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Sustainable Management of Soil Degradation

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"A nation that destroys its soil destroys itself"

\- Franklin D. Roosevelt

Can our agriculture meet the challenge of food security for growing population of the country projected to exceed 2 billion by the year 2030? Concerns are also growing about the long-term sustainability of agriculture. Soil degradation in India is estimated to be occurring on 147 million hectares (Mha) of land, including 94 Mha from water erosion, 16 Mha from acidification, 14 Mha from flooding, 9 Mha from wind erosion, 6 Mha from salinity, and 7 Mha from a combination of factors (Bhattacharyya et al. 2015). Erosion results in the degradation of a soil's productivity in a number of ways: it reduces the efficiency of plant nutrient use, damages seedlings, decreases plants' rooting depth, reduces the soil's water-holding capacity, decreases its permeability, increases runoff, and reduces its infiltration rate. The sediment deposited by erosive water as it slows can bury seedlings and cause the formation of surface crusts that impede seedling emergence, which will decrease the year's crop yields. The combined effects of soil degradation and poor plant growth often result in even greater erosion later on. Causes of soil degradation are both natural and human-induced. Natural causes include earthquakes, tsunamis, droughts, avalanches, landslides, volcanic eruptions, floods, tornadoes, and wildfires. Land clearing and deforestation, inappropriate agricultural practices, improper management of industrial effluents and wastes, over-grazing, careless management of forests, surface mining, urban sprawl, and commercial/industrial development are the result of human-induced soil degradation. Foul agricultural activities and practices can also add to the land degradation in a number of ways depending on land use, crops grown and management practices adopted. Consequently it becomes a serious problem in both rainfed and irrigated areas of India with the declining crop productivity, increasing land use intensity, changing cropping patterns, high input use and declining profit (Joshi and Agnihotri, 1984; Parikh and Ghosh, 1995; Srinivasarao et al. 2013).

Agricultural Activities Leading to Land Degradation

Inappropriate agricultural practices have a direct and adverse impact on widespread land degradation which reflects on the food and socio-economic condition of farmers of India. Excessive tillage and use of heavy machinery, imbalanced fertilization, poor crop rotation,

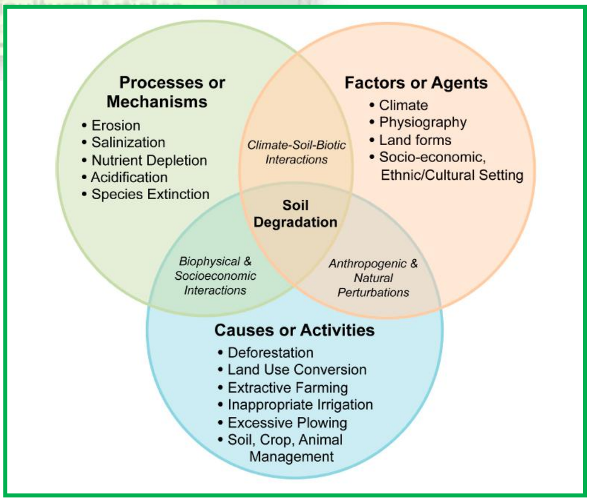

Fig. 1. Processes, factors and causes of soil degradation (Lal R, 2015)

burning of crop residue and inadequate organic matter inputs, poor water management, overuse of pesticide are growing concern over the sustainable management of soil quality as well as to combat soil degradation. How do these agricultural activities going to affect land degradation is discussed here as follows.

Excessive Tillage and Use of Heavy Machinery: Excessive tillage coupled with use of heavy machinery from land preparation to the harvesting without taking consideration of adequate soil conservation measures lead to poor physical condition of soil resulting in poor crop establishment. Consequently, yield of the crop is also affected. Different cost effective practices like unnecessary tillage for land preparation and planting, indiscriminate irrigation, and excessive fertilizer applications lead to the loss of topsoil through the action of water and wind, or waterlogging, which results in soil salinization and are also the main sources greenhouse gas (GHG) emission from agricultural systems which contribute to global warming leading to the climate change.

Imbalanced Fertilization: Intensive agriculture with very high nutrient turnover in soil plant system coupled with indiscriminate and imbalanced chemical fertilizer use results in imbalanced consumption ratio of 6.2:4:1 (N:P:K) in 1990–1991 has widened to 7:2.7:1 in 2000–2001 and 5:2:1 in 2009–2010 compared with a target ratio of 4:2:1. With the increase in food grain production with time, the number of elements deficient in Indian soils increased from one (N) in 1950 to nine (N, P, K, S, B, Cu, Fe, Mn, and Zn) in 2005–2006. The SOC pool, including its quantity and quality, is the defining constituent of soil (Krupenikov et al. 2011; Manlay et al. 2007). Indeed, SOC pool is the most reliable indicator of monitoring soil degradation, especially that caused by accelerated erosion (Rajan et al. 2010). Soil degradation depletes the SOC pool, along with it, plant available N and other essential nutrients such as P and S. Developing strategies to ensure the SOC pool is to increase and preferably maintain above the threshold or critical level of 10 to 15 g/kg (1.0%–1.5%), which is essential for reducing soil degradation risks and reversing degradation trends. Imbalanced fertilization practice has aggravated the problem of deficiencies in available nutrients and is the root cause of deteriorating soil fertility and productivity of crops. Even excessive use of nitrogen over phosphorus and potash fertilizers and little use of organic source of nutrients have resulted in depletion of other soil available nutrients. Therefore, balanced fertilization of nitrogen, phosphorus, potassium, sulfur and zinc along with application of farmyard manure, compost, green manure and biofertilizers should be practiced for sustained soil health and enhanced productivity of crops in the years to come.

Poor Crop Rotations: One of the reasons of soil erosion in cultivated areas is improper crop rotation coupled with lack of proper soil and water conservation measures. Proper crop rotations are used to reduce pests and diseases in the cropping system and to control weeds by including smothering crop species (e.g. cowpeas) or green manure cover crops. It may also give benefits in terms of improved soil quality with more or deeper roots and root exudates, better distribution of nutrients in the soil profile as deep-rooted crops bring up nutrients from below and to increases biological activity. Through rotations, peak labour times may be reduced and labour better distributed throughout the year if planting and harvest times are different depending on the needs of the farmer, whether it be for cash income or subsistence. It also enhances the production of residues by alternating crops that produce few and/or short-lived residues with crops that produce a lot of durable residues which also reduce soil erosion. Otherwise, unsuitable cropping patterns with low soil organic matter in marginal areas are solely responsible for accelerated wind and water erosion.

Crop Residue Burning: It has been reported that nearly 3.7 Mha suffer from nutrient loss and/or depletion of SOM due to the burning of crop residues for cooking, heating or simply disposal (Sehgal and Abrol, 1994). According to the Ministry of New and Renewable Energy

(MNRE, 2009), ~500 Mt of crop residues are generated every year and ~125 Mt are burned for cooking, heating which also adds to SOM loss.

Poor Water Management: Inefficient use of irrigation water causing runoff or overflow, seepage from unlined water courses, non-conjunctive use of surface and ground water resources and poor drainage, improper use and maintenance of irrigation system and extraction of ground water in excess of the recharge capacity resulting in a rise of the water table in most canal command areas contribute significantly to soil degradation problems like waterlogging and salinization, excess nitrate and other nutrients leaching causing soil pollution.

Soil Pollution: Pollution in soil is associated with the indiscriminate use of fertilizers, over use of pesticides, insecticides and herbicides, dumping of large quantities of solid waste without proper treatment, deforestation and soil erosion. These all lead to contamination of soil and water with toxic substances and heavy metals resulting in soil as well as environment pollution. Some commercial fertilizers also contain appreciable quantities of heavy metals, which have undesirable effects on the soil plus environment.

Strategies to Mitigate Land Degradation

Land degradation is the major consequences of direct interference of human activities in the natural phenomenon. It results in loss of natural fertility of soil because of loss of nutrients, less vegetation cover, changes in the characteristic of soil, pollution of water resources from the contamination of soil through which water sweeps into ground or runoff to the water bodies and changes in climatic conditions. There are several physical, chemical and biological soil conservation means to mitigate land degradation such as bunding, use of strips and terraces, contour ploughing can decrease erosion and slow runoff water. Physical barriers such as embankments or use of vegetative buffer strips and geotextiles and soil husbandry, are some of the important measures which can be successfully adapted to control soil erosion (Srinivasarao et al. 2014). In addition, integrated nutrient management (INM), conservation agriculture (CA), agro-forestry and diversified cropping system, reclamation of acid and salt affected soils and drainage (desalinization), irrigation management for improving input use efficiency and pollution control are also different available options to conserve soil and water.

Physical means: The following mechanical soil and water conservation measures may be adopted for controlling soil erosion, retaining maximum rainfall within the slope and safe disposal of excess runoff from the top to the foot hills of India depending on the degree and length of the slope and physical configuration of the land. These structures are often used to control extreme soil degradation. The measures are:

Bunding-small earthen barriers built on agricultural lands with slopes ranging from 1%–6% slope. Bunds are used in agriculture to collect surface *run-off*, increase water infiltration and prevent soil erosion.

Graded bunds-constructed across the slope for safe disposal of runoff in medium to high rainfall areas of ~600 mm year^{-1} and are recommended for up to 10% slope.

Contour bunds- either mechanical or vegetative barrier created across the slope for safe diversion of excess runoff and retention of eroded soil.

Bench terrace and half moon terrace-adopted where soil depth is >1.0 m. Half-moon terraces are level circular beds having 1 to 1.5 m diameter cut into half-moon shape on the hill slopes. Beds are used for planting and maintaining saplings of fruit and fodder trees in horticulture/agro-forestry land uses.

Grassed waterways-channels laid out preferably on natural drainage lines in the watershed.

Water harvesting ponds-dug-out embankment type of water harvesting structures are used for creating seasonal and perennial ponds at the foot of a micro-watershed for irrigation and fish farming purposes.

Conservation bench terrace-these are used to stabilize the yield of rainfed crops by interfiled water harvesting.

Gully control structures-are provided to reduce erosive velocity of runoff water, facilitate establishment of vegetation and provide protection helping the stabilization of gully beds.

River Bank Erosion Control

For river bank erosion control, bio-engineering technologies such as spurs, retaining walls and earthen embankments may be used in conjunction with suitable vegetation such as giant cane (*Arundo donax)*, five-leaf chaste trees (*Vitex negundo)*, morning glory (*Ipomoea sp.)*, Bamboo (*Bambusa vulgaris*), napiergrass (*Pennisetum purpureum*) or munja (*Saccharum munja)* (CSWCR&TI Vision, 2011).

Natural Geotextiles: Researchers of China, Thailand and Vietnam indicated that even short-term use of biological geotextiles (maize stalk mats, bamboo mats, borassus and buriti mats and wheat straw mats) in highlands significantly improved biomass and decreased runoff and soil loss (Bhattacharyya et al. 2011, Bhattacharyya et al. 2012, Fullen et al. 2011, Smets et al. 2011). Combined presence of jute geotextiles and vegetation cover decreased erosion rates by ~95% and runoff by ~70% with respect to bare plots (that had ~18 ton ha^{-1} $year^{-1}$ soil loss) on a 20% land slope of Bangladesh (Mahmud et al. 2012).

Integrated Nutrient Management: Integrated nutrient management envisages the application of NPK mineral fertilizers along with organic manures, increases crop productivity, improves SOC content, and decreases soil loss. The practice of INM includes all possible sources of plant nutrients to optimize nutrient inputs, soil nutrient supply with crop demand and reducing N losses while improving crop yield while substantially reducing N losses and GHG emissions. In general, the INM method provides a "win–win" opportunity to simultaneously increase crop production and reduce environmental impact. Saha et al. (2007) revealed that the addition of organic manure gave more positive balances of nutrients. Application of chemical fertilizers along with the organic manures increased soil organic carbon by 0.71%. FYM and poultry manure along with full recommended dose of NPK fertilizers to wheat was essential for improving crop productivity, grain quality, profitability, soil health and sustainability of wheat–soybean system. According to the CSWCR&TI Annual Report (2012) integrated nutrient management also decreases soil loss. Runoff and soil loss increased with increase in slope from 0.5% to 2.0% at Bellary.

Conservation Agriculture (CA): There are mainly four principles in the concept of conservation agriculture which includes: (1) causing minimum disturbance to the soil surface by using no- or minimum-tillage, (2) keeping the soil surface covered all the time through practices such as retention of crop residue, mulching, or growing cover crops, (3) adopting crop sequences or rotations that include agroforestry in spatial and temporal scales, and (4) controlled traffic (FAO, 2010). Thus it helps in increasing in water stable aggregates, greater SOC concentrations, and protection from wind and water erosion. Introduction of a legume crop improved C retention in surface soils under conservation tillage even with only short-term adoption. Adoption of CA, as a complete package, is one of the major strategies for increasing SOC stock. Although crop residue incorporation initially leads to immobilization of inorganic N, addition of 15–20 kg N ha^{-1} with straw incorporation eventually increases yield of rice and wheat. Incorporation/retention of rice residue in the soil returns essential organic C and N back to the field to favourably impact soil structural status. Surface residue placement had greater C retention than residue incorporation in a maize-wheat-greengram cropping system (Das et al. 2013). Conservation agriculture increased soil-water retention more at lower suctions due to increase in micro-pores and inter-aggregate pores caused by enhanced SOC content and higher activity of soil fauna e.g., earthworms and termites. Even

CA holds considerable promise in the arid region, because it can control soil erosion by wind and water, reduce compaction and crusting. Despite many benefits of CA practices as mentioned above, the adoption rate in India is very low. Jat et al. (2012) opined that the major constraints to the use of CA include insufficient amounts of residues due to water shortage and degraded nature of soil resource, competing uses of crop residues, resource poor smallholder farmers, and lack of in-depth research.

Intercropping, Contour Farming and Diversified Cropping: Agronomical practices like use of cover crops, mixed/inter/strip cropping, crop rotation, green manuring and mulch farming are very important practices associated with integrated nutrient management. It is beneficial as it is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Care should be taken into account with the soil, climate, crops and varieties having no competition with each other for physical space, nutrients, water, or sunlight. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade. Growing soybean (*Glycine max*)/groundnut (*Arachis hypogoea*)/cowpea (*Vigna radiata*) with maize (*Zea mays*)/jowar (*Sorghum bicolor*)/bajra (*Pennisetum glaucum*) is a common example of intercropping in the drylands (Srinivasarao et al. 2014). Contour farming or Contour bunding is the farming practice of plowing and/or planting across a slope following its elevation contour lines. These contour lines create a water break which reduces the formation of rills and gullies during times of heavy water run-off, which is a major cause of soil erosion. Soil erosion prevention practices such as this can drastically decrease negative effects associated with soil erosion such as reduced crop productivity, worsened water quality, lower effective reservoir water levels, and flooding, etc. Contour farming is considered an active form of sustainable agriculture. Now a day, greater emphasis is be given on crop diversification due to unsustainability of the rice–wheat system throughout the India. Having a higher water requirement of rice it can be replaced by other crops in some areas and with legumes such as green gram, cowpea or dhaincha as they are better option for conserving resources as well as improving productivity.

Integrated Farming Systems: In India, there is about 65% of the total farmers are of marginal (<1 ha) and out of these nearly 40% of them are exposed to food insecurity. Hence, integrated farming systems is one of the most well-acceptable, single window, and sound strategy for harmonizing simultaneously joint management of land, water, vegetation, livestock, and human resources. Integrated Farming (IF) is a whole farm management system which aims to deliver more sustainable agriculture by enhancing soils' productive potential and reducing risks of degradation by including tree crops with a high quality of leaf litter with higher root binding ability and erodibility from rainfall/runoff can be reduced.

Agroforestry: Perennial woody vegetation in agroforestry systems recycles nutrients, maintains soil organic matter, and protects soil from surface erosion and runoff by their ability of (i) vegetative buffer strips to decrease surface transport of agrochemical pollutants, (ii) large volumes of aboveground and belowground biomass of trees to store C deeper in the soil profile, and (iii) trees enhance soil productivity through biological N fixation, efficient nutrient cycling, and deep capture of nutrients. Thus, it also contributes to the enhancement of water-quality, C sequestration, and soil improvement. Legume-based agroforestry has the capacity to support biological N fixation to enhance subsequent soil N availability and therefore improve soil fertility and crop yields (Rosenstock et al. 2014).

Reclamation of Acid and Salt Affected Soils and Drainage (Desalinization)

Amelioration of acid soils is mainly done by liming. Lime raises soil pH, thereby increasing the availability of plant nutrients and reducing toxicity of Fe and Al (Sharma and Sarkar, 2005, Fageria and Baligar, 2008, Bhat et al. 2007). Application of high quality irrigation water (low electrical conductivity) and growing of salinity tolerant crops is the most efficient method to reclaim saline soils involving proper tillage practices, irrigation and leaching followed by application of green manures. Tolerant crops also support formation of stable soil aggregates, which help to improve soil tilth. Rice is the potential crop for reclamation of sodic soils. Gypsum, phosphogypsum or acid formers like pyrites, sulphuric acid, aluminium sulphate and sulphur are the major chemical used for reclamation of alkali soils. The treated field should be kept submerged with good quality water to facilitate reaction and subsequent leaching. In addition, proper drainage through deep and open drains can be adopted wherever problems persist.

Irrigation Management for Improving Input Use Efficiency and Pollution Control: Efficient utilization, management and conservation of water can be promoted with development of irrigation facilities like drip irrigation and sub-surface irrigation. Scheduling of irrigation is a very important aspect in this regard to improve crop productivity and reduce soil degradation. Sound surface irrigation methods like sprinkler or drip give better input efficiency through improving the yield simultaneously saving considerable volume of water. Utmost care should be taken to reuse the treated domestic and municipal wastes, sludges, pesticides, industrial wastes, *etc.* so that there is no possibility of pollution of soil.

Conclusion

Appropriate mitigation strategies are the need of the hour to combating land degradation with with the changing climate. Soil degradation can be physical (e.g., decline in structure, crusting, compaction, erosion, water imbalance), chemical (e.g., acidification, salinization, elemental imbalance comprising of toxicity or deficiency, nutrient deficiency), biological (depletion of SOC pool, reduction in soil biodiversity, decline in microbial biomass-C) or ecological (e.g., disruption in elemental cycling, decline in C sink capacity). Conservation agriculture coupled with other technologies like integrated nutrient management, micro-irrigation, fertigation, and management of problem soils using specific and necessary technologies, efficient irrigation management are some of the most feasible solutions for preventing land degradation as well as improving crop productivity in a sustainable manner to meet the demand of food and socio-economic stability. The ultimate goal is to adopt a holistic and integrated approach to soil resource management so that the finite nature of soil resources must never be taken for granted, they must be used, improved and restored.

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