

Soil and water conservation practices for achieving land degradation neutrality

M. Madhu* and Dinesh Jinger

ICAR-Indian Institute of Soil and Water Conservation, Dehradun, Uttarakhand 248 195

In India, 120.7 Mha of land is degraded, mainly by water and wind erosion and vegetation loss, reducing soil carbon, fertility, and productivity—the key indicators of Land Degradation Neutrality (LDN). Controlling erosion is essential for sustainability and LDN. Agronomic practices such as conservation tillage, cover crops, mulching, broad-bed furrow, ridge and furrow, bench terracing, vegetative barriers, and agroforestry restore soil health and enhance productivity. Geotextiles further protect slopes and riverbanks in high-rainfall regions. Agroforestry also improves fertility through nitrogen fixation, carbon sequestration, and efficient water use. Integrated adoption of these measures is crucial for soil conservation, food security, and achieving LDN.

Keywords: Agroforestry, Cover crops, Conservation agriculture, Residue retention, Soil erosion

UNREGULATED exploitation of natural resources to meet the demands of a growing population, combined with climate change, has intensified land degradation in India. About 120.7 Mha, nearly 36.6% of the country's area, is degraded, with 73.2 Mha affected by water erosion and 12.4 Mha by wind erosion. These processes reduce soil fertility and productivity, causing annual nutrient losses of 5.37–8.40 Mt, deplete about 115 Mt of soil organic carbon, and increase the risks of floods, landslides, and desertification. Globally, soil erosion is recognized as a major threat to food security and ecosystem services. The United Nations Convention to Combat Desertification (UNCCD) defines LDN as a state where land resources remain stable or improve to sustain productivity and ecosystem functions. Monitoring relies on Sustainable Developmental Goal (SDG) indicator 15.3, which includes land cover, productivity, and soil organic carbon. Since erosion directly reduces carbon stocks, it is also recommended as a complementary LDN indicator. In India's agrarian economy, erosion control is critical for food security and resilience to climate change. Agronomic measures such as contour farming, conservation tillage, cover crops, mulching, vegetative barriers, intercropping, agroforestry, and innovative land configurations restore soil functions and support climate-smart agriculture. Strengthening adoption of these low-cost practices offers a sustainable pathway to rehabilitate degraded lands and achieve LDN.

Agronomic soil and water conservation practices

Conservation tillage: Conservation tillage, combined with practices such as soil cover and crop diversity, has emerged as a sustainable option for long-term food production. Conservation tillage practices include zero tillage (ZT), reduced or minimum tillage, mulch tillage, and ridge tillage. These approaches help reduce soil disturbance, limit crop residue loss, moderate soil evaporation, and minimize erosion, while also improving water use efficiency (WUE) compared to conventional tillage. ZT and reduced-till systems are particularly effective in humid and sub-humid regions. In dryland areas, however, tillage plays an important role in conserving soil moisture.

Broad bed furrow: The use of broad bed furrow (BBF) offers multiple benefits in rainfed farming. Raised beds act as an effective drainage tool, reducing waterlogging while enhancing crop yields. BBF conserves soil moisture, improves infiltration, and minimizes runoff and erosion. It provides drainage during heavy rains and retains moisture during dry spells, thereby reducing the impact of extreme weather and supporting higher productivity. The system typically consists of a raised flatbed about 95 cm wide and a shallow furrow around 55 cm wide and 15 cm deep, laid across the slope. Planting soybeans on BBF has shown a 21% increase in yield compared to flatbed planting, with higher net returns.

Ridges and furrows: The formation of ridges and furrows is highly effective for conserving soil moisture and reducing runoff and soil loss, especially in light



Broad-bed and furrow



Ridge and furrow

soils. In medium to deep black soils, furrows are opened 50–60 cm apart across the slope after primary tillage, usually during late June to July. Cultivating crops under the ridge-and-furrow system across the main land slope, with a gradient of 0.2–0.4% on fields having a 1–3% slope, helps conserve more rainwater *in situ*. In vertisols, the ridge-and-furrow method conserved significantly more rainwater and improved crop performance, resulting in 26% higher winter sorghum grain yield and 25% greater WUE compared to flat sowing.

Contour cultivation: Contour cultivation involves carrying out field operations, including sowing, along the contour or across the slope. This creates small barriers that slow down rainwater, reduce runoff, and minimize soil loss. By increasing surface roughness, it promotes ponding in furrows, enhances infiltration, and lowers erosion. Studies have shown that contour farming can reduce annual runoff by about 10%, soil loss by nearly 50%, and water loss by 32%. It also helps retain nutrients like nitrogen and phosphorus more effectively than up- and downslope tillage.

Conservation furrow system: The conservation furrow is a low-cost, *in situ* practice designed for conserving rainwater and soil in rainfed regions with

400–900 mm rainfall and moderate slopes of 1–4%. It is particularly useful in alfisols and similar soils that face crusting and early runoff problems. In this method, furrows are opened 3–5 m apart along the contour or across the slope, either at planting or during intercultural operations using a country plough. These furrows capture runoff water and enhance soil moisture in nearby crop rows, especially during dry spells. Adoption of this system has been shown to improve crop yields by 10–25%.

Compartmental bunding: Compartmental bunding involves dividing fields into small square or rectangular sections to impound rainwater. It is commonly practiced in medium and black soils to store monsoon water in the soil profile for use by *rabi* crops. By allowing more time for rainwater to infiltrate, it wets the soil profile thoroughly, enabling timely sowing of winter crops and improving yields. The recommended compartment size depends on land slope: 6 m × 6 m for up to 1% slope, 4.5 m × 4.5 m for 1–2% slope, and 3 m × 3 m for slopes around 2%. This practice has been shown to increase sorghum yields by 17% and WUE by 13%, over flat sowing.

Cover crops: Cover crops are grown to protect soil



Conservation furrow



Compartmental bunding



Cover crop



Residue retention/mulching

from erosion and nutrient losses through leaching and runoff. They provide soil cover during fallow periods, reducing erosion and suppressing weeds. Leguminous cover crops also fix atmospheric nitrogen, enhancing nutrient cycling and soil fertility. By intercepting rainfall and slowing runoff, cover crops reduce sediment loss and improve soil biological, chemical, and physical properties, including organic carbon content, cation exchange capacity, aggregate stability, and water infiltration.

Residue management/mulching: Residue management or mulching is an essential practice in modern soil and water conservation. It improves water infiltration, retains organic matter, reduces erosion, and helps maintain soil moisture under variable climatic conditions. Applying crop residues such as straw in soybean and wheat systems can increase WUE by 17–23%, while maize–wheat systems under conservation agriculture (permanent beds with crop residue or ZT with residue) can boost water productivity by 30–45% in maize and 16–19% in wheat.

Crop diversification: Crop diversification is a key agronomic strategy for optimizing natural resource use and sustaining agro-ecosystem services. Diversifying crops enhance the resilience of farming systems and ensures better ground cover throughout the year. For example, replacing upland paddy with soybean or

groundnut in hilly areas can reduce sediment yield by around 28–30%. Similarly, diversifying continuous wheat with wheat-pea, wheat-barley-pea, or wheat-barley-maize-pea rotations can increase WUE by 8–15%. Rotating wheat with field pea or other low-water-demand, early-maturing crops further improves yield and WUE.

Mechanical soil and water conservation practices

Contour and graded bunding: Field bunding across slopes helps retain runoff, enhance infiltration, and conserve soil moisture. Contour bunds are constructed along contour lines on slopes of 2–6% with annual rainfall below 600 mm. They typically have a height of 50 cm, a cross-sectional area of 1.61 m², and a vertical interval of 0.9 m, with horizontal spacing of 50–70 m, while excess runoff is drained through waste weirs. Graded bunds, on the other hand, have a longitudinal slope of 0.2–0.4%, a vertical interval of 0.75 m, and a cross-sectional area of 0.83 m², spaced 60–70 m apart, making them suitable for black soils prone to waterlogging. In semi-arid regions, field bunding has been shown to increase crop yields by over 14% and WUE by about 10% due to improved soil moisture.

Bench terracing: Bench terracing is a common soil conservation practice in hilly areas with steep slopes. It transforms steep land into a series of level



Contour bunding



Graded bunding



Bench terracing

strips supported by risers, reducing slope length and conserving soil and moisture, thereby improving crop productivity. It is generally recommended for slopes of 16–33%, but has been used on slopes up to 50% in regions like the Nilgiris and Himalayas. Bench terraces are classified by terrain and cropping needs: Levelled (table-top) terraces suit medium rainfall and deep, permeable soils, while inward-sloping terraces are ideal for high-rainfall areas and water-sensitive crops like vegetables.

Conservation bench terracing: Conservation bench terracing is practiced in low- to medium-rainfall areas of vertisols with contour or graded bunds. In this system, about 30% of the upstream area near the bund is leveled by cutting around 15 cm of soil and depositing it near the bund, creating flat land for assured crop production even in drought years. The lower one-third of the inter-banded area is also leveled to spread runoff water over a larger surface. Typically, water-demanding crops are grown in the leveled receiving area, while drought-tolerant crops are sown in the unlevelled donor area. This ensures reliable harvests in drought years and allows for two crops during normal rainfall years, thereby enhancing both cropping intensity and overall productivity.

Conservation ditching: It is also known as inverted contour bunding, developed by ICAR-IISWC, Research Centre, Ballary, Karnataka especially for black soil. Conservation ditching involves creating trapezoidal ditches along the contour or slope to collect and convey excess runoff safely. These ditches reduce soil erosion, improve water infiltration, and help manage excess water in areas prone to runoff. They are particularly useful for crops grown on sloping lands, where



Contour ditching



Conservation bench terracing

uncontrolled water flow can damage soil structure and reduce fertility.

Contour trenching: Contour trenching is a technique in which small trenches are dug along the contour lines of sloping land to capture and store rainwater. These trenches slow down runoff, promote infiltration, and reduce soil erosion. Trenching can be practiced on slopes not exceeding 20%. Trenches are usually 45 cm with a spacing of 10–30 cm between trenches. The captured water increases soil moisture in adjacent crop areas, making it particularly effective in semi-arid regions or areas with shallow soils. Contour trenches are simple and cost-effective, providing immediate benefits in moisture conservation and soil fertility.

Biological soil and water conservation practices

Vegetative barriers: Vegetative barriers, also known as live bunds, are an effective, low-cost alternative to physical soil conservation structures. They consist of closely spaced rows of grasses or shrubs planted along the contour to control erosion, reduce runoff, and enhance soil moisture. These barriers also provide biomass for rural communities and can be combined with small bunds on steeper slopes to improve effectiveness. Vetiver, Guinea, and lemon grass are suited to various soils and agro-ecological regions. For example, planting two rows of grass at one-meter vertical intervals on a 2% slope reduced runoff, soil loss, and increased crop yields in maize-wheat systems.

Agroforestry systems: Agroforestry systems integrate trees with crops to enhance soil fertility, improve microclimates, conserve water, and reduce erosion, making them highly effective in rainfed areas. Trees improve soil structure, increase organic carbon,



Contour trenching



Agri-horticulture system



Silvo-aromatic system

enhance moisture retention, and facilitate nutrient cycling, which helps mitigate drought impacts and improve crop productivity. Hedgerows, such as those with *Gliricidia*, can reduce runoff by 29% and soil loss by up to 48%, stabilizing slopes and improving soil fertility over time. Additionally, agroforestry contributes significantly to carbon sequestration in both biomass and soil, with potential rates ranging from 0.3 to 15 Mg C/ha/yr, helping mitigate climate change while enhancing overall land productivity.

Bio-engineering soil and water conservation practice

In non-arable lands, combining agronomic and engineering measures effectively controls soil erosion, and geotextiles play a significant role in this approach. Geotextiles are woven mats made from natural fibers such as jute, coir, or giant cane, used to stabilize slopes, protect riverbanks, and improve soil moisture retention. When placed at regular intervals along slopes, geotextiles reduce runoff, prevent soil loss, and enhance crop productivity. For instance, using geotextiles in rainfed groundnut and maize systems has been shown to increase yields by 36–64%, improve soil organic matter, and reduce runoff by up to 24%.

Table 1. Impact of different soil and water conservation practices on soil carbon, soil properties, runoff, soil loss, and productivity

SWC practices	Location	Crop/Cropping system	Impact
Minimum tillage	Madhya Pradesh	Soybean-Wheat	52% ↓ in soil loss
BBF	Andhra Pradesh	Black gram	Yield ↑ by 12.8%
Ridges and furrows	Tamil Nadu	Potato	30% ↓ in soil loss and 8% ↑ in potato equivalent yield
Contour farming	Telangana	Green gram	Yield ↑ by 45% over up and down cultivation
Compartmental bunding	Uttar Pradesh	Sorghum	Conserved soil moisture by 14.0–30% over farmer's practice
Cover crops	Gujarat	Clusterbean	Soil loss reduced by 73% over fallow.

Residue retention/mulching	Gujarat	Cowpea + castor intercropping	Reduced runoff by 59.6% respectively over farmer practice.
Contour bunding	Rajasthan	Mustard	Economic and biological yield ↑ by 14.4% and 15.3% over no bunding
Bench terracing	Gujarat	Sapota and cowpea	↓ runoff by 34% ↓ soil loss by 25%
Conservation bench terraces	Uttarakhand	Rice, maize, cowpea	↓ runoff by 80% ↓ soil loss by 88%
Contour trenching	Rajasthan	Aonla + Anjan grass + bamboo	↓ runoff by 86% ↓ soil loss by 125%
Vegetative barrier	Gujarat	Pigeon pea	↓ runoff by 20% ↓ soil loss by 51%
Silvo-aromatic system	Gujarat	Lemon grass + <i>Meliadubia</i>	↑ total CO ₂ -sequestration by 255 % over sole Melia.
Geotextiles	West Bengal	Groundnut	Crop yield and SOC ↑ by 64.2% and 53%, respectively.

SUMMARY

Land degradation affects 120.7 Mha in India, mainly from water and wind erosion, leading to vegetation loss, and soil fertility decline. Controlling erosion is vital for achieving LDN and sustaining productivity. Agronomic measures (e.g. conservation tillage, broad-bed furrow, ridges and furrows, contour farming, cover crops, mulching, diversification) improve infiltration, conserve moisture, and enrich soils. Mechanical interventions (basin listing, subsoiling, bunding, terracing, ditching, trenching) reduce runoff and stabilize slopes. Biological measures (vegetative barriers, agroforestry) curb erosion, recycle nutrients, and sequester carbon. Bio-engineering solutions like geotextiles reinforce slopes, protect riverbanks, and enhance yields in erosion-prone areas. Integrated adoption of these practices ensures sustainable land management, strengthens food security, and advances India's LDN goals.

*Corresponding author email: madhupmd@gmail.com