Review Article

Soil restoration strategies for sustaining soil productivity: A review

ABSTRACT

Soil degradation, characterised by a deterioration in quality and a drop in ecosystem products and services, is a key impediment to obtaining the necessary increase in agricultural productivity. Soil is a living and dynamic organism that degrades when standard agricultural practices are used. Healthy soil is a crucial pillar of sustainability because it provides various ecosystem services in addition to controlling microbial activity, nutrient recovery, and decomposition. In human time spans, soil is a non-renewable resource that is vulnerable to deterioration due to complex interactions between processes, variables, and causes occurring at a variety of geographical and temporal dimensions. Accelerated erosion, depletion of the soil organic carbon (SOC) pool and biodiversity loss, loss of soil fertility and elemental imbalance, acidification and salinization are among the key soil degradation processes. The strategy aims to minimize soil erosion, boost SOC and N budgets, boost soil biota activity and species diversity (macro, meso, and micro), and improve structural stability and pore geometry. Improving soil quality (i.e., expanding the SOC pool, improving soil structure, and boosting soil fertility) can lower the hazards of soil degradation (physical, chemical, biological, and ecological) while also benefiting the environment.

Keywords: - carbon pool, degradation, ecological benefits, soil health, soil quality, soil resilience and sustainable agriculture.

INTRODUCTION

Erosion and soil pollution are only a few of the many ways that soil can degrade, and under severe circumstances, it can even become completely unproductive. Salinization, erosion, nutrient depletion due to intensive agricultural methods, and contamination with toxic metal ions are the primary factors that cause soil quality to deteriorate. Every country in the world faces the formidable challenge of maintaining food security to meet the needs of an ever-increasing population and soil degradation is adversely connected with food security due to the loss of arable land. According to population census data, the global population will rise from 7.6 billion in 2018 to 8.3 billion in 2030 and 9.2 billion in 2050 [97]. We must restore damaged soil and halt the ongoing deterioration of productive soils in order to feed this growing population. According to some recent estimates, the agricultural lands are 8% improved, 25% severely degraded, and 44% mildly to moderately affected [26]. According to the local conditions, there are numerous techniques for the regeneration of impacted soils. It includes erosion control through vegetation management and soil structure improvement. Salt-affected soils require chemical amendments as well as high-quality irrigation water and a comprehensive drainage system [65]. Proper fertilizer and crop management are required to maintain soil fertility, while heavy metal effects can be mitigated through in situ immobilization using immobilizing agents and phytoremediation. For all countries, especially those at risk for food deficincy, restoring the soil quality for crop production through suitable soil management and conservation approaches is crucial. In order to preserve soil properties and prevent soil degradation, soil organic matter (SOM) is essential. Bacteria come in a wide variety of species, each with a unique function in the soil environment. Several species nonetheless produce and secrete plant growth hormones that promote the growth of roots.

Soil Indicators

Soil indicators are required for both the design and monitoring phases of restoration planning. For these two reasons, however, separate information is required. Information about soil (and site) characteristics that may affect the likelihood that the intervention will be successful is primarily needed during the design phase. The indicators' input features can be both intrinsic characteristics such as topographic slope angle and aspect, surface rockiness, soil depth, texture, stoniness, structure, existence of subsoil pans, and subsoil moisture conditions, or more dynamic attributes such as acidity and salinity [62]. By identifying "optimal" ranges of values for these variables that increase the likelihood that restoration will be successful and/or reduce risks and costs, land suitability schemes can be used to support planning. There are various methods for creating indicators, from straightforward categorical or parametric schemes to more intricate methods that incorporate multicriteria analysis and decision support frameworks.

Depending on the time and space scales, several types of soil data are required to monitor and evaluate restoration. Yet, it is crucial that indicators concentrate on "slow variables" due to the significant geographical and temporal variability of ecosystems, particularly in drylands. So that short-term variations in land and socioeconomic conditions do not cloud the assessment of long-term changes and the sustainability of land management [109]. Slow indicators, such as better structure and porosity as well as increased topsoil depth and water-holding capacity, can more immediately represent impacts on fundamental soil attributes.

RESTORATION OF ERODED AGRICULTURAL LAND

When there isn't much vegetation on the earth's surface, soil erosion begins. Various agroforestry models have been developed and evaluated for water-eroded lands in the northwestern and northeastern Himalayan regions [40, 43]. Although water erosion can sometimes significantly degrade an area, wind erosion is the predominant agent. Many agronomic and biological strategies are used to restore degraded agricultural land; some of them are discussed below, and some other management practices (Fig. 1) can also be employed so as to conserve soil losses.

a) **Crop management:** Effective crop management techniques prevent wind and water erosion. The essential rule for restoring degraded agricultural land is to keep the soil covered [77]. Another useful strategy is to prevent soil from erosion by leaving crop remains on the soil surface after harvest.

b) **Intercropping:** The impact of rains is decreased early in the season by the soil cover provided by fast-growing legumes such as cowpeas and beans before cotton or maize develops a canopy to shelter the soil [10, 67]

c) **Crop selection:** If there is too much time between the harvest of one crop and the sowing of the following crop, then additional cover crops may be necessary. Cover crops boost the stability of the conservation agriculture system, improved soil qualities reduce the effects of erosion, and biodiversity in the agro-ecosystem is encouraged for its potential.

d) **Crop rotation:** It is the process of growing a variety of crops in the same area over the course of several seasons. This has the advantage of preventing the pathogen and pest build-up that results from continuously cultivating one species of crop [14, 31].

e) **Cover cropping:** Cover crops are "close-growing crops that provide seeding protection, soil protection, and soil improvement between ordinary crop production seasons as well as between trees in orchards and in vineyards." They are sometimes referred to as green manure crops. [79, 29]

f) **Shelterbelts:** They are employed to safeguard both irrigated and rainfed agriculture. They currently serve primarily the purpose of guarding irrigation channels and priceless agricultural land against sands that are sneaking in. Shelterbelts lower wind speed, enhance the microclimate, and boost animal output.

g) **Strip cropping:** The process of producing crops in alternate strips of row crops or forage/grass is referred to as strip cropping. This farming strategy is an efficient way to reduce soil erosion [53]. Strips of hay, pasture, or legume forages are also widely employed in rotation with row crop crops.

h) **Employ suitable tillage practices**: The main goals of tillage are to achieve optimal soil physical conditions for greater crop yield. It also guarantees that seedbeds are prepared, planted, and weeds are eradicated on schedule. Tillage procedures should be used with the understanding that the soil is neither too fine nor too crumbly, and that it breaks up the hardpan if necessary.

i) **Mulching**: Spreading or placing plant materials such as straw, banana leaves, dry leaves, sugar cane trash, dried grass and other agricultural wastes on the bare soil surface can help reduce soil erosion and conserve moisture.

j) **Agroforestry:** It is the practice of planting trees or shrubs or preserving naturally occurring trees. Trees reduce the amount of splash erosion by minimizing the effect of raindrops on the soil. They stabilize soil temperature by covering it and lowering water evaporation. They also operate as wind breaks, reducing wind erosion. They also play a vital role in deep soil nutrient recycling; leguminous trees fix nitrogen, which aids food crops.

k) **Contour farming**: It is the practise of cultivating across a hill instead of up and down. Contour farming on mild slopes has been shown to prevent soil loss by up to 50%. Water collection is the primary goal of contour ridges. Plant wastes are laid out in lines following the contour to build rubbish lines.

l) **Physical soil protection measures**: Physical structures in agricultural land restoration are permanent elements composed of earth and stones that are meant to protect the soil from unregulated flow and erosion while also retaining water when needed.

[Fig. 1 Restoration of eroded soils with different management practices]

Soil Fertility Restoration:

Soil fertility can be restored through sustainable land management practices such as climate change mitigation through the cultivation of bioenergy crops, animal protein production through intensive rotational grazing, and biodiversity restoration through the transformation of degraded croplands into conservation plantings. Degraded soils come in a variety of well-known types, including sandy soils in dry regions, waterlogged soils, contaminated soils, mined soils, and soils damaged by salt. The following methods can be used to restore the fertility of soils:

1. **Balanced Use of Fertiliser**: Fertilizer equilibrium is essential for sustaining soil production and nutrient utilization efficiency. It is not only intended for the delivery of a specific amount of nutrients such as nitrogen, phosphorous, and potassium to soil in the form of fertiliser but also for the application of fertilizer in a balanced amount. Balanced fertiliser distribution also improves fertiliser usage efficiency, which leads to increased crop production by improving the physical, biological, and chemical properties of the soil. It is also essential to make certain that the plants are resistant to cold, pests, insects, diseases, and drought. Imbalanced fertilizers promote diseases of the soil and waste of resources, whereas balanced fertilisers enhance soil health [28].
2. **4 R’s Approaches**: The 4Rs (right source, right quantity, right application time, and right site) strategy can be used to regulate soil fertility. First, choose the best fertiliser source for managing soil fertility status. The source of fertiliser is determined by assessing which critical nutrient has become deficient in the soil [58]. Soil and plant tissue tests, as well as the nutrient removal rate of harvested crops, provide this sort of information. Second, choose the appropriate fertiliser rate based on the assessment of plant nutrition needs [86]. Examine the relationship between the crop's nutrient intake and yield. Third, choose the appropriate application timing; crop nutrient absorption varies depending on the growth period or season. Certain nutrients are exclusive to crops during various growing seasons. Assess the soil's nutrient supply dynamic as well, because the soil heats over the growing season and the mineralization of organic matter increases, resulting in net nutrient buildup. Fourth, choose the best location for fertiliser application; position the nutrients where the plant can easily absorb them via the roots when needed. Subsurface fertiliser placement covers the soil with crop remains, which can save soil water and nutrients [107].

3. **No Tillage**: Tillage practises often impact soil chemistry, such as pH, exchangeable cations, soil total nitrogen, and cation exchange capacity. No tillage for a longer length of time benefits the improvement and preservation of structural and chemical qualities. Plant residues left in the field or on the soil surface during no-tillage methods can enhance the organic matter in the surface soil [82]. The buildup of organic matter in the top centimetres of soil under no-tillage methods can modify the pH of the soil depending on the type of organic matter.

HEAVY METALS (HMs) IN SOIL PLANT SYSTEM: -

In addition to contaminating the food chain, a high concentration of HMs in the soil has negative impacts on agricultural yield and soil quality, which is a worrying scenario globally. Heavy metal ions disrupt the balance of nutrients in the soil by competing with nutritional components for absorption by plants [88]. Their pollution has long-term persistence, bioaccumulation in plants, and toxicity for biotic life in the soil. Many studies have been done on soil contamination and its prevalence in connection to various sources, and the majority of these studies have linked anthropogenic activities such as careless fertiliser use, untreated industrial wastes, pesticides, traffic, and sewage irrigation to the problem [21, 91].

Strategies of restoring heavy metals: -

Checking HMs activity in soil and their penetration into plant tissues and the food chain are all part of restoring heavy metal-contaminated soil. It includes a variety of techniques, such as changing farming practises to reduce heavy metal inclusion, phytoremediation, ex situ treatment, and in situ stabilization. Exogenous application of microorganisms and organic acids is also beneficial in soil metal pollution reduction because they promote plant development and make the plant more resistant to stress in addition to metal detoxification [45]. Apart from heavy metal-contaminated soils, phytoremediation technology is suited to a variety of reclamation procedures [76]. The advantages of phytoremediation are threefold: phyto-stabilisation (risk reduction), sustainable land management through phyto-extraction of heavy metals, which enhances soil quality, and phyto-extraction of precious metals such as Au, Tl, Ni, and so on.

- **Growing of Hyper-Accumulator Plants**

The initial stage in this practise is to identify certain hyper-accumulators that are suitable for the specific contaminated circumstances because they are often metal-specific. There are several characteristics for selecting them: they must be high biomass-related, fast-growing, toxic-tolerant, and have a good antioxidant system [105]. The higher the biomass of the plants, the higher the extraction ratios of HMs from the soil by the plants; similarly, the plants will be able to withstand the harsh environmental circumstances caused by HMs. Plants also exude root exudates, which increase soil quality and speed up the soil restoration mechanism [76]. These plants also develop phytochelatins to help them survive HM stress [66, 104]. A variety of hyper-accumulator plants for various heavy metals have been described, such as *Helianthus annuus* [19], *Sedum alfredii* [103], *Sorghum bicolor L.* [78], *Solanum nigrum* [76], *Salix babylonica L., Brassica juncea* [11], *Crotalaria juncea* [98], *Thlaspi caerulescens* [59], *Brassicaceae* [57], *Brassica chinensis*, *Salix viminalis L.* [61], *Salix spp.,* etc., which can enhance their ability to extract metals from soil.

- **Strive for Transgenic Plants**

Transgenic plants have been developed for phytoremediation, but more avenues must be opened in this direction. Although hyper-accumulators have a strong capacity to recover soils, many of them have limits, such as limited biomass output. This can be controlled by using genetic engineering to transfer hyperaccumulation genes into higher biomass plants; another option is to transfer overexpression genes from other organisms such as animals, yeast, and bacteria into plants to improve phytoremediation [15]. Transformation from other organisms (e.g., bacteria) and plants, as well as overexpression of genes from the same plants, are the key ways for this process to occur [56].

SOIL SALINITY AND SOIL SALINIZATION

Soil salinity is a measure of salt content in soil that is commonly reported as electrical conductivity (EC). Soil salinization is the process through which salt concentrations in soil increase to the point that they have an influence on agricultural productivity, environmental health, economy, and quality of life [46].

Due to excessive leaching of base producing cations, salt-affected soils have high amounts of either soluble salts or exchangeable sodium, or both. The cations are sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), while the anions are chloride (Cl^-), sulfate (SO_2^{-4}), bicarbonate (HCO^{-3}), carbonate (CO_2^{-3}), and nitrate (NO^{-3}).

Classification of Salt-Affected Soils: -

- **Saline Soils: -** Soils having calcium, magnesium, and sodium as main exchangeable cations (Ca and Mg more than Na), and sulphate, chloride, and nitrate as prominent anions (also known as "white alkali" or "solonchak" soils). Salt problems in general; sodium adsorption ratio (SAR) <13;

exchangeable sodium percentage (ESP) <15 of total CEC; pH <8.5; EC of saturation extract >4 dS m^{-1}; white colour due to white crust of salts on the surface; good permeability for water and air; the salt concentration is sufficient to negatively impact the growth of the majority of crop plants; Typically found in arid or semi-arid regions where low rainfall and high evaporation rates concentrate salts in soils; seldom found in humid regions [93].

Reclamation of Saline Soils: Some of the successful and well-known technical interventions to address the problems of waterlogging and soil salinity are salt leaching using ponded fresh water, sub-surface drainage, mulching between two irrigations and during the fallow season, and irrigation management [5, 89]. Farmers' revenue increased three times after implementing subsurface drainage technology on saline soils. Subsurface drainage technology was able to produce an additional 128 man-days of employment per hectare per year [84]. The technique is beneficial, but its quick adoption is hampered by obstacles such as higher initial costs, operational challenges, a lack of community engagement, and concerns with the safe disposal of drainage effluents.

- **Sodic soils** (also known as "non-saline sodic soils," "alkali soils," or "solonetz"):- soils with a high exchangeable sodium content in comparison to calcium and magnesium; the primary salts are sodium carbonate and sodium bicarbonate [93]. SAR >13; ESP >15; pH = 8.5-10.0; EC of saturation extract <4 dS m^{-1}; dark colour; a low rate of permeability for water and air; soils generated owing to exchange of Ca^{2+} and Mg^{2+} ions via Na^{+} ions; sodium issues.

Reclamation of Sodic Soils: Chemical additions comprise components such as land levelling, bunding, flushing, drainage for excess water removal, excellent quality irrigation water, amendment application, crop selection, and effective nutrient management. Chemical amendments used for sodic soil reclamation can be divided into two categories: soluble calcium sources (e.g., gypsum, calcium chloride, and phospho-gypsum) and acids or acid formers (e.g., elemental sulphur, sulphuric acid, iron and aluminium sulphates, pyrites, and lime sulphur). As additives for restoring sodic soils, farmyard manure and press mud are also utilized [102]. Organic matter enhances soil microbial biomass, but gypsum reduces soil pH.

- **Saline-sodic soils:** These types of soils are intermediate between saline and sodic soils; SAR>13, ESP>15, pH>8.5; EC of saturation extract>4 dS m^{-1}; air and water permeability is affected by sodium content; soils formed by simultaneous methods of salinization and alkalization; challenges with sodium and other salts; leaching converts these soils to sodic soils [93].

Reclamation of Saline-sodic Soils: -

1. Improving drainage: drain tiles or ditches must be installed to prevent the accumulation of excess water and to improve the soil's drainage. This will help remove excess salts and reduce the soil's sodicity.
2. Appropriate soil excavation: Deep plowing and soil excavation must be done at the initial stage of soil reclamation. Soil that is compacted and heavily saline may require complete removal, especially if the soil layer is thick.
3. Gypsum application: Gypsum is an effective amendment for reducing soil sodicity. It helps replace sodium ions with calcium, which improves soil structure, aeration, and water-holding capacity. Gypsum and lime containing calcium (Ca^{2+}) can substitute sodium ions at the cation exchange sites during leaching [34]. Gypsum should be applied at a rate of 1-2 tons per acre and mixed thoroughly with the soil.
4. Use of organic matter: Organic matter can improve soil structure and the soil's water-holding capacity. Organic matter can be added through the use of green manure, crop residues, or animal manure.
5. Use of soil amendments: Soil amendments such as sulfur, phosphoric acid, sulfuric acid, and organic matter can be used to remediate sodic soils by reducing the soil's pH and alkalinity [85]. However, the use of these amendments should be done carefully and with precautions as high doses of these amendments can have negative effects on soil health.
6. Planting tolerant crops: Salt-tolerant crops such as barley, wheat, and cotton can be planted to reclaim soil, as they are tolerant to high levels of salinity and can improve soil structure and fertility.

Phytoremediation of Salt affected soils: -

The procedure of eliminating excess salts from soil by growing various types of plants is referred to as phytoremediation of salt-affected soils. Growing salt-tolerant trees, shrubs, and grasses is a low-cost, environmentally acceptable method of repairing salt-affected soils. Plants absorb excess salts from the soil and store them in their biomass, a process known as phytoaccumulation or phytoextraction [42]. It reduces the quantities of exchangeable sodium and soluble salts in the soil.

They also improve soil physical (bulk density, porosity, infiltration, water holding capacity, etc.), chemical (nutrient concentrations), and biological (microbial population) qualities and total soil productivity. *Acacia nilotica, Prosopis juliflora, Tamarix articulate, Eucalyptus tereticornis*, *Casuarina equisetifolia,* and others are among the potential plants for sodic soil reclamation [90].

Bio-remediation of Salt affected soils: -

The bio-remediation strategy, which incorporates plant-microbial interaction, has gained popularity across the world for improving the productivity of salt-affected soils. Microorganisms can play an important role in mitigating salt impacts on agricultural plants if their properties are properly harnessed. Microorganisms in the rhizosphere might improve plant development and yield under salt-stress environments in a variety of ways, both directly and indirectly. Some plant growth-promoting rhizobacteria may directly promote plant growth and development by supplying plants with fixed nitrogen, phytohormones, iron, and soluble phosphate [20, 87].

SOIL QUALITY RESTORATION

Soil quality restoration of deteriorated soils is a difficult endeavour, particularly in regions dominated by tiny, resource-poor landholders. The re-carbonization of the diminished SOC pool, which is required for a variety of tasks, necessitates the regular addition of biomass-C and critical elements (i.e., N, P, and S). There are three fundamental approaches to restore soil quality:

(i) Reducing pedosphere or soil solum losses

(ii) Producing a positive soil C budget while increasing biodiversity

(iii) Boosting water and elemental cycling.

Converting to a restorative land use and implementing conservation-effective strategies would, among other things, sustain/improve soil and ecosystem C pools, improve soil quality, and boost net primary production (NPP). Aside from the positive effects on water quality, one of the most important ecological benefits of soil conservation and restoration is an increase in the C pool in the soil and terrestrial biosphere, with the accompanying negative feedback on climate change (Fig. 2). Soil quality improvement would increase resistance to climate change by diminishing the effects of severe events, regulating microclimate oscillations, minimising diurnal/annual changes in soil temperature and moisture, and mitigating climate change [50].

[Fig. 2 Ecological benefits of Soil conservation.]

SOIL RESILIENCE

Soil resilience refers to the soil's capacity to regain its quality in a scenario of natural or manmade disturbances. Soil resilience is not the same as soil resistance since resilience refers to "elastic" properties that allow a soil to restore its quality after being perturbed or destabilised [4, 23, 49]. Sound rhizosphere activities are critical for soil resilience in the face of human and natural disturbances. Because soil is a dominant site of microbial metabolism, it is important to identify management systems that promote soil microbiota and related microbial processes.

There are no ways for managing soil resilience that are generally applicable; however, there are various approaches for guaranteeing sustainable soil management [41, 70]. Each of these options involves trade-offs that must be evaluated openly and critically. Due to the high demand for agricultural products to meet the needs of an increasing and increasingly affluent population and emerging economies (e.g., India, China, Brazil, Mexico), agricultural practises and their impact on soil, climate, gaseous emissions, water resources, biodiversity, as well as economic, political, social, and environmental dimensions, must be considered more than ever before [1].

CONSERVATION AGRICULTURE (CA) FOR SOIL RESTORATION:-

CA is based on four main principles: (i) the retention of crop residual mulch; (ii) the insertion of a cover crop into the rotation cycle; (iii) the incorporation of INM, a combination of chemical and biofertilizers; and (iv) the removal of soil mechanical disturbances. CA provides various co-benefits when properly applied to compatible soil types, including lower fuel use and improved soil C sequestration [33]. Mechanical tillage is a resource-intensive procedure that may be reduced or eliminated to reduce the use of fossil fuels.

Conversion of plough/traditional tillage to CA, on the other hand, can be conservation-effective, reverse degradation trends, and start soil restoration processes in action, particularly on sloping areas and those subject to increased erosion by water and wind under conventional management [71, 95]. Retaining crop leftover mulch and including a cover crop (forages) into the rotation cycle while minimising bare fallows can save soil and water while improving the SOC pool in the surface layer.

Increases in soil biodiversity, MBC, and earthworm and termite activity, as indicated in the hierarchy idea, can all promote aggregation and contain C inside stable micro-aggregates. Increased bioturbation by earthworms or termites can boost the solum's C sink capacity and soil profile depth by strengthening elemental cycling in combination with linked cycling of C and H_2O [95]. Incremental improvements in rhizospheric processes, fueled by biotic mechanisms, would restore soil quality and slow deterioration. However, CA is a system-based and holistic approach. The removal of agricultural leftovers and biomass for other uses (e.g., biofuels, industrial reasons) while eliminating ploughing is not CA but rather an extractive farming system with detrimental implications for soil and the ecosystem. As a result, comparing unrelated datasets might result in inaccurate estimations of SOC sink capacity associated with a correctly installed CA system and a misunderstanding of agronomic yields [108]. Furthermore, improving soil quality necessitates more than the addition of new varieties and chemical fertilisers. Some of the soil management practises are diversified so as to enhance soil properties (Table 1).

[Table 1 Different agronomic practices for enhancing soil properties]

NATURAL BASED SOLUTIONS FOR SOIL RESTORATION PROCESS

NATURAL FARMING

Masanobu Fukuoka, a Japanese farmer and philosopher, coined the term "natural farming approach" or "natural way of farming" in his 1975 book The One-Straw Revolution [30]. This natural farming method employs organic manures, such as farmyard manure (FYM), sheep manure, cow dung and urine, vermicompost, green manures, and biodynamic formulations, while avoiding the use of artificial fertilisers and chemicals [64]. With rising global food demand, there is an increasing desire for chemical-free, nutritious, and nutritional food [37, 100]. Natural farming faces a number of challenges, including yield losses in the early years of practise, difficulties in developing site-specific solutions to improve soil health and fertility, the unwise recommendation of a blanket solution for all types of soils, and costs associated with supplying natural inputs such as manure, etc. [81].

Natural farming provides potential for sustained crop yields; practises to minimise soil degradation and address problematic soils, which could increase soil fertility; location-specific interventions encouraging the use of organic manures, chemical fertilisers, and balanced fertilisation; and proper empirical confirmation in terms of research. All of these promises have contributed to the commercialization and adoption of natural farming practises [101].

ORGANIC MANURES

Farmers often utilise a variety of organic manures, such as FYM, sheep penning, tank silt, green manuring, bio-fertilisers, and natural mineral applications [6, 23]. Organic manures are a rich source of diverse plant nutrients that increase nutrient availability and soil physicochemical qualities.

The carbon dioxide generated during the breakdown of organic manures works as a CO_2 fertiliser [49]. Among several organic manures, FYM application is the most important organic input for improving soil fertility. This practise has been used to replenish soil fertility for centuries.

These manures have been shown to improve soil organic carbon, soil aggregate stability, and water-stable aggregates, which have a beneficial effect on nutrient retention as well as accessibility in the rhizosphere; improve nutrient availability; enhance dehydrogenase/microbial activity; aid phosphatase enzyme activity; and promote soil microbe metabolic activity [8]. All of the following soil factors contribute to greater sustainable crop yields [55].

SHEEP PENNING

Sheep penning/corralling is a practise in which the sheep flock is enclosed by hurdles/pens/fences but is allowed to roam directly in the cultivated fields during the nights within crop cycles, that is, after crop harvesting and before the start of field operations for the rainy season, and the valuable fecal matter and urine is thus returned directly to the soil [2, 16]. Because this penning is done between cropping seasons, the dry soil conditions can reduce the risk of soil compaction caused by sheep/goat trampling.

Sheep penning in fields before cropping has a positive effect on crop yields that can last for two to three cropping seasons. This form of sheep penning results in the capture and recycling of urine, which creates a critical conduit for effective nitrogen cycling in soil [24]. Another intriguing feature of sheep penning site dung is its resilience to breakdown, which is ascribed to slower decomposition/disintegration and lesser nutrient leaching when compared to cow manure [12]. As a result, it is preferable to use urine and feces for cultivation connected with sheep penning rather than FYM treatment [27], and it may also be advised in lowland regions with significant leaching potential and very acidic conditions.

TANK SILT

Tanks are naturally or intentionally constructed depressions/catchments where nutrient-rich silt from rainy season runoff of fertile topsoil is deposited and reducing dry season tank storage capacity [13, 25, 35]. As a result, there is a historic practise of excavating the deposited finer proportion of silt from the tank bed once every 5-10 years [18], and the tank silt is employed as an external amendment in crop cultivation. The addition of tank silt, particularly in rainfed agriculture areas, addresses the crops' thirst (irrigation water) and hunger (incorporation of soil nutrients) in a highly cost-effective manner [47, 60]. It is an efficient method of substituting artificial fertilisers by employing tank silt as an organic supplement; it also enhances soil quality and moisture stress tolerance during mid-season dry periods, which can boost crop yield in rainfed agriculture soils [7, 92].

The process of applying tank silt to agricultural areas is known as 'soil hybridization.' Soil hybridization by tank silt increases soil physicochemical parameters, promoting optimal crop development and yields. Tank silt treatment increases crop yields while also bringing out the dynamic changes in the soil on a long-term basis [18]. As a result, tank silt addition, an age-old traditional practise, has grown in popularity in recent decades and must be reintroduced in order to recycle and replenish natural resources in a sustainable way [99].

ZEOLITES

Natural zeolites minerals are typically found in Maharashtra, Madhya Pradesh, and Gujarat's western Deccan Traps [75]. They are naturally occurring crystalline, microporous aluminosilicates with a high cation exchange capacity, and their ion exchange properties are critical in plant nutrition. Zeolites have a somewhat alkaline nature with a pH of about 8.0 due to their huge surface area and perform as an effective buffering agent when used as an amendment [69]. Their ability to raise soil pH, increase cation exchange capacity (CEC), enhance rhizospheres with readily available P, and promote negative charge is responsible for decreasing heavy metal phytoavailability in soils after zeolites addition [3, 48].

BENTONITE

Bentonite minerals are mostly composed of montmorillonite clay, which has the natural capacity to hold together soil water and nutrient components [21]. Bentonite is added to sandy soils to improve their ability to hold water and retain moisture, to form soil aggregates that aid in stabilizing the soil, to promote microbial activity by creating a microhabitat for soil microbes, and to improve CEC, which impacts the soil's ability to use nutrients efficiently [36, 52, 68]. Bentonite application to soil acts as an excellent soil conditioner in dry environments, increasing crop yields in a variety of crop species.

BIOCHAR

Biochar has piqued the interest of agriculturists, environmentalists, and policymakers worldwide due to its wide range of applications in improving soil quality, remediating heavy metal contamination, and perhaps helping to mitigate climate change [9]. Biochar is a resistant, persistent carbon compound formed by the slow pyrolysis of biomass at 300-600 °C in an oxygen-limited atmosphere. Under these conditions, heat treatment produces biochar with a very large specific surface area, high adsorption capacity, and long-term persistence in soil [63].

This biochar can improve soil quality both directly as a plant nutrient source and indirectly as a soil conditioner by altering the soil's physical conditions [51, 72] Due to its solid and stable structure, biochar could absorb moisture up to 11% of its weight, which was less than that of soil organic matter (up to 20% of its weight). It has been discovered that applying biochar to soil decreases bulk density while increasing porosity and aggregate stability [54, 74]. The pores of biochar aid in the binding of hazardous heavy metals, assisting in soil rehabilitation.

FLY ASH

When coal is burned in thermal power plants, fine residues are captured from the flue exhaust. When sprayed in sufficient quantities, these tiny wastes, known as fly ash, can affect soil texture. In comparison to sand, the hollow spheres in the structure of fly ash are liable for a higher active surface area, capillary action, and nutrient and moisture-holding capacity. Fly ash's active surface area boosts cation exchange capacity [32]. It can be used in conjunction with FYM, sewage sludge, and biochar. Similarly, co-application of fly ash with sewage press mud cake and biochar enhanced crop production considerably when compared to the control [73, 80, 106].

Fly ash is disposed of either wet or dry. The fly ash is washed off with water in artificial lagoons and is known as "pond ash" in the wet approach, whereas it is disposed of in landfills and fly ash basins in the dry method [63]. Both methods lead to soil degradation and are harmful to human health.

CONCLUSION

As we know, the soil is being disturbed due to anthropogenic and natural causes, which may affect the soil's property and environmental sustainability. Different forms of soil degradation have their own set of reclamation procedures that may be used depending on the prevalent conditions in a given region. Soil stabilisation is accomplished by correct vegetation, farming practises, and other temporary structure management for erosion control. Similarly, for salty soils, diverse amendments (e.g., gypsum, acids, organic matter, etc.) and the availability of excellent-quality water are required to manage soil salinization. Soil fertility may be regulated by minimising cultural practises and cultivating less nutrient-depleted crops. Crop rotation is the most significant agronomic practise for managing the fertility conditions of less fertile soil. Balanced fertiliser application also regulates soil fertility; it may also decrease the leaching of surplus nutrients into below-surface water, which is helpful to the environment. Heavy metal reclamation can be accomplished by in situ immobilisation of metal ions using various immobilising agents that can lower metal ion activity in soil, thereby reducing absorption and toxicity. Phytoremediation in conjunction with metal mobilizers (e.g., organic acids, sulphur, chelators such as EDTA, etc.) is an emerging technology for permanently removing metal ions from soil. All of these approaches are involved in the restoration of soil attributes in some way and can be used concurrently in a controlled manner in severe situations of soil degradation.

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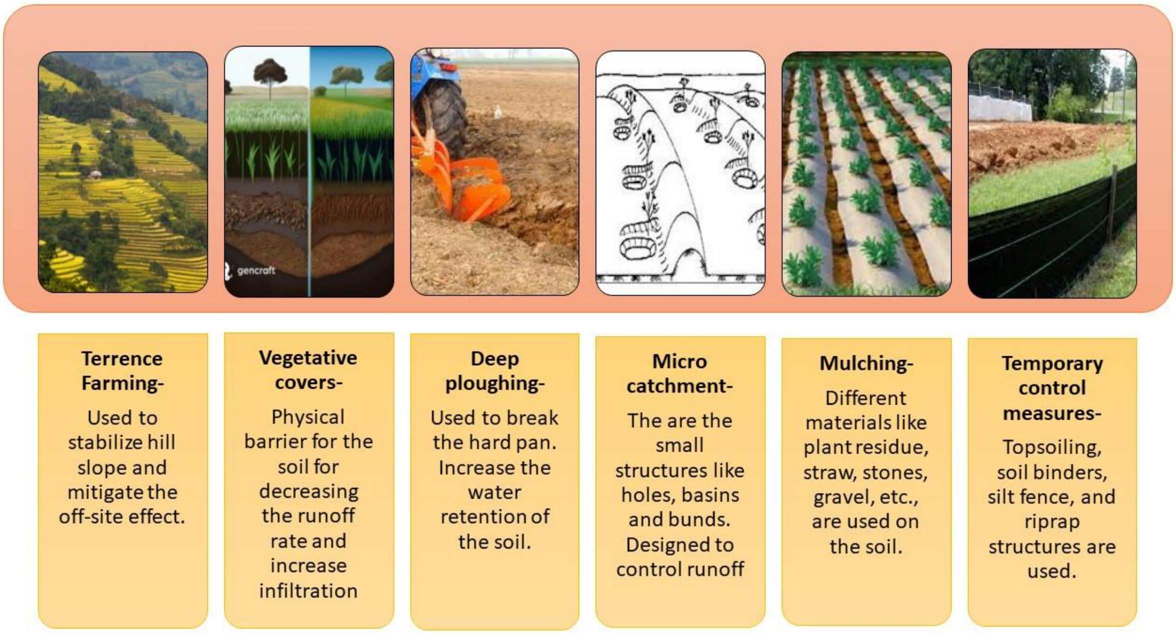
[Table(s)]

Table 1. Different agronomic practices for enhancing soil properties.

Sr No.	Soil management practices	Crop	Enhanced properties	Place	References
1.	No tillage with Subterranean clover	Olive	More available water, soil carbon and nitrogen content,	Toledo, Central	[38]

	and vetch (*Vicia Sativa* L.) cover system.		higher production	Spain	
2.	Sub-soiling with mulching	Winter wheat and peanut	Higher precipitation storage efficiency (PSE), precipitation use efficiency (PUE) and crop yield	Luoyang, East China	[39]
3.	No tillage	Corn and Soyabean	Increased SOC, Total N, EC, porosity, productivity, and higher yield	Ohio, USA	[17]
4.	Vegetative cover and chipped pruned residue	Apricot	Lowers the bulk density, total runoff, runoff coefficient, sediment yield, soil erosion and sediment concentration	Valencia province, Eastern Spain	[44]
5.	Sub-soiling, ridge planting with straw mulch	Maize and Wheat	Increases available P, K, Total N, soil organic matter, and water use efficiency	North China	[83]
6.	Empty Fruit Bunch (EFB)	Oil palm	Enhances soil faunal activities, base saturation, secondary macro nutrients, soil moisture content and water infiltration	Riav province, Indonesia	[96]

[**Figures**]



Terrence Farming- Used to stabilize hill slope and mitigate the off-site effect.

Vegetative covers- Physical barrier for the soil for decreasing the runoff rate and increase infiltration

Deep ploughing- Used to break the hard pan. Increase the water retention of the soil.

Micro catchment- The are the small structures like holes, basins and bunds. Designed to control runoff

Mulching- Different materials like plant residue, straw, stones, gravel, etc., are used on the soil.

Temporary control measures- Topsoiling, soil binders, silt fence, and riprap structures are used.

Fig. 1 Restoration of eroded soils with different management practices

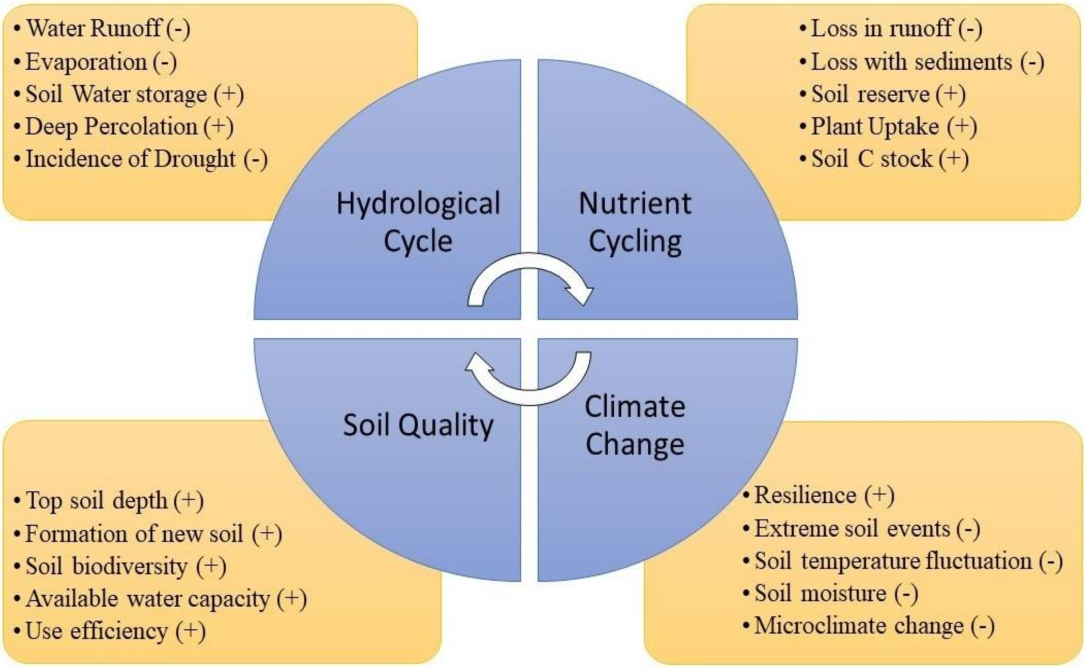


Fig. 2 Ecological benefits of Soil conservation.