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Soil Degradation vs Soil Retrogression: A Review

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ABSTRACT

Soil is a critical resource for the future of humanity. India's total geographical area (328.7 Mha) is projected to be degraded by 147 million hectares (Mha). This is particularly concerning because India is home to 18 per cent of the world's population but only has 2.4 per cent of the world's land area. Soil degradation is characterized as processes that cause soil quality to deteriorate and make it less suitable for a specific purpose, such as crop production. Soil erosion, a degradation process, can take place anywhere from a few years to centuries and this changes the soil's composition and humus content. The process of soil retrogression is pedogenically induced and it is caused by the loss of nitrogen, ecosystem efficiency and standing plant biomass and it can only be reversed by a rejuvenating disruption that resets the mechanism. Retrogression occurs over time scales ranging from thousands to millions of years. The decrease in biomass over long time scale distinguishes retrogression from degradation. The United Nations Convention to Combat Desertification (UNCCD) developed the conceptual framework for Land Degradation Neutrality (LDN), to provide a scientific approach to planning, implementing and monitoring LDN. Soil retrogression and degradation are two regressive processes. It is critical to prioritize soil health in decisions taken to tackle deterioration and the value of soil as the source and destination of everything should be reaffirmed once more.

Key words: LDN, Retrogression, Soil degradation, Soil erosion.

Soil is a vital resource for the future of humanity. It needs to be protected and enhanced. Instead, more than half (52%) of all fertile, food-producing soils globally are now classified as degraded and many of them severely degraded (UNCCD, 2015). Food protection, climate change, flood risk management, drought tolerance, drinking water quality, agricultural resilience in the face of new crop diseases, biodiversity and potential genetic resources are all affected by soil depletion, which is a serious and rising global problem. Discussions around climate change seldom refer to soil, even though the soils globally, down to one metre in depth, contain 1,500 billions of tonnes of organic carbon, over three times as much carbon as the atmosphere. Soil degradation adds carbon (C) and reactive nitrogen (N) to the atmosphere, increasing global warming, which in turn accelerates degradation processes (Lal, 2004).

Soil is important for agriculture and the food we eat. Soil is an indefinitely renewable resource when managed properly, but they are effectively a finite resource when managed incorrectly. In natural conditions, forming an inch of soil from parent rock will take 500-1,000 years.

According to recent figures, every year:

- 1.9 billion hectares are affected by soil degradation.
- 12 million hectares (23 hectares every minute) of land are lost to food production.
- 24 billion tonnes of productive soil are washed or swept away irreversibly (3.4 tonnes for every human on the planet).

It is also projected that this will lead to a 12% decline in global food production over the next 25 years, resulting in a 30% increase in world food prices (UNCCD, 2015). This will occur during a period when more production is demanded of soils than ever before, due to the growing global population and climate change. About 147 million hectares (Mha) of India's total geographical area (328.7 Mha) is estimated to be degraded. This is extremely serious because India supports 18 per cent of the world's human population, but has only 2.4 per cent of the world's land area (Bhattacharyya *et al.*, 2015).

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Definition

a. Soil degradation

It is the change in soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries. Degraded soils have a health status such that they do not provide the normal goods and services of the particular soil in its ecosystem. It has also been defined as the rate of adverse change in soil qualities resulting in decline in productive capacity of land due to processes induced mainly by human intervention (FAO, 2015).

b. Soil retrogression

Soil retrogression is the reduction in ecosystem productivity and standing plant biomass, declines in the availability of nutrients and shifts in both aboveground and belowground communities to dominance by nutrient-stress-tolerant, slow-growing species that are adapted to nutrient poor conditions (Lambers and Poorter, 1992).

As a result, there will be a decrease in land fertility, a loss of vegetative cover, a qualitative and quantitative reduction in water resources, soil depletion and air pollution. Degradation is a stage of evolution that results in a decrease in resource capacity. Since the beginning of soil agriculture, there has been an issue with soil depletion. However, it has become even worse in recent decades as India's population has grown at a rate of about 1.8 per cent per year, necessitating the ploughing of marginal land to meet the food demand.

Difference between soil degradation and retrogression (Table 1)

Soil degradation

Causes

Soil degradation can be divided into four categories: (i) physical, (ii) chemical, (iii) biological and (iv) ecological. Soil physical deterioration causes a decrease in structural attributes such as pore geometry and continuity, making a soil more susceptible to crusting, compaction, decreased water infiltration, increased surface runoff, wind and water erosion, increased soil temperature variations and desertification. Acidification, salinization, nutrient loss, reduced cation exchange ability (CEC), increased Al or Mn toxicities, Ca or Mg shortages, leaching of NO_3-N or other important plant nutrients, or contamination by industrial wastes or by-products are all signs of soil chemical degradation. Depletion of the soil organic carbon (SOC) pool, loss of soil biodiversity, a decrease in soil C sink capability and increased greenhouse gas (GHG) emissions from soil into the atmosphere are all signs of soil biological degradation. One of the most serious effects of soil biological depletion is that it becomes a source rather than a drain of greenhouse gas emissions (CO_2 and CH_4). Ecological degradation is the result of a combination of the other three factors and it causes disruptions in ecosystem functions such as elemental cycling, water infiltration and purification, hydrological cycle perturbations and a drop in net biome productivity.

Soil degradation in India due to various causes

On 147 million hectares (Mha) of degraded land in India, soil depletion is estimated to be occurring, with 94 Mha due to water erosion, 16 Mha due to acidification, 14 Mha due to floods, 9 Mha due to wind erosion, 6 Mha due to salinity and 7 Mha due to a combination of factors. Water erosion is India's most severe environmental issue, resulting in topsoil loss and terrain deformation. The average soil erosion rate was 16.4 tonne ha $^{-1}$ year $^{-1}$, resulting in an annual total soil loss of 5.3 billion tonnes across the region, according to a first approximation study of existing soil loss results. Nearly 29% of total eroded soil is permanently lost to the sea, while 61% is simply transferred from one place to another and the remaining 10% is deposited in reservoirs (Bhattacharyya *et al.*, 2015). According to Ighodaro *et al.* (2020), farmers' perception on the impact of soil erosion on various aspects of their agricultural and food security levels: farm enterprise, amount of food available to the home and number of families who are food self-sufficient are in the order of 81 percent, 62 per cent and 67 per cent respectively.

Impact

Desertification

It is known as "land degradation in arid, semiarid and dry sub-humid areas caused by a variety of factors such as climatic fluctuations and human activities." Desertification is accelerated by the destruction of vegetation, which is most commonly caused by human activities. When vegetation is removed from a soil, it becomes more vulnerable to wind and water erosion. When top soil is removed by water or wind, organic material is lost, resulting in a decrease in soil aggregation and stability and thus soil fertility. As organic material is lost, the soil's water-holding ability and nutrient content are decreased, putting additional pressure on vegetation survival.

During 2011-13, the area under desertification (arid, semi-arid and dry sub-humid regions of the country) was 82.64 Mha, compared to 81.48 Mha in 2003-05. As a result, desertification has increased by 1.16 million hectares. For the years 2011-13, Kerala had 9.77 per cent of its total geographical area under desertification/land degradation. The desertification area in Kerala has increased about 0.23%

Table 1: Difference between soil retrogression and soil degradation.

Parameters	Soil retrogression	Soil degradation
Area	Related to related to ecosystem ecosystem	Any area
Process	Pedogenically driven process	Natural and anthropogenic processes
Impact	Loss of soil horizon and decline in nutrients	Alteration of soil composition and humus quality
Quantity of soil loss	Negligible	High
Temporal scale	Millions of years	Few years to decades
Management	Reversed by rejuvenating disturbances	Sustainable management practices

since 2003-05. The most significant process of desertification/ land degradation in the state is vegetation degradation (8.69% in 2011-13 and 8.46% in 2003-05) (SAC, 2016).

Flood and landslides

Floods are one of the most dramatic examples of human-environment interaction. Under the global warming scenario, the frequency of large floods and severe precipitation events has risen significantly. In recent years, India has experienced some of the most unusual severe precipitation events, which has resulted in flooding and the loss of lives. Kerala witnessed one of the biggest natural disasters,that occurred in the past 100 years, due to an abnormally heavy rainfall in the south west monsoon season of 2018 starting from June to August. The flood and landslides have caused devastating damage in 13 out of 14 districts of the state, claiming hundreds of lives and destroying hectares of crops, even to the extent of changing the very geographical configuration of the region. (Department of Soil Survey and Soil Conservation, 2018).

Decline in soil health

Soil organic carbon is the most abundant component of soil organic matter (approximately 58%) and is essential for agricultural production and a variety of other soil functions. Soil degradation exacerbates the depletion of organic matter in agricultural soils, which in turn exacerbates the depletion of organic carbon. Almost 42-78 billions of tonnes of carbon have been lost from soils over the last century due to degradation, mostly emitted to the atmosphere as carbon dioxide (CO_2) and other greenhouse gases (GHGs) with negative implications for climate change and food production (Lal, 2005).

Land use change also results in the loss of nitrogen from soils and unlike carbon, which is lost annually over 50-100 years, nitrogen is lost very quickly in the form of nitrous oxide, which is the most persistent and potent of all the major greenhouse gases in terms of global warming. Nitrogen losses increased the net GHG impact of converting grassland to crop production by 50%, resulting in a reduction in soil fertility and nutrient cycle disruption.

Reduction in yield and productivity

Because soil degradation is linked to land degradation, a significant amount of arable land is lost as a result. Agrochemical-induced soil degradation and soil erosion have resulted in the loss of about 40% of the world's agricultural land. The majority of crop production practices deplete topsoil and harm the natural soil composition that allows agriculture to thrive.

Decline in biodiversity

Soil degradation can result in microbial community disruption, the disappearance of climax vegetation and a reduction in animal habitat, all of which can lead to biodiversity loss and animal extinction. Seasonal changes in vegetation have a significant impact on soil microbiological processes. In degraded soils of arid and semi-arid regions, changes in soil moisture regimes can also affect MBC and activity (Fterich, 2014).

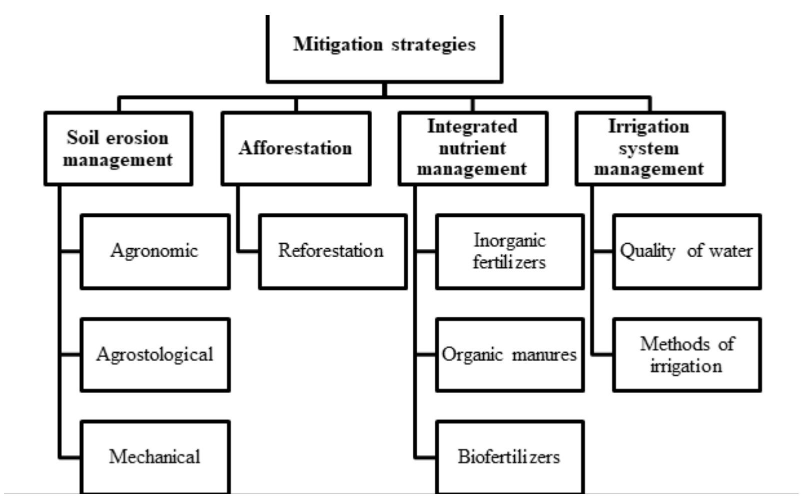
Socio-economic impact

Recent increases in the human population have placed a great strain on the world's soil systems. More than 6 billion people are now using about 38% of the land area of the earth to raise crops and livestock. The estimated cost of land degradation in US is about $40 billion per year (Mani *et al*., 2012).

Management (Flow chart 1)

Soil erosion management

Soil erosion can be controlled by encouraging new approaches to land management techniques and methods. Three main themes and 11 sub-themes related to soil erosion control practices emerged from the systematic review. Agronomic, agrostological and mechanical practices are the three main themes. Both agronomic and agrostological practices are considered biological



Flow chart 1: Mitigation strategies for soil degradation.

techniques. Intercropping, cover crop, mulching, organic matter, cultivation of grass, contour farming, bunds, micro basin, tillage, contour terrace and geo-textile are the 11 sub-themes.

Afforestation

It's a tall order to prevent deforestation. Deforestation, on the other hand, can be reduced, resulting in a dramatic reshaping and restoration of forests and vegetation cover. Individuals can be educated and sensitised about sustainable forest management and reforestation efforts as their population grow. Furthermore, preserving the integrity of guarded areas can reduce demonstrations significantly.

As a result, people all over the world must respect forest cover and reduce some of the human-caused activities that encourage logging. The ability of soil to naturally regenerate can be restored by reducing deforestation. To prevent soil degradation, governments, international organisations and other environmental stakeholders must ensure that appropriate measures are in place to make zero net deforestation a reality.

Integrated nutrient management

Increased crop productivity, improved SOC content and reduced soil loss are all benefits of using NPK mineral fertilisers in combination with organic manure. Integrated use of organic and inorganic fertilizers stimulates the number and activity of microorganisms resulting in an increase in the organic carbon content of soil (Dhillon *et al*., 2020). In the northwest hill region of India, runoff and soil loss increased with increase in slope from 0.5% to 2.0% and use of integrated nutrient management improved the soil health and SOC storage in all cropping systems resulting in reduced soil loss (Srinivasarao *et al*., 2009). The biofertilizers provide an easy, effective and low input integrated nutrient management system that can be effectively used for nutrient mobilization, enhance crop production and maintain soil health (Rajinder and Sukhminderjit, 2018).

Irrigation system management

Irrigation scheduling based on crop critical stages or atmospheric demand promotes optimum plant growth and increases the transpiration component of evapo-transpiration water loss, improving crop productivity and reducing soil degradation. Surface irrigation methods such as sprinklers or drip give better input efficiency than flooding. It not only raises yields and increases input efficiency, but also saves a significant amount of water. Furthermore, when irrigation water is applied through flooding in Vertisols, a significant amount of irrigation water is lost beyond the root zones due to bypass flow. Water loss through bypass flow in Vertisols could be reduced by scheduling irrigation based on the atmospheric demand for water, *i.e*. (irrigation water/ cumulative pan evaporation) based scheduling. Irrigation scheduling at 0.8 irrigation water/cumulative pan evaporation significantly improved the soil water extraction, root length density and grain yield of wheat over irrigation at 0.6 IW/ CPE (Bandyopadhyay *et al*., 2009).

Soil retrogression

Causes

- Loss of parent substrate-derived nutrients
- Change in plant functional traits
- Linkage between belowground and aboveground consumers

Loss of parent substrate-derived nutrients

The best-characterized driver of retrogression is the reduced availability of parent substrate-derived nutrients during long-term pedogenesis, which may arise through several mechanisms (Chadwick and Chorover, 2001). The loss of parent substrate-derived nutrients is an unavoidable consequence of weathering and soil development over thousands to millions of years, though the rate at which this occurs is likely to be highly dependent on climate. Chemical weathering is the breakdown of primary minerals in bedrock caused by rainwater, plant exudation of organic acids, mycorrhizal fungi hyphae and physical disturbance. Phosphorus and cations are lost by leaching and runoff as these minerals dissolve, especially as soil exchange sites diminish due to changes in soil mineralogy or are filled by hydrogen (H) and aluminium (Al) ions during soil acidification. Phosphorus, though substantially less mobile than cations, can also be lost through leaching and in addition can be transformed into bound forms that are believed not to be readily available for plant uptake. Mineralogical changes that occur during soil development are a key cause of decline in nutrient availability and ecosystem retrogression (Peltzer *et al*., 2010).

Changes in plant functional traits

As ecosystem development proceeds from the progressive phase to the maximal biomass phase and finally to the retrogressive phase, the dominant plant species should shift generally from fast-growing, short-statured species to tall, slower growing, dominant species and finally to long-lived, slow-growing species (Grime, 2001). Species richness and diversity at the community level are less consistently responsive to ecosystem retrogression than functional traits, but they can shift during retrogression. Aboveground biomass and net primary production (NPP) decrease as retrogression progresses, while the proportion of belowground biomass increases.

Linkages between belowground and aboveground consumers

Consumer organisms abundance or biomass should decrease as the availability of their food resources decreases during retrogression. Microorganisms (bacteria and fungi) are the primary consumers in the belowground food web. Soil microflora biomass and respiratory activity generally decline during retrogression. Changes in ecosystem properties aboveground mirror those belowground. The loss of parent-substrate-derived nutrients during pedogenesis drives plant trait adaptations that act as positive feedbacks to low soil nutrient availability, such as high NUE (nutrient use efficiency), long leaf span, high LMA (leaf mass per unit area) and high levels of quantitative defensive compounds (Vitousek, 2006). Reduced litter quality during retrogression promotes more stress-tolerant soil biota, which slows nutrient cycling even more by reducing soil microbial activity and causing the formation of more recalcitrant or organically bound compounds, which further reduce nutrient availability.

Management

- Ameliorating soil physical properties
- Reinvigorating soil biology
- Modifying the water cycle
- Applying suitable quantities of missing nutrients

After an impact, vegetation in young landscapes tends to return to its original state, whereas vegetation in older landscapes will only partially recover or collapse. Man-made disturbances (clearing, burning, grazing and farming) accelerate the deterioration of old systems (new system states) and key system functions may be permanently lost. Restoration expectations (end-points) in old landscapes are different from young landscapes and a stable system state different from the original state may be the best outcome (Walker *et al.*, 2001).

Restoration methods based on an understanding of the consequences of retrogressive succession are broken down into seven steps:

1. Determine the magnitude and stage of the system's retrogression prior to the disturbance. This is observational ecology, focusing on intact areas of similar surrounding ecosystems, if possible. It entails establishing large biophysical constraints, successional patterns and ties to land-use and previous disturbance using local information, fieldwork and published literature.
2. Determine the magnitude of the abiotic changes resulting from the most recent disruption. In essence, these are the abiotic constraints that will govern the new state of sustainability for the system. Characterize the significant improvements in soil hydraulic, chemical and biological properties in particular. Soil and terrain analysis (nutrient status, organic matter material, compaction and infiltration) as well as digital elevation modelling may be used (potential for sediment and organic matter transport).
3. Identify, where possible, areas in the local landscape where similar abiotic constraints caused by natural erosion or past disruptions have resulted in a stable state and could serve as "landscape analogues" for the system in need of restoration.
4. Determine the main species in the pre-disturbance site as well as any natural landscape analogues. Understand their life cycles and disturbance responses as much as possible (phenology, root strategies, seed banks, regeneration characteristics, growth rates, plasticity). This knowledge can help determine the optimal species mix, how it can be implemented and whether specific management interventions will help the new system reach a stable state more quickly.
5. Determine whether there are any management options for entirely or partially reversing the retrogression.
6. Establish endpoint parameters for the new "state" that are consistent with the intended land use (production systems, conservation and stabilisation), such as vegetation structure, composition, productivity and/or function. If healthy plant communities must be restored for conservation reasons, aim to align them as closely as possible to landscape analogue communities.
7. Establish the main device drivers and develop the restoration software based on points 1 to 6 above (objectives, implementation methods, costs and monitoring protocols).

Policy framework

Land degradation neutrality

The aim of land degradation neutrality (LDN) is to preserve or improve land-based natural resources and the ecosystem services that come with it. To encourage a more proactive policy response to land degradation, the principle of land degradation neutrality (LDN) was introduced into the global debate. The UNCCD's primary aim is to create capacity to achieve LDN, which has been adopted as a priority for Sustainable Development Goal 15.

LDN is defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD, 2016). The concept was raised to galvanise effort around a concrete target of "no net loss" and it aims to maintain the world's resource of healthy and productive land through a dual-pronged approach of measures to avoid or reduce land degradation, combined with measures to reverse existing degradation, such that losses are balanced by gains (Cowie *et al.*, 2017). The LDN aim is a global objective and countries have been encouraged to make voluntary national commitments to LDN.

Key elements of the scientific conceptual framework for LDN

LDN is a new way of dealing with land loss. It recognises that global environmental change would have an effect on the land system and thus promotes adaptive management throughout the planning, implementation, tracking and analysis of LDN. The system is built around a counterbalancing process that projects and attempts to balance expected positive and negative changes in order to achieve neutrality. The system is made up of five modules that are all linked together.

1. Module A

LDN's vision and goals are recorded in this text.

2. Module B

explains the LDN frame of reference, that is, the baseline against which neutrality is assessed.

3. Module C

establishes the neutrality mechanism (the counterbalancing mechanism).

4. Module D

The theory of change (logic model), which articulates the roadmap for implementing LDN, preparatory assessments and enabling policies, learning and governance are among the elements required to achieve LDN.

5. Module E

explains how to track LDN, including how to measure, check and interpret LDN indicators.

CONCLUSION

Soil degradation and retrogression are two regressive evolution processes linked to a stable soil's loss of equilibrium. Retrogression is caused mainly by soil erosion and refers to a process in which the land returns to its natural physical condition as a result of succession. Degradation is a form of evolution that is distinct from normal evolution and is influenced by the local climate and vegetation. They can be reversible if habitat restoration is designed and agricultural systems that restore soil are introduced. Soil health must be prioritized in decision-making to combat depletion and it must be regarded as a critical resource for humanity's long-term survival. The ultimate aim of soil resource management should be to take a comprehensive and integrated approach. Soil resources are limited and must be used, improved and restored in order to be used, improved and restored.

Conflict of interest: None.

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