages is a potential approach for preventing land degradation, while enhancing productivity, mitigating climate change and realising the sustainable development goals. Building capacities of communities and establishing institutions in villages are essential for upscaling and maintaining of soil and water conservation structures and community assets in the village. Furthermore, prioritisation and scaling of location specific land and water conservation technologies hold the key to establish carbon-positive villages.

KEYWORDS

agroforestry, carbon balance, carbon sequestration, greenhouse gas emissions, integrated farming system, land degradation

1 | INTRODUCTION

With only 2.5% of the world's geographical area and 4% of its water resources, India is home for 17% of the global population and 15% of the animal population (Srinivasarao, Lal et al., 2015). Additionally, placed at the 140th position globally, the Country contributes 6.2% of the annual greenhouse gas (GHG) emissions (FAO, 2019) with a per capita emission of 1.9 tonnes (Baumert et al., 2005). Furthermore, the agriculture sector in India contributes to 16.5% of the gross domestic product while providing employment to around 66% of the Country's population (World Bank, 2019). Simultaneously, operational land holdings, a critical component in determining socio-economic farmer security, increased from 129.22 million (2005–2006) to 146.45 million (2015–2016) while their average size declined (from 2.28 ha in 1970–1971 to 1.08 ha in 2015–2016) (DAC, 2020). Therefore, small and marginal farmers (i.e. < 2 ha of land), account for the majority of the land holdings (126 of 146.45 million) of which, 68.5% are possessed solely by marginal farmers (< 1 ha of land), clearly reflecting the large proportion of smallholder farmers in the Indian agriculture system. Consequently, large tracts of potentially fertile lands are either left uncultivated or suffer from low productivity owing to lack of physical infrastructure along with financial and human capital (NITI Aayog, 2016).

Agricultural production of India has reached 290 million tonnes in 2019 and aiming at 298 million tonnes during 2020–2021 (DAC, 2020). India has experienced remarkable increase in agricultural productivity over the last decades (Pingali, 2012) and leads in production of various commodities like milk, jute and pulses and occupies the second position in terms of rice, wheat, sugarcane, cotton, fruits and vegetables production globally (FAO, 2019). However, an undernourished portion of the population of approximately 14% renders food security a critical concern for the Country (von Grebmer et al., 2020). Increasing food demand of the growing population, especially the increasing demand for high-value products as incomes increase, poses a major challenge for Indian agriculture. There is a transformative progress in comprehending and addressing food security concerns during the last 50 years. Although food security was synonyms with increased production in the 1950s, environmental health, primary health care and primary education are also being focussed upon now. As Swaminathan (2001) acknowledged, prioritising ecological factors can lead to long-term sustainability of food systems. An integrated approach is necessary for increasing food production, distribution and service delivery mechanisms in view of the rapidly changing climatic conditions, continued population growth, urbanisation, changes in diets and depletion of natural resources (Lal, 2012). In this context, building resilient, carbon-positive and sustainable villages is imperative for reducing and reversing land degradation while enhancing productivity, mitigating climate change and realising the sustainable development goals. The present article aimed to provide a critical appraisal of the ongoing efforts in India towards building carbon-positive villages and assess the potential of various technologies towards establishment of carbon-positive villages. We hypothesised that by enhancing adoption of various conservation practices and other mitigation technologies, the GHG emissions can be reduced significantly and villages can be made carbon positive.

2 | PRODUCTIVITY CONSTRAINTS OF TROPICAL ECOSYSTEMS

2.1 | Land degradation

Various organisations have attempted to assess the state of land degradation and desertification in India since it is a widespread problem. Estimates of land degradation by different organisations vary widely, for example, 53.28 million ha (million ha) (NRSA, 1985), 120.7 million ha (NAAS, 2012), 123 million ha (NWDB, 1985), 146.82 million ha (NBSS & LUP, 2004) and 173.64 million ha (MOA, 1985). An estimate by GLASOD (FAO, 1994) puts erosion by water as the leading cause for degradation affecting 32.8 million ha land area followed by wind erosion (10.8 million ha), fertility decline (29.4 million ha), salinisation (4.1 million ha) and inundation (3.1 million ha). The total area affected by diverse degradative processes is 80 million ha (Table 1). The annual economic loss due to land degradation in India was valued at Rs 2.60 *lakh crores* (one *lakh crore* = one trillion; 1US$ = Rs.76) in 2014–2015, which was 2.09% of the Country's gross domestic product (TERI, 2018).

2.2 | Desertification

Desertification can be briefly explained as the expansion of desert type landforms and landscapes in areas where there has not been in the recent past (Le Houerou, 2002). Drylands in India experience severe problem of desertification. Around 82.64 million ha of dryland area in India is presently impacted from desertification with an

TABLE 1 Estimates of land degradation in India by various processes (area in million ha)

Process of degradation	FAO, 1994	NAAS, 2012
Water erosion	32.8	73.3 (land area) and 9.3 (forest area)
Wind erosion	10.8	12.4
Soil fertility decline	29.4	—
Waterlogging	3.1	0.9
Salinisation	4.1	6.5 (land area) and 0.1 (forest area)
Lowering of watertable	0.2	—
Acid soil	—	10.8 (land area) and 7.2 (forest area)
Mining/industrial areas	—	0.2
Total	80.4	120.7

Abbreviations: FAO, Food and Agricultural Organisation; NAAS, National Academy of Agricultural Sciences increase of 1.16 million ha with wind erosion being the dominant process responsible for degradation in arid regions, while soil fertility decline, vegetation loss and water erosion are the leading causes in semiarid and dry subhumid regions (SAC, 2016). The Thar Desert region of India is severely negatively impacted by wind erosion. Removal of nutrient-rich soil from fields and their subsequent deposition in non-agricultural areas are major wind erosion–associated concerns in the region. Furthermore, climate change and desertification in dryland regions foster reductions in crop and livestock productivity along with biodiversity losses. Detrimental impacts associated with moisture stress, drought severity and habitat degradation are predicted to impact 178 million people with a rise of 1.5°C and 220 million with a rise of 2°C temperature by 2050 (IPCC, 2019). Therefore, region-specific prioritisation depending on severity is required for combating erosion.

2.3 | Soil erosion

Soil erosion is recognised as one of the major challenges for agriculture in India. The extent of erosion in the Country is estimated at 5.1 Gt yr^{-1}, out of which 34.1% of the eroded soil is deposited in the reservoirs, 22.9% is transported outside the Country (mainly to oceans) and the remaining 43.0% is displaced within the river basins (Sharda & Ojasvi, 2016). Accelerated soil erosion depletes the soil organic carbon severely and quickly. Soil carbon is displaced through runoff and erosion owing to its low density and higher concentration in surface (Singh et al., 2018). The eroded sediments are enriched with carbon with the enrichment ratio varying between 1.5 and 5.0 (Lal, 1999). The eroded sediments comprise a soil organic carbon concentration ranging between 8 and 12 g kg^{-1}, total C displaced by erosional process is 16.4 Mg ha^{-1} yr^{-1} in arid and semiarid regions of India, which leads to carbon loss of 0.131–0.197 Gg C yr^{-1} and 120.96–181.44 Tg C yr^{-1}, with an annual loss of 13.5 million tonnes of major crops (Narayana & Babu, 1983; Singh et al., 2016). The economic cost of soil erosion in cropland areas during 2014–2015 was about 0.35% of GDP (TERI, 2018). Adoption of conservation measures that reduce erosion in turn leads to reduction of carbon emissions from erosion-prone ecosystems.

2.4 | Ground water exploitation and depletion of water table

Overextraction of groundwater for a prolonged duration through sustained pumping leads to water-level decline and depletion, a concern affecting many regions of India. While groundwater levels have declined by 61% between 2000 and 2017, agriculture remains the dominant cause for the same as 89% of extracted water is utilised for irrigation purposes (Bhattarai et al., 2021; Taylor et al., 2012). Excessive depletion is further leading to withdrawal from deeper layers for meeting growing demand.

2.5 | Impacts of land degradation on climate

India is likely to suffer from a higher frequency of extreme temperature and precipitation events (IPCC, 2014). Climate change intensifies land degradation by aggravating the drivers responsible for erosion such as wind, temperature, combined with increased flood and drought spells. Global warming is projected to increase frequency, amount and intensity of precipitation events globally particularly in high latitudes of northern hemisphere, which will further contribute towards land degradation (Hoegh-Guldberg et al., 2018).

Temperature changes impact the nitrogen and carbon cycles and microbiota through faster nitrogen cycling and changes in the carbon allocation (Solly et al., 2017). Ecosystems and biodiversity are vulnerable to climate change and weather extremes. Land degradation processes are driven by unsustainable exploitation of vegetation leading to loss of vegetation and biomass carbon, causing net carbon releases (Lal, 2012). Degradation by different activities in tropical and subtropical regions is estimated to cause carbon releases up to 0.6 Gt C yr^{-1} (Pearson et al., 2014). Land acts as both carbon source and sink by regulating exchange of gases, water and aerosols between surface and atmosphere; sustainable management of land resources is critical for reducing detrimental climate change effects on environment and societies.

3 | CARBON POSITIVE VILLAGE

In the absence of human interference of climate system, the stocks of carbon in the atmosphere, oceans, soils and forests exist in dynamic equilibrium (Mathur & Awasthi, 2016). Carbon neutrality is a dynamic balance between the rate of emissions and their removal, which indicates that the total emissions are balanced by total offsets, and there is net zero carbon emissions (Goodfield et al., 2014). A Carbon-positive balance scenario indicates further reduction in the GHG emissions and enhanced removal of CO_2 by way of sequestration (McDonough, 2016). The carbon balance for assessment of neutrality and net removal from the atmosphere considers all the important GHG emissions expressed in terms of CO_2 equivalents. In India where nearly 66% of the people live in villages (World Bank, 2018) and agriculture supports more than 60% of the population (Deshpande, 2017), minimising emissions and enhancing removals leading to net-negative emissions and positive carbon balance in all the spheres of agriculture activities will lead to establishment of carbon-positive villages (Figure 1). A village is an administrative and management unit, a contiguous geographical area ranging from few hundred hectares to few thousand hectares depending on the topography. The available resources in the village are managed by the communities for various agricultural activities and focussing mitigation interventions at this scale will be effective in minimising resource degradation and establishing carbon-positive villages. The stepwise process of development of carbon-positive village is presented in Figure 2.

Globally, agriculture, forestry and other land use (AFOLU) sectors contributed 24% of the greenhouse gas emissions (GHG) emissions during 2007–2016, and the extent of contribution is increasing gradually

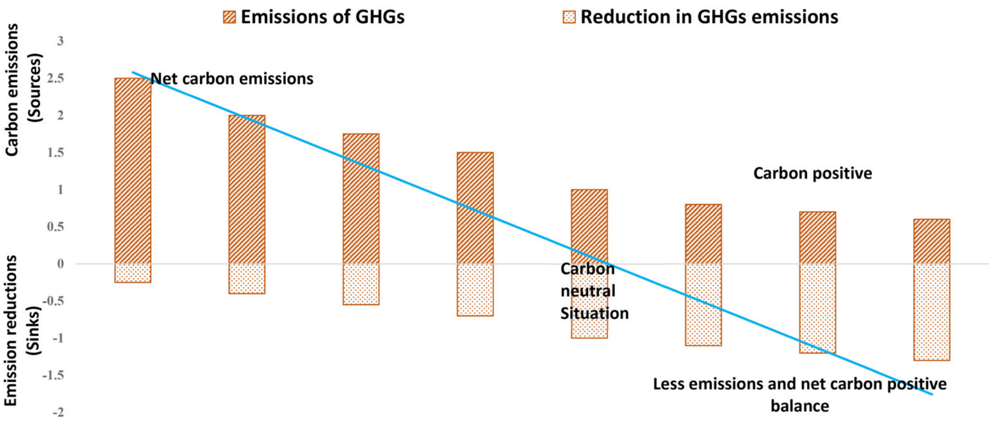

FIGURE 1 Transformation of a village from net carbon emissions to carbon positive [Colour figure can be viewed at wileyonlinelibrary.com]

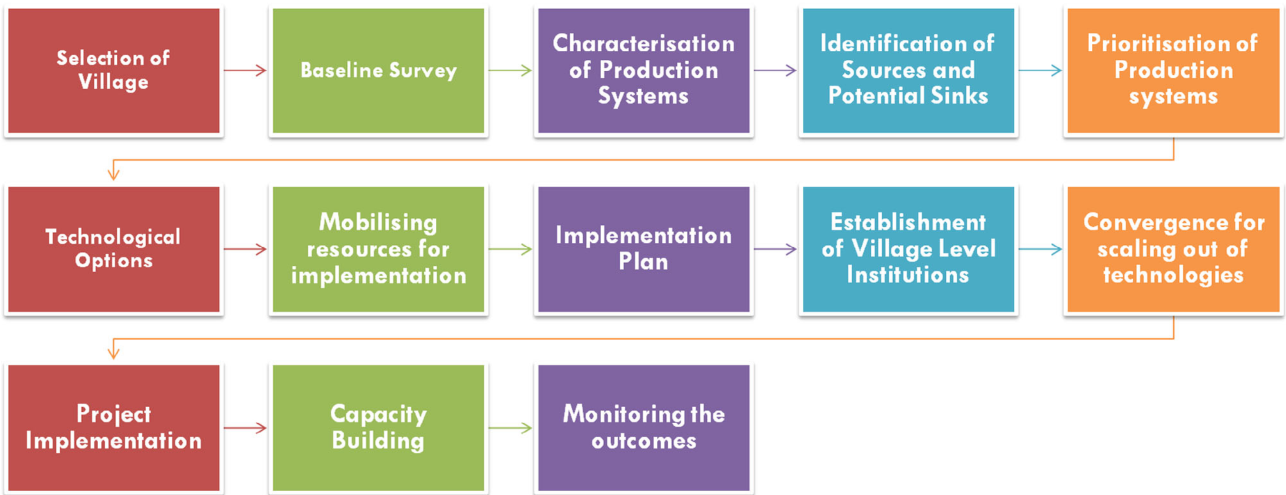

FIGURE 2 Process of establishing carbon-positive village for attaining the United Nations (UN)-Sustainable Development Goals (SDGs) [Colour figure can be viewed at wileyonlinelibrary.com]

(IPCC, 2014). In India, the agriculture sector has contributed to 14% of the total emissions during the year 2016 (MoEFCC., 2021). Enteric fermentation by animals, rice cultivation, nitrogen emissions from soils and applied fertilisers, crop residue burning and emissions due to manure management are the important sources of emissions in India (MoEFCC., 2021). Apart from the above, land and vegetation degradation in agricultural landscapes, use of fossil fuels in various agricultural operations and activities related to land use change contribute towards carbon emissions (Foley et al., 2005). However, these activities provide potential opportunities for minimising GHG emissions, can enhance resource efficiency, productivity and sequester CO_2 from the atmosphere thus contributing to the net negative emissions.

Agriculture in a developing country like India is highly diversified, location specific and resource driven, meeting the household and market demands for producing diversified products. Continuous and unabated land degradation is contributing to decline in productivity, loss of productive soil, loss of biodiversity and threatening the livelihoods of millions in developing countries (Bhattacharyya et al., 2015). Efforts in arresting land degradation minimises the emissions, while their rehabilitation enhances productivity and contributes towards carbon sequestration and emissions removals (Pearson et al., 2014). Agriculture in developing countries would be sustainable and contribute towards net negative emissions when climate resilient/smart technologies are adopted by communities on large scale. An enabling and conducive environment leading to adoption of climate resilient smart technologies by communities in villages can lead to establishment of carbon-positive villages. Development of such villages will meet the objectives of climate change mitigation, enhanced productivity and livelihood improvement. Further they can contribute towards sustainability by contributing towards various Sustainable Development Goals (SDGs) like climate adaptation and mitigation (SDG 13), arresting land degradation (SDG15) minimising poverty (SDG 1) and improving farmer income (SDG 2) (https://sdgs.un.org/goals).

4 | ACHIEVING CARBON-POSITIVE VILLAGE

4.1 | Land and water conservation technologies

Conservation technologies can be defined as approaches that conserve land and water, reduce loss of soil carbon, promote crop productivity and sequester carbon (Mahajan et al., 2021). Besides, land

TABLE 2 In-situ moisture conservation practices, the extent of soil loss (Mg ha^{-1} yr^{-1}), CO_2 emissions (CO_2 kg ha^{-1} yr^{-1}) and impact on crop productivity (kg ha^{-1})

Practice	Location	Soil	S	SL	CP	CO_2	References
TCB in finger millet with *Saccharum* spp	Southern Odisha	Red lateritic Sandy loam	5	4.03 (8.26)	1500 (1100)	29.55 (60.57)	Dass et al. (2011)
Deep ditch 60 cm in finger millet	Ballowal Saunkhri, Punjab	Sandy loam	4	12.75 (28.00)	910 (520)	93.50 (205.33)	Bhushan et al. (2009)
BBF in maize	Bhopal, Madhya Pradesh	Black soils	2	1.90 (3.50)	1295 (1122)	13.93 (25.67)	Mandal et al. (2013)
BBF in groundnut	Targhadia, Gujarat	Black soils	—	0.48 (0.58)	932 (839)	3.52 (4.25)	Vekariya et al. (2015)
BBF in soybean	Parbhani, Maharashtra	Medium black soils	1	2.23 (4.78)	1354 (860)	16.35 (35.05)	Pendke et al. (2019)
RB 40 cm in black gram	Bhilwara, Rajasthan	Sandy clay loam	2	1.61 (3.65)	1033 (568)	11.81 (26.77)	Jat et al. (2013)
CF at 2.7 m distance in soybean	Parbhani, Maharashtra	Black soils	—	0.36 (1.02)	834 (632)	2.64 (7.48)	AICRPDA Annual Report (2014)–15
Mulching with sugarcane trash in maize	Ballowal Saunkhri, Punjab	Sandy loam	1–6	12.91 (34.56)	4060 (2810)	94.67 (253.44)	Bhushan et al. (2013)
Live mulch with sunhemp in amla (*Emblica officinalis*)	Dehradun, Uttarakhand	Silty clay loam	2	5.00 (10.25)	6850 (4650)[a]	36.67 (75.17)	Dubey et al., 2015
VB with *Cenchrus ciliaris* in sunflower	Solapur, Maharashtra	Black soils	2	0.36 (0.61)	867 (618)	2.64 (4.47)	Bhanavase et al. (2007)
VB with *Dichanthium annulatum*	Bellary, Karnataka	Deep black soils	1	0.52 (3.25)	6152 (Fallow)	3.81 (23.83)	Mishra et al., 2018
Strip cropping of maize—blackgram (4:8) with deep tillage ridging after sowing	Bhilwara, Rajasthan	Sandy clay loam	2	0.60 (2.65)	2262 (1140)	4.40 (19.43)	Jat et al. (2017)
Intercrop of groundnut and Pigeonpea (4:2)	Phulbani, Odisha	Red soils	2	8.03 (15.19)	5557 (2153)	58.94 (111.50)	Subudhi and Senapati (2016)

Note: Values in parenthesis indicates the control (no practice). Carbon loss is arrived by taking the carbon content of eroded soil as 1% (Lal, 2004) and the extent of C oxidation from eroded carbon is 20% (Lal, 1995)

Abbreviations: BBF, broad bed and furrow; CF, conservation furrow; CP, crop productivity enhancement; RB, raised bed; S, slope (%); SL, soil loss; TCB, trench cum bunding; VB, vegetative barrier

[a]Forage yield of *Dichanthium annulatum*

restoration strategies can also help build soil carbon pool in presence of optimum water and nutrients (Lal, 2015).

4.1.1 | In-situ moisture conservation: Farm water on farm and village water in village

In-situ and ex-situ are the two major approaches of water harvesting and moisture conservation characterised based on the site of water harvesting. While in-situ measures collect water within the harvesting area with the soil acting as storage, the ex-situ measures diverts water outside the harvesting area and the reservoir for collection can be natural or artificial.

The feasibility of a conservation practice depends on several factors such as field slope, precipitation distribution, soil properties, crop type, etc. Bunding (mechanical approach commonly adopted in sloping lands to collect surface runoff, increase water infiltration and prevent soil erosion) is one of the effective in-situ measures suitable for red soils with 8% slope (Chowdhury et al., 2016). Land configurations, such as broad-bed and furrow, ridge and furrow, etc., are effective in-situ conservation measures (Srinivasarao, Gopinath, et al., 2016). Broad bed and furrows minimised soil loss and reduced loss of carbon to 46% compared with that of the flat on grade system in Vertisols of Central India (Table 2, Mandal et al., 2013). Opening of conservation furrows is one of the effective measures for in-situ conservation and for minimisation of carbon loss. Vegetative barriers planted on contours are effective in minimising runoff, soil loss and carbon. Some of the promising vegetative barriers are *Dichanthium annulatum*, *Panicum turgidum*, *Cynodon dactylon* and *Cenchrus ciliaris* for arid regions (Gupta, 1966), *Chrysopogon zizanioides*, *Cymbopogon citratus* and *Saccharum* spp. for semiarid regions of India (Dass et al., 2011). In Inceptisols of Maharashtra receiving a rainfall of 723 mm vegetative barrier of *Cenchrus ciliaris* recorded minimum runoff, reduced the extent of soil loss by 41% in comparison to no barrier and contributed to higher grain yield of sunflower (40%) (Bhanavase et al., 2007). A combination of vegetative barriers with trench-cum-bund can further minimise soil and carbon loss; lowest runoff (8.1%) and soil loss (4.03 Mg ha^{-1} yr^{-1}) were observed in the rainfed uplands of Kokriguda watershed, Southern Odisha (Dass et al., 2011). Groundnut + pigeon pea (4:2) intercropping systems recorded the lowest soil loss (8.03 Mg ha^{-1} yr^{-1}), which was 47% lower than the cultivated fallow and enhanced yields by 158% in the hilly tribal areas of Kandhamal District of Odisha (Subudhi & Senapati, 2016).

4.1.2 | Land treatments for soil, water, fertility and C loss minimisation

Land treatments comprising of contour bund, graded bund, compartmental bund, trench-cum-bunding and contour trenches are widely adopted in watershed development programmes for erosion control. A contour bund consists of earthen embankments built across the slope of land following the contour closely. It divides the area into several strips which act as a barrier thereby reducing soil and carbon loss by decreasing the quantity and velocity of runoff (Mishra & Tripathi, 2013).

Contour bunding was found to reduce the surface runoff and soil loss considerably in many regions. Contour bunding at 0.7 m vertical interval minimised soil loss to 0.03 Mg ha^{-1} yr^{-1} and carbon loss to 0.22 kg^{-1} ha^{-1} yr^{-1} and enhanced sorghum yield by 10% in comparison to no bunding in red soils of Bundelkhand region in central India (Narayan et al., 2014). Contour bunding supported by live bunding with species like *Leucaena* has reduced the soil loss to a minimum at Bangalore (Gund & Durgunde, 1995). In Dehradun, which receives a rainfall of 1450 mm, graded bunding reduced the soil and carbon loss by 77% in comparison to control with a slope of 8% (Table 3; Khola & Sastry, 2005). Laser land levelling can minimise application losses of water, reduce energy requirement and enhance water productivity. Highest water productivity was observed in the laser levelled fields, which was 48%, 78% and 49% higher as compared to control (unlevelled), in rice, wheat and sugarcane, respectively. The extent of savings in energy is up to 31.5% due to laser land levelling in comparison to no levelling (Naresh, Singh, et al., 2014).

4.1.3 | Terracing and bund formation in hill ecosystems

Terracing and formation of bunds are generally recommended in hilly regions with relatively high rainfall. Adoption of mechanical soil and water conservation approaches can ensure retention of maximum rainfall and safe disposal of runoff from steep slopes thereby reducing erosion. Bench terracing in Dehradun, with a slope of 8%, minimised soil and carbon loss by 96% in comparison to no terracing (Table 4). In the northeast region of Meghalaya, bench terracing minimised soil loss and carbon loss up to 97% than control and contributed to yield enhancement up to 135% in maize and 309% in rice (Patiram., 2002). Use of perennials such as *Erythrina poeppigiana* can minimise carbon loss and contribute towards carbon sequestration. Intermittent bench terracing is another approach for arresting the soil loss, conservation of water and soil in steep slopes of the Western Ghats has minimised the soil loss to 92% than control and enhanced crop yields up to 18% in Maharashtra (Badhe & Magar, 2004). Reducing the soil and carbon loss from fields retains the soil and carbon in the village itself.

4.1.4 | Farm pond technologies for water storage and efficient recycling

Efficient in-situ conservation of soil moisture combined with harvest, storage and recycling of the excess runoff for supplemental irrigation can lead to successful growth of rainfed crops. Farm ponds effectively capture the excess runoff after in-situ conservation and safely divert the runoff into a pond, thus conserving the water and soil carbon in the field itself. The importance of rainwater harvesting for agriculture has further increased as an adaptation strategy in view of increased climatic variability and frequency of extreme weather events. The advantages of use of harvested water for supplemental irrigation are significant and improvement in crop yields was observed up to 560% depending on crop, duration and degree of dry spell and quantity of water applied (Srinivasarao et al., 2015; Srinivasarao, Prasad, et al., 2016). Due to efficient use of harvested water, the water use efficiency was observed to enhance considerably (15.88 kg ha^{-1} mm^{-1}) compared to farmers' practice (3.90 kg ha^{-1} mm^{-1}, Table 5; Das et al., 2012). Diversion of runoff water in to farm pond helps in harvest of as much rainwater from the farm in the farm itself and helps in collection and storage of soil and carbon in the field itself.

4.1.5 | Restoring soils with recycling eroded soils in farm and village tanks

Desilting of ponds (Water bodies of fresh water often gets filled during the rainy season with runoff which is used for irrigation and recharge) and water storage tanks was found to be an economically profitable activity for creating more water holding capacity and returning the silt back to the fields as a source of organic matter and plant nutrients. The organic carbon content of sediments ranged from 5.3 to 27.2 g kg^{-1}, with an average of 10.7 g kg^{-1} in Medak, Telangana (Osman et al., 2015). The quantity of tank silt (is a fine soil brought through surface runoff during rainfall from catchment area which is applied to fields as an amendment during dry period when the water body is dry) application to fields ranged from 12.5 to 62.5 Mg ha^{-1} yr^{-1}, which results in addition of 125 to 625 kg ha^{-1} of carbon to soil (Table 6). The nutrient content of tank silt is highly variable and vary from place to place. In Medak District of Telangana, the nutrient content of tank silt varied between 328 and 748 mg Nkg^{-1} with other constituents varying as follows; available phosphorus (5–35 mg kg^{-1}), potash (271–522 mg kg^{-1}), available sulphur (12–30 mg kg^{-1}), zinc (1.2–5.6 mg kg^{-1}) and boron (0.4–0.8 mg kg^{-1})

TABLE 3 Land treatments for soil and water conservation, soil loss (Mg ha^{-1} yr^{-1}) and carbon emission minimisation (CO_2 kg ha^{-1} yr^{-1}) and their impact on crop productivity (kg ha^{-1}) and water productivity (kg m^{-3} water)

Practice	Location	Soil	S	SL	CP	CO_2	WP	References
CB in maize	Dehradun, Uttarakhand	Silty clay loam	8	10.13 (83.04)	1219 (fallow)	74.29 (608.96)	—	Khola & Sastry (2005)
GB in maize	Dehradun, Uttarakhand	Silty clay loam	8	19.51 (83.04)	1412 (fallow)	143.07 (608.96)	—	
GB in sorghum	Sindhanur, Karnataka	Clay	6	0.57 (3.81)	1117 (879)	4.18 (27.94)	—	Rao et al. (1998)
CT in citrus	Nagpur, Maharashtra	Clay	3	3.14 (4.60)	—	23.03 (33.73)	—	Panigrahi et al. (2006)
CST in tea plantation	Udhagamandalam, Tamil Nadu	Silty clay loam	25	1.81 (5.38)	3430 (3040)	13.29 (39.49)	—	Madhu et al. (2001)
CCT with 0.2% channel grade in cashew (*Anacardium occidentale* L.)	Nasik, Maharashtra	Silty clay loam	26	1.07 (10.92)	—	7.85 (80.15)	—	Patil et al. (2007)
ST in cashew (*Anacardium occidentale* L.)	Sindhudurh, Maharashtra	Sandy loam	14–15	0.52 (18.17)	405 (280)	3.82 (133.37)	—	Badhe & Magar (2004)
LLL in rice	Modipuram, Uttar Pradesh	Sandy loam	—	—	6420 (6105)	—	0.30 (0.25)	Jat et al. (2009)
PLL with RB in wheat	Modipuram, Uttar Pradesh	Sandy loam	—	—	5100 (2670)	—	2.15 (0.56)	Jat et al. (2011)
LLL in wheat	Meerut, Uttar Pradesh	Sandy loam to loam	—	—	4470 (3750)	—	1.35 (0.76)	Naresh, Singh, et al. (2014)
PLL with wide RB in wheat	Meerut, Uttar Pradesh	Sandy loam to loam	—	—	5230 (2520)	—	1.88 (0.68)	Naresh, Rathore, et al. (2014)

Note: Values in parenthesis indicates the control (no practice). Carbon loss is arrived by taking the carbon content of eroded soil as 1% (Lal, 2004) and the extent of C oxidation from eroded carbon is 20% (Lal, 1995)
Abbreviations: CB, contour bunding; CCT, continuous contour trench; CP, crop productivity enhancement; CST, contour staggered trench; CT, contour trench; GB, graded bunding; LLL, laser land levelling; PLL, precision land levelling; RB, raised bed; S, slope (%); SL, soil loss; ST, staggered trench; WP, water productivity

higher than the surrounding soil (Osman et al., 2009). The extent of yield improvement ranged from 22% in maize to 36% in sorghum due to the application of tank silt while improving water-associated efficiency and productivity of different crops at several locations in Anantapur, Warangal, Solapur and Bhilwara Districts (Reddy & Dixit, 2017). Tank silt application is recommended as an organic amendment for improving water use efficiency and productivity.

Impact of tank silt application in degraded Alfisols of Andhra Pradesh, India, indicates strong response of maize and castor yields and found to improve soil physical, chemical and biological properties (Srinivasarao, Gopinath, et al., 2016). Results revealed reduction in bulk density of soil from 1.5 to 1.25 g cc^{-1} on application of tank silt having clay content between 60 to 80%. Additionally, application of tank silt at 50, 100, 150 and 375 tractor loads per hectare enhanced available water content by 0.002, 0.007, 0.012 and 0.032 g g^{-1} soil, respectively. Tank silt application resulted in improvement in soil moisture content along with the ability of crops to withstand dry spells of 4–7 days thereby reflecting the role tank silt can play during prolonged dry periods (Osman et al., 2009).

4.1.6 | Restoration of *Jhum* lands in hill ecosystems

Shifting cultivation (*Jhum* cultivation- Slash and burn method of cultivation) is a traditional land use prevalent in hilly ecosystems of North East India. Due to growing population, the shifting cultivation cycle is reduced to 3–4 years in recent times as compared to 10–12 years in the past resulting in land degradation (Kumar et al., 2016). Ram & Singh (1993) observed soil erosion resulting from shifting cultivation to be particularly high (40.9 Mg ha^{-1}) along with an organic carbon loss of 702.9 kg ha^{-1} on steep slopes. Similarly, Singh & Singh (1981) estimated soil loss from hill slopes to be 147, 170 and 30 Mg ha^{-1} yr^{-1} under first year, second year and abandoned *jhum*, respectively. Several technologies like agroforestry, terrace farming, hedgerow cropping and sloping agricultural land technology (SALT; integrated approach applied in sloping lands) can lead to soil resource conservation and increased grain production (Lamichhane, 2013). Cultivation of different hedgerow species in *jhum* fields can prove to be beneficial to farmers. Hedgerow species like *Alnus nepalensis*, *Crotalaria tetragona*, *Gliricidia maculata*, *Indigofera tinctoria*, *Cajanus cajan*, *Flemingia macrophylla*, *Desmodium rensonii* and *Tephrosia candida*

TABLE 4 Terracing and bund formation in hill ecosystems and the extent of soil loss (Mg ha^{-1} yr^{-1}) and carbon emission (CO_2 kg ha^{-1} yr^{-1}) and their impact on crop productivity enhancement (kg ha^{-1})

Practice	Location	S	SL	CO_2	CP	References
BT in maize	Dehradun, Uttarakhand	8	3.07 (83.04)	22.51 (608.96)	1317 (fallow)	Khola & Sastry (2005)
25% maize on US +75% rice on BT in LS	ICAR-NEH Region, Meghalaya	27–35	1.10 (35)	8.07 (256.9)	Maize - 971 (412) rice −1077 (263)	Patiram. (2002)
IBT	Sindhudurh, Maharashtra	14–15	1.49 (18.17)	10.93 (133.37)	330 (280)	Badhe & Magar (2004)

Note: Values in parenthesis indicates the control (no practice). Carbon loss is arrived by taking the carbon content of eroded soil as 1% (Lal, 2004) and the extent of C oxidation from eroded carbon is 20% (Lal, 1995)
Abbreviations: BT, bench terracing; CP, crop productivity enhancement; IBT, intermittent bench terracing; ICAR-NEH, Indian Council of Agricultural Research-North-Eastern Himalayan; LS, lower slope; S, slope (%); SL, soil loss; US, upper slope

TABLE 5 Farm pond technology for water harvesting, its efficient use and crop productivity enhancement

WHS	L	WH	SLA	CP	References
Farm pond an supplemental irrigation in cotton hybrid NHH 44	Nagpur, Maharashtra	6885	2.25	1300 (1000)	Ambati et al. (2011)
Farm pond and irrigation in Bt hybrid cotton	Yeotmal, Maharashtra	15,120	0.28	1900 (1600)	
Jalkund and irrigation in rice and vegetables (rice equivalent yield)	Umiam, Meghalya	—	—	1867 (462)	Das et al. (2012)
Farm pond and irrigation in safflower	Parbhani, Maharashtra	125	—	607 (270)	Samindre & More (2012)
Farm pond and irrigation in groundnut	Namakkal, Tamil Nadu	3023	—	2200 (1800)	Mohan et al. (2013)

Note: Values in parenthesis indicates the control (no practice)
Abbreviations: CP, crop productivity enhancement (kg ha^{-1}); L, location; SLA, soil loss averted (Mg ha^{-1} yr^{-1}); WH, water harvested (m^3); WHS, water harvesting structures

TABLE 6 Restoring soils with recycling of eroded soils in farm and village tanks (tank silt application)

Crop	L	QTA	C added	GYI
Sorghum	Belgavi, Karnataka	42.8	428	1550 (1135)
Groundnut	Chikkaballapur, Karnataka	62.5	625	1068 (846)
Finger millet	Chikkaballapur, Karnataka	62.5	625	1898 (1541)
Maize	Tumakuru, Karnataka	12.5	125	3300 (2700)
Finger millet	Tumakuru, Karnataka	12.5	125	2400 (1900)

Note: Values in parenthesis indicates the control (no practice). Carbon added is arrived by taking the carbon content of eroded soil as 1% (Lal, 2004)
Abbreviations: C, added (kg ha^{-1} yr^{-1}); GYI, grain yield improvement (kg ha^{-1}); L, location; QTA, quantity of tank silt applied (Mg ha^{-1} yr^{-1})
Source: Reddy & Dixit, 2017.

have been found suitable for farming (Lenka et al., 2012). SALT with *Alnus nepalensis* and *Indigofera dosua* species in test crop maize resulted in minimised soil loss and carbon loss upto 84%–89% compared to no practice (Lamichhane, 2013; Singh, 2019). Furthermore, Saha et al., 2012 through a study at Changki, Nagaland, demonstrated that soil and carbon loss was minimised by 22% by planting in contour hedgerow with *Crotalaria tetragona* in *jhum* fields as compared to traditional *jhum* sites (38.14 Mg ha^{-1} yr^{-1}; Table 7).

4.1.7 | Land and water conservation in coastal and island ecosystems

Soil erosion is a major land degradation problem in the sloping and undulated terrain of islands. Soil erosion resulted in fertility degradation and loss of top soil due to high-intensity storms and steep topography. However, the island suffers from soil moisture deficit during dry season due to high evapotranspiration and runoff associated with soil erosion, which has a scour potential to reduce the soil productivity by removing the most fertile topsoil and obstruct the agricultural operations. Therefore, soil erosion control and water conservation are essential for island ecosystems. The soil mass of islands is essential not only for maintaining fertility but also for the survival of island ecosystems. Relatively higher soil loss (124.8 Mg ha^{-1} yr^{-1}) was observed in rice-fallow as compared to ginger-fallow cropping pattern (70.6 Mg ha^{-1} yr^{-1}) in the South Andaman (Islands) District (Table 8). Staggered contour trenches and continuous contour trenches in cashew in coastal Goa resulted in minimising carbon loss to the extent of 36 and 48%, respectively, compared to no conservation measures (Mahajan et al., 2021).

4.1.8 | Efficient rice systems for improved water use efficiency and reducing GHGs

In India, rice-based cropping system contributed 17.5% of the greenhouse gas (GHG) emissions from the agriculture sector during 2016 (MoEFCC., 2021). Various management practices were developed, which can significantly reduce the methane and N_2O emissions in rice cultivation (Table 9). Submerged rice fields are often regarded as a major source of methane emissions from soil. This can be mitigated using several strategies such as alternate wetting and drying, direct-dry seeding (Tabbal et al., 2002), aerobic rice (Bouman et al., 2005), non-flooded mulching cultivation and system of rice intensification (SRI). Apart from crop establishment methods, nitrogen management is equally important from view of GHG emissions. Carbon equivalent emission (CEE) was reduced by 27.4% in SRI and 30.1% in modified SRI over conventional method of planting (Jain et al., 2014). CEE in transplanted rice in various districts of Punjab ranged from 800 to 2100 kg C ha^{-1} with an average of 1300 kg C $ha^{-1}$and in the direct seeded rice (DSR) between 800 and 1500 kg C ha^{-1} with 1200 kg C ha^{-1} as average. DSR and SRI are alternatives to conventional puddled transplanted rice, which can save water, labour, increase farmers' income and minimise emissions (Pathak et al., 2013).

4.2 | Agro-forestry systems as a sustainable land use

Agroforestry systems can remove significant amounts of GHGs from atmosphere through increased carbon storage in biomass aboveground and belowground and in soil organic carbon (Goswami et al., 2014). Tree systems provide multiple benefits when integrated in to landscapes and provide enhanced returns to farmers, stabilise productivity and imparts resilience to production systems, minimise risk for agricultural production and provides environmental services (Korwar et al., 2014). Agroforestry systems help improve farmer livelihood by mitigating global warming and enhancing carbon sequestration (Ajit et al., 2013). The extent of carbon sequestration from agroforestry systems in India ranges from 2.36 to 14.42 Mg ha^{-1} yr^{-1}, depending on the tree density (Rizvi et al., 2011). Of the several tree-based systems, short rotation intensive systems have the potential to sequester substantial quantities of carbon in a short time, which can reach up to 14 Mg ha^{-1} yr^{-1} and can be taken up in degraded lands which are not suitable for intensive cropping (Prasad et al., 2012). This can in turn minimise erosion and carbon loss (Table 10).

4.3 | Integrated farming systems for adaptation and mitigation

Integrated farming system (IFS) is a holistic system that utilises the resources available at the farm efficiently, diversifies income from multiple sources, distributes income throughout the year, recycles resources and minimises use of external inputs considerably. Animal component of the system contributes to emissions, whereas perennials act as sinks (Meera et al., 2019). The net mitigation depends on the nature of sources and sinks on the farm and their quantity (Reddy et al., 2020). In humid regions of Kerala, the IFS comprising of coconut, agroforestry and livestock is a sink with 228 kg CO_2 ha^{-1} yr^{-1} where an IFS consisting of agroforestry, crops, livestock and pasture is a source with emissions of 877 kg CO_2 ha^{-1} yr^{-1} (Table 11).

4.4 | Solar lifting devices for energy conservation and improved carbon footprint

Solar water pumps are becoming increasingly popular for lifting water and bringing additional area under irrigation as well as generating

TABLE 7 Restoration of *Jhum* lands in hill ecosystems minimising soil loss (mg ha^{-1} yr^{-1}) and carbon emissions (CO_2 kg ha^{-1} yr^{-1}) and impact on improvement in crop productivity (kg ha^{-1})

Practice	SL	CO_2	CP	Reference
SALT with *Alnus nepalensis* species with maize	6.30 (58)	46.24 (425.72)	2250 (800)	Lamichhane (2013)
SALT with *Indigofera dosua* species with maize	9.00 (58)	66.06 (425.72)	2000 (800)	
HRGFG with finger millet	5.04 (9.71)	36.99 (71.27)	1413 (952)	Lenka et al. (2012)
HRGFI with finger millet	6.33 (9.71)	46.46 (71.27)	1367 (952)	
Bamboo (*Bambusa vulgaris*) fence across the slope	8.92 (50.74)	65.47 (372.43)	1069 (737)	Ray et al. (2018)
Gliricidia + drumstick + ginger + pigeonpea (8:2)	3.45 (11.84)	25.32 (86.90)	Ginger-11,300 (fallow)	Jakhar et al., 2017
CH with *Crotalaria tetragona*	29.75 (38.14)	218.36 (279.95)	—	Saha et al. (2012)
Agriculture (hedge row–based system) agro-forestry system	1.97 (35.27)	14.46 (258.88)	—	Rathore et al. (2010)
AS (alder-based) agro-forestry system	8.91 (35.27)	65.40 (258.88)	—	
AH (guava-based) agro-forestry system	12.49 (35.27)	91.67 (258.88)	—	

Note: Values in parenthesis indicates the control (No practice). Carbon loss is arrived by taking the carbon content of eroded soil as 1% (Lal, 2004) and the extent of C oxidation from eroded carbon is 20% (Lal, 1995); *Alnus* = alder

Abbreviations: AS, agrisilviculture; AH, agrihorticulture; CH, contour Hedgerow; CP, crop productivity improvement; HRGFG, hedge row + grass filter species (*Gliricidia sepium* + *Saccharum officinarum*); HRGFI, hedge row + grass filter species (*Indigofera teysmanni* + *Saccharum officinarum* spp); SALT, sloping agricultural land technology; SL, soil loss

TABLE 8 Impact of soil and water conservation measures on minimising soil loss (Mg ha^{-1} yr^{-1}) and carbon emissions (CO_2 kg ha^{-1} yr^{-1}) in coastal and island ecosystems

Practice	L	SL	CO_2	References
Double cropping (rice-pulses/vegetables)	South Andaman Islands	86.0 (105.3)	631.4 (773.5)	Nanda et al. (2019)
No till + maize	Port Blair	4.3 (15.8)	31.7 (115.9)	ICAR-CIARI, Annual report (2004)–05
CCT + *Stylosanthes* + *Glyricidia* in cashew	Goa	1.4 (6.7)	10.3 (49.2)	Manivannan & Desai (2007)
CCT in cashew	Central Coastal Agricultural Research Institute, Goa, India	12.3 (23.6)	90.3 (173.2)	Mahajan et al. (2021)
SCT in cashew		15.1 (23.6)	110.8 (173.2)	

Note: Values in parenthesis indicates the control (no practice). Carbon loss is arrived by taking the carbon content of eroded soil as 1% (Lal, 2004) and the extent of C oxidation from eroded carbon is 20% (Lal, 1995)
Abbreviations: CCT, continuous contour trench; L, location; SCT, staggered contour trench; SL, soil loss

TABLE 9 Efficient rice systems reducing GHGs (CO_2 equivalent kg ha^{-1} yr^{-1}) and their effect on crop productivity (kg ha^{-1})

Practice	Location	Soils	GHGs	CP	References
MSRI cultivation	IARI, New Delhi	Alluvial soil	169.2 (242.2)	5750 (5880)	Jain et al. (2014)
DSR on raised beds	Jalandhar, Punjab	Alluvial soil	1200.0 (1300.0)	5400 (6050)	Pathak et al. (2013)
SRI	IARI, New Delhi	Alluvial soil	135.9 (220.2)	1180 (4530)	Suryavanshi et al. (2013)
LCC-based urea application in rice-wheat cropping system	IARI, New Delhi	Alluvial soil	3380.0 (3734.0)	5600 (4900)	Bhatia et al. (2012)
DDSR on raised beds	Modipuram, Uttar Pradesh	Silty loam	695.1 (1203.0)	4900 (7300)	Pathak et al. (2011)
TR on raised beds	Haryana	Sandy loam to clay loam	827.8 (1200.8)	—	
WDS + neem coated urea in rice	Modipuram, Uttar Pradesh	Silty loam	256.1 (356.3)	4406 (4839)	Annual Report IIFSR (2017)–18

Note: Values in parenthesis indicates the control (no practice); neem = *Azadirachta indica*
Abbreviations: CP, crop productivity; DDSR, direct drill seeded of rice; DSR, direct seeded rice; GHGs, greenhouse gases; LCC, leaf colour chart; MSRI, modified system of rice intensification; SRI, system of rice intensification; TR, transplanted rice; WDS, wet direct seeding

additional income for farmers by selling surplus power to distribution companies (Majdali, 2019). Governments are also promoting solar power as a climate change mitigation strategy as it contributes towards decentralised power generation and helps in subsidy reduction for agriculture sector (NAPCC, 2018). A solar pump can minimise emissions to the extent of 0.891 Mg CO_2 ha^{-1} yr^{-1} (MoEFCC., 2021). It is generally used for providing irrigation water replacing an electric pump. The Government of India is promoting use of solar pumps on a massive scale in regions where the watertable is shallow. The National Solar Mission (NSM), launched on 11th January, 2010, had set a target for deployment of 100 Giga Watts of solar power by the year 2022. About 0.237 million solar pumps have been installed out of which 65,892 solar pumps were installed during 2018–2019 alone in the states of Andhra Pradesh, Chhattisgarh and Rajasthan (Table 12).

5 | VILLAGE INSTITUTIONS FOR ENHANCING ADOPTION OF TECHNOLOGIES

Institutions established at the village level, such as the village climate risk management committees, custom hiring centres, Salaha Samithi (An advisory committe constituted to make important decisions at local level for the implementation and adoption of various agricultural technologies) self-help groups, commodity groups and watershed user's association, help mobilise farmers' opinion about the performance of introduced technologies and provide a platform to discuss various aspects of the introduced technologies (NAIP, 2012; Srinivasarao, Gopinath, et al., 2016). Making carbon-positive villages requires adoption and scaling up of proven land and water conservation technologies on a large scale which requires participation of village institutions (Chary et al., 2019). Village institutions can guide the implementing agency/organisation about the local resources and preferences of people while choosing technological options. As the proven land and water technologies are to be scaled-up in the entire village, comprising of private holdings and community areas, the role of community structures is key for the establishment of structures in the community land, protection of assets created, their maintenance in the long run and their sustainable use. Village institutions help in identification of appropriate trees for development of agroforestry, pasture lands for minimising erosion and can play a key role for their survival and taking up of regulated grazing and protection of structures in long run.

Custom hiring centres (CHC) are a new concept, which involves purchase of costly farm equipment and making them available for use by farmers on rental basis (Srinivasarao, Dixit, et al., 2013). The CHC is centrally located in the village, generally managed by a committee,

TABLE 10 Agroforestry system for enhancing carbon sequestration potential (Mg of CO_2 ha^{-1} yr^{-1})

Practice	Location	Tree species	CSP	References
Silvipasture	Karnal, Haryana	*Prosopis juliflora*	8.64	Kaur et al. (2002)
Silvipasture	Dehradun, Uttarakhand	*Leucaena leucocephala*	13.17	Narain et al. (1997)
Agrisilviculture	Chhattisgarh, Raipur	*Gmelina arborea*	10.83	Swamy & Puri (2005)
Agrisilviculture	Jhansi, Uttar Pradesh	*Albizia procera*	13.54	Ramnewaj & Yadav (2006)
Agrisilviculture	SBS Nagar, Punjab	*Populus deltoides*	34.40	Chauhan et al. (2010)
Agrisilviculture	Khammam, Telangana	*Leucaena leucocephala*	52.77	Prasad et al. (2012)
Agrihorticulture	Himachal Pradesh	Fruit trees	44.47	Goswami et al. (2014)
Boundary plantation	Saharanpur, UP	*Populus deltoides*	16.69	Rizvi et al. (2011)
Block plantation/wood lots	Khammam, Telangana	*Leucaena leucocephala*	50.14	Prasad et al. (2012)

Abbreviation: CSP, carbon sequestration potential

TABLE 11 Integrated farming systems (IFS) for sustainable land and water management

Component	Location	Emissions	Sequestration of GHGs	Net GHG emission	References
		CO_2 equivalent kg ha^{-1} yr^{-1}			
A-IFS	Coimbatore, Tamil Nadu	4561	3684	877	Bama et al. (2020)
H-IFS	Karamana, Kerala	3414	3642	−228	Meera et al. (2019)
C-IFS	Karamana, Kerala	1979	995	984	
R-IFS	Karamana, Kerala	2392	1593	799	
B-IFS	Karamana, Kerala	1646	3087	1441	

Abbreviations: A-IFS, agroforestry based IFS model (crops + livestock + horticulture + pasture + agroforestry); B-IFS, banana-based IFS model (crops+ horticultural+ agroforestry+ livestock+ pasture); C-IFS, coconut-based IFS model (coconut+ horticultural+ spices+ agroforestry+ pasture+ livestock+ fish); H-IFS, homestead-based IFS model (coconut+ horticultural+ agroforestry +livestock+ fish); R-IFS, rice-based IFS model (crops + livestock + fish)

TABLE 12 Solar water lifting devices for energy conservation and emission reductions (t CO_2 ha^{-1} yr^{-1})

Practice	Location	Objective	Emission reduction	References
Off-grid solar photovoltaics–solar pumps for lifting water for irrigation	PAN India	Reducing electricity consumption and minimising electric load on the power grid	0.85 (Replacing 5HP electric pump)	MoEFCC. (2021)
Solar-powered irrigation pumps	Bihar and Gujarat	Timely irrigation in regions with irregular power supply		
Solar water pumps for salt farmers of Kutch, Gujarat, India	The Little Rann of Kutch, Gujarat	For pumping water in regions with undependable power supply		

Abbreviations: HP, horse power; PAN, presence across Nation (India)

which determines the hiring rates, while the rentals collected are used for equipment maintenance (Srinivas et al., 2017). The central and provincial governments in India are supporting the concept of CHCs, and it is being scaled up. Large-scale adoption of farm equipment (broad bed and furrow maker, ridge and furrow planter, raised bed planter, etc.) which are essential for in-situ land and water conservation, can minimise soil and carbon loss and contribute towards carbon-positive villages (Srinivasarao, Gopinath, et al., 2016). Institutions such as seed bank and fodder bank providing quality seed and green fodder in the villages can potentially help in enhancing the residue turnover of soil thus contributing to soil carbon sequestration and minimising enteric fermentation by way of enhanced green fodder availability (Prasad et al., 2015).

6 | CARBON BALANCE WITH RESILIENT MANAGEMENT TECHNOLOGIES-A CASE-STUDY

6.1 | Case-study of a carbon-positive village in India

The village D. Nagenahalli, Tumakuru District in Karnataka of Southern India, is prone to prolonged dry spells and drought. The total area of the village is about 378 ha with 269 households. The average rainfall is about 735 mm, and crops, such as finger millet, pigeonpea, maize, groundnut and rice, are predominantly grown. As part of National Innovations in Climate Resilient Agriculture project, several

TABLE 13 Improved management practices adopted in D. Nagenahalli village of Tumkuru District of Karnataka

Category	Improved practices adopted	Farmers' practice
Improved cultivars in annuals	Rice (MAS-26), finger millet ('ML-365', 'ML-322', 'Indaf-7'), pigeonpea ('BRG-2', 'BRG-4') maize ('NAH-1137'), groundnut ('ICGV-91114', 'GPBD-4')	Adopted local varieties in rice ('Hamsa') and other crops
	In-situ incorporation of green manure with dhaincha (*Sesbania*) before cultivation of crops	Green manuring was not practiced
Water harvesting and its utilisation	Water harvesting by construction of farm ponds, check-dams, farm tanks	Water harvesting was not followed
	In-situ moisture conservation with trench-cum-bunding, conservation furrow, mulching, compartmental bunding, land levelling, ridge and furrow, field bunding	In-situ moisture conservation measures were not followed
	Aerobic rice cultivation with intermittent flooding	Rice cultivation with continuous flooding
	Adoption of direct seeded rice cultivation	Traditional transplanting method
Agro-forestry	Adoption of agri-horti systems with *Mangifera indica*, *Tamarindus indica*, *Anacardium*	Agri-horti systems with arecanut (*Areca catechu*) coconut (*Cocos nucifera*) in limited area
	Agri-silvi systems with *Acacia auriculiformis*, *Melia dubia*	Not adopted
Nutrient management	Soil test based fertiliser application	Blanket application
	Tank silt application	Application of tank silt was not followed
	Green leaf manuring from trees	Green leaf manuring was not practiced
	Production and use of bulky organic manures in the village such as farm yard manure, vermicompost	Usage of organic manures is markedly less
	Shredding of crop residues in the field	Crop residues are used for the local purpose or burnt on field
Livestock interventions	Adoption of high yielding multicut fodder sorghum variety (CoFS-29), Napier grass (*Pennisetum* sps. Variety CO-3) and Guinea grass (*Panicum maximum*)	Cultivation of green fodders was taken up in limited area
	Improved feeding practices with more concentrates, mineral mixtures, rice bran, green fodder, etc.	Grazing fallow lands and rice straw feeding
	Improved breeding practices (artificial insemination, etc.)	No specific practice

technologies suitable to the prevalent crop and animal production systems were demonstrated in the village since 2010 so as to enhance awareness among the farming community. Due to the demonstrations, several technologies were adopted by farmers in the village. The traditional practices and the improved practices adopted by farmers in the village are furnished in Table 13. GHG emissions due to the adoption of improved practices from annuals, perennials, fields with input use (fertilisers), changes in land uses, afforestation/deforestation and livestock were calculated using the eX-ante appraisal carbon-balance tool (Ex-ACT) (http://www.fao.org/tc/exact/ex-act-home/en/). Some of the technologies, which were adopted in significant scale in the village, are construction of low cost check-dams for harvesting water for providing critical irrigation, in-situ moisture conservation practices, soil test–based nutrient application, rationalising nitrogen application, adoption of horticulture systems such as *Mangifera indica*, *Tamarindus indica*, agri silviculture with *Grevellia robusta*, *Acacia*, etc. (Table 13). Due to the adoption of these practices, the GHG emissions were to the tune of 620.3 Mg CO_2 equivalents yr^{-1}, whereas the extent of sinks was 799.8 Mg CO_2 equivalents yr^{-1}. This indicates enhancement of sinks in the village making the village a net sink (179.5 Mg CO_2 equivalents yr^{-1}), and the village has become carbon-positive (Figure 3).

About nine villages were identified so far where the extent of sinks is higher than the sources due to the adoption of the various improved practices (Figure 4). Action plan for making village carbon-positive should identify technologies, which can enhance productivity, contribute to climate resilience and also mitigation of GHG emissions for each of the prevalent cropping and farming systems. These technologies are to be made familiar to the farming community by way of various methods of transfer of technology. The management practices to be adopted for achieving carbon positive village will be varying as crops grown in a region are dependent on rainfall, soils, prevalent animal systems, the food habits of communities and market opportunities (Reddy et al., 2018). Such action plan should involve farming community, development departments, research institutes and other institutes operating in the village (Srinivasarao, Prasad, et al., 2016; Srinivasarao, Rani, et al., 2016). Establishment of suitable support systems by way of facilitating the supply of inputs, machinery, access to water, production technology, marketing, etc. is critical for enhancing the adoption of technologies by large number of farmers. This will

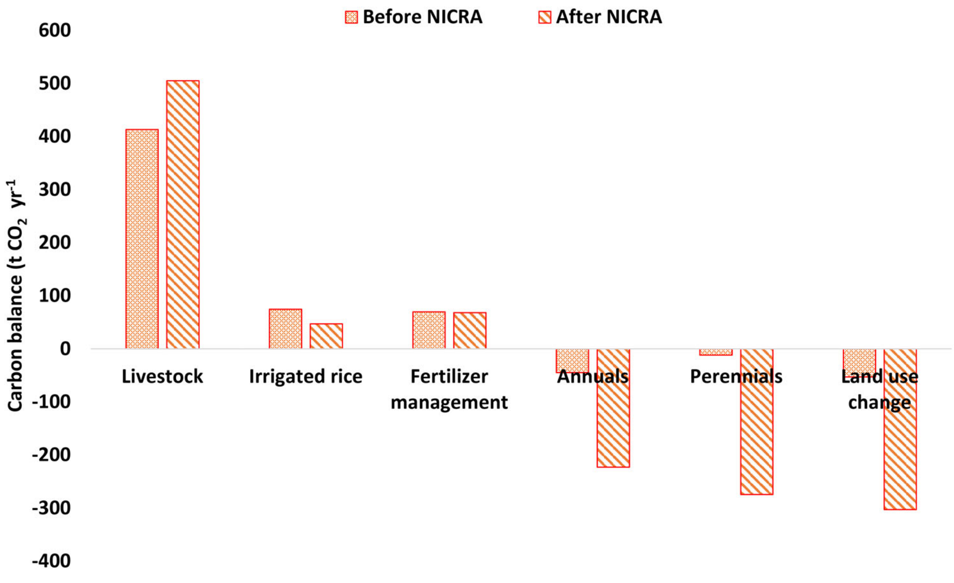

FIGURE 3 Sources and sinks due to various interventions in D. Nagenahalli village of Tumkuru District, Karnataka, India [Colour figure can be viewed at wileyonlinelibrary.com]

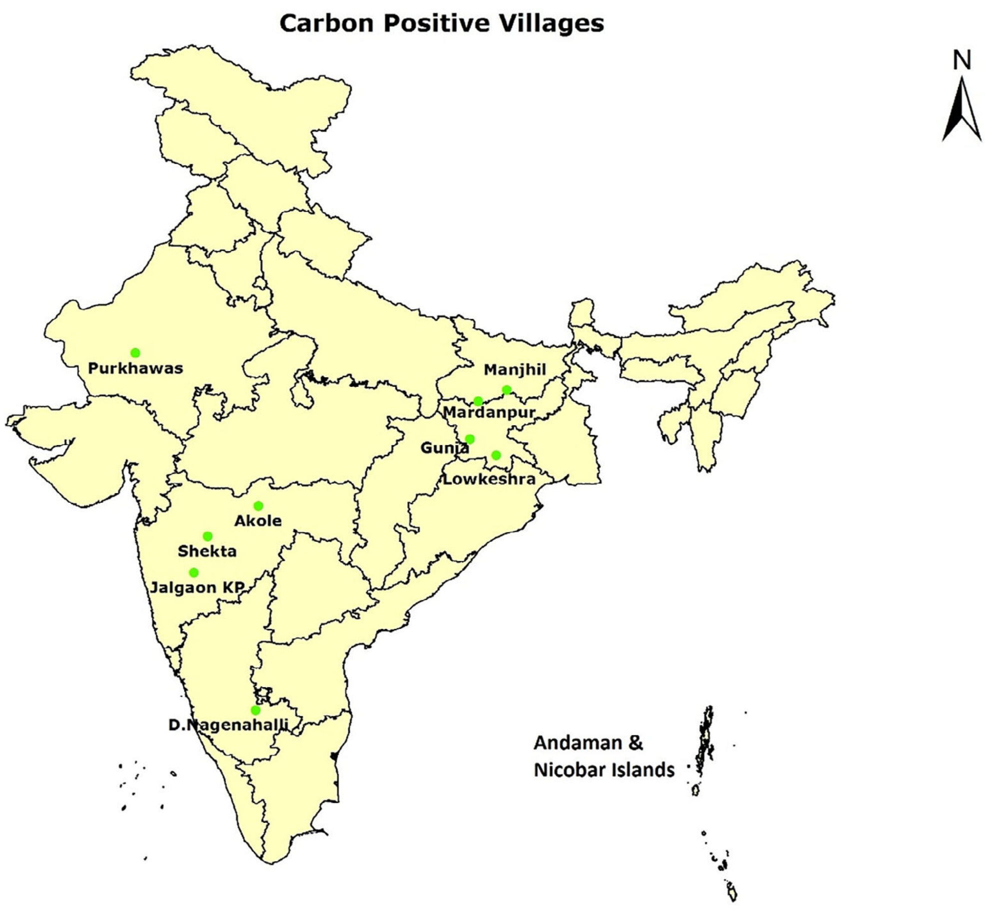

FIGURE 4 Map of carbon-positive villages as reported by McDonough, 2016; Srinivasarao, Prasad, et al. (2016); Srinivasarao et al. (2017); Reddy et al. (2020) and Mathur & Awasthi (2016) [Colour figure can be viewed at wileyonlinelibrary.com]

help to minimise emissions and enhance sinks in the village (Srinivasarao, Prasad, et al., 2016).

Adoption of climate smart/resilient technologies enhanced sinks, and the extent of mitigation achieved ranged from 4848 to 25,166 Mg CO_2 over a period of 20 years for a village with an average area of 500 ha, and the reduction in emissions ranged from 0.72 to 1.15 Mg ha^{-1} CO_2 yr^{-1} in seven drought-prone villages of Maharashtra (Srinivasarao, Veni, et al., 2013). In Bihar, villages prone to frequent droughts and floods witnessed enhancement of sinks ranging from 0.19 to 2.41 Mg ha^{-1} yr^{-1} through technology adoption (Figure 4; Reddy et al., 2020). Technologies such as conversion of land to perennials, in-situ moisture conservation, residue incorporation, green manuring, soil test–based nutrient application and improved water management practices in rice cultivation contribute towards sinks. Practices such as conversion of land from fallow or perennials to annuals, application of high doses of fertilisers and increase in the number of animals in the village contribute towards GHG emissions (Srinivasarao et al., 2017). The case-study clearly shows adoption of technologies results in enhancement of sinks much more than the sources of GHG emissions in these villages, providing evidences of making villages carbon positive. However, identification of drivers of land degradation and potential land and water conservation technologies is important and essential in making villages carbon positive in the target region (Chotte et al., 2019).

7 | CONCLUSIONS

Our study has clearly indicated the extent of mitigation possible by way of various land and water conservation and other mitigation technologies in various ecosystems. The extent of carbon balance achieved in the villages due to adoption of these practices ranged from 0.05 to 1.23 Mg CO_2 e ha^{-1} yr^{-1} which provides evidence for establishing carbon-positive villages. The extent of mitigation achieved is variable depending on the mitigation technologies adopted and also the extent of adoption of technologies. Some of the technologies are effective in minimising emissions, while some, such as various agro-forestry practices, are effective in enhancing sinks. An enabling environment that can contribute towards the adoption of these technologies not only results in mitigation of GHGs but also contribute towards productivity enhancement, resource use efficiency and meeting the SDGs. Guidance on identification of appropriate soil and water conservation measures in a region depending on resource endowments of farmer will be most helpful in enhancing adoption of these practices.

8 | WAY FORWARD

Capacity building of village communities, systematic implementation, monitoring and accurate quantification of mitigation achieved are pivotal for assessing the benefits realised from technologies. Information about impact of several technologies particularly related to loss and gain in carbon is limited and requires focussed efforts. For a developing country like India, where much of the population resides in villages, making villages carbon positive is a feasible option to meet the challenges of climate change, land degradation, attaining the SDGs, enhancing resource efficiency and productivity. Our article describes the technological options, which cover varied aspects of agriculture for transforming villages into carbon positive along with requisite evidences. The technological options need to be prioritised depending on the stakeholders involved in each location. Appropriate policy and institutional support are needed for increasing the ambit of these practices across diverse agro-ecosystems.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

This review article is based on already published article and the data is already available in the literature

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