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# Achieving land degradation neutrality in developing countries

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**ABSTRACT**

Land degradation, decline in functionality and weakening of ecosystem services (ESs), is a serious problem in India. Different processes of land degradation include decline in soil structure, soil erosion by water and wind, salinization, depletion of soil organic matter (SOM) content, negative nutrient budget and elemental imbalance, water imbalance including drought and inundation, loss of above and below-ground biodiversity, top soil removal for brick making etc. As a signatory to implementing the concept of land degradation neutrality (LDN) implemented by United Nations Convention to Combat Desertification (UNCCD), India aspires to restore 26 Million hectares (M ha) of degraded lands by 2030. Realizing the target necessitates establishment of baseline state-of-the-land-resource capital through choice of key land/soil parameters, establishment of critical level of key soil properties, selection of region-specific sustainable land management (SLM) practices, involvement of community and land managers in implementation of SLM to restore degraded land, and development of a protocol for payments to farmers for ESs (PESs). Supporting land managers through PESs must be done on the basis of transparent, just and fair price and based on societal value of the resource for specific ESs such as carbon sequestration, restoring ground water and conserving surface water, improving water quality, and restoring above and below-ground biodiversity. Once the program is implemented, its impact on land quality must be documented in a 5-yearly state-of-the-land report at national level. There must be channels of communication between scientists and policy makers, and the latter and general public. Environmental education must be part of the curricula from primary school to post graduate level.

## 1. INTRODUCTION

The term "land" comprises soil, water, and air. Vegetation, an important component of land, is closely associated with soil. That being the case, the term land quality refers to its capacity to sustain ecosystem services (ESs) for humans and nature. Therefore, land degradation would imply decline in its capacity to provide ESs because of the disregard to planetary boundaries through anthropogenic activities (Rockström *et al.,* 2009; Steffen *et al.,* 2015) involving land misuse and soil mismanagement. Nine planetary boundaries sensitive to anthropogenic activities include: stratospheric $O_3$ depletion, loss of biosphere integrity, chemical pollution, climate change, ocean acidification, freshwater consumption and the global hydrological cycle, land system change, nitrogen and phosphorus flows to the biosphere and oceans, and atmospheric aerosol loading (Stockholm Resilience Center, 2015). Despite the long list, some critical parameters such as the terrestrial and soil carbon stocks must also be included among the planetary boundaries. Depletion of soil organic carbon (SOC) content and stock below the critical/threshold level can set-in-motion soil degradation trends (Lal, 2020a; 2020b). Human impacts on planetary boundaries are amplified by the earth system interactions. Thus, a thorough understanding of earth system dynamics (Lade *et al.,* 2020) is essential to reducing the risks of land degradation. It is important to demarcate safe operating space so that the environmental footprint (land degradation) can be reduced. The global annual cost of land degradation may be as much as US $300 billion, of which $24 billion is incurred in South Asia (Nkonya *et al.,* 2016). Mythili and Goedecke (2016) reported that 44% of India's land area is degraded because of numerous and complex causes. The cost of land degradation and land use change (LUC) in India may be up to 2.54% of the gross domestic product (GDP) in 2014-15 (TERI, 2019).

Panagos *et al.* (2018) estimated that the 12 M ha of agricultural area in the European Union, that suffers from severe erosion, loses about 0.43% of crop productivity every year or Euro 1.25 billion $yr^{-1}$. The high cost of land degradation (Berry *et al.,* 2003) may be lot more than that of inaction (Nkonya *et al.,* 2016).

With direct ecological and economic consequences, and the risks of land degradation being exacerbated by the current and projected climate change, trends in land degradation must be reversed. The future challenge for developing countries (e.g., India) is to develop an effective strategy of feeding themselves without aggravating land degradation and environmental pollution, which are already under great stress. Despite numerous challenges, India aspires to achieve land degradation neutrality (LDN) by 2030. Therefore, the objective of this article is to define the concept of LDN adopted by the UNCCD and outline a strategy for developing countries to reverse the degradation trend and develop a long-term plan to realize LDN.

## 2. HISTORICAL DEVELOPMENT OF THE CONCEPT OF LDN

The UNCCD commissioned a white paper for presentation at the Rio+20 conference held in Rio de Janeiro in 2012. The paper, entitled "Zero Net Land Degradation" (ZNLD), was prepared by Lal *et al.,* 2012. However, the term ZNLD is not the same as zero land degradation (UNCCD, 2013), the former specifically aims at preventing the degradation of productive land and restoring land that is already degraded. Implementation of a global program on ZNLD involves cooperation among international organizations including UNCCD, United Nation Framework Convention on Climate Change (UNFCCC), United Nations Environment Program (UNEP), Food and Agriculture Organization (FAO) of the United Nations, national governments, and non-government organizations (NGOs). The Rio+20 meeting, entitled "The Future We Want," specifically focused on the significance of land management and especially that of soil, to sustainable agriculture and food security, climate change and water availability. The conference also recognized the "need to achieve a land degradation neutral world". The term LDN implies no net loss of the land-based natural capital relative to a reference state or baseline (Chasek *et al.,* 2015; Cowie *et al.,* 2018). The concept of LDN was also included in the sustainable development goals (SDGs) of the United Nations or the Agenda 2030 (UN, 2015a). Therefore, the SDG target 15.3 specifically states that its intention is to "combat desertification, restore degraded land and soil, including land by desertification, drought and floods, and strive to achieve a land degradation neutral world". In this context, each country must fix targets of land restoration. Accordingly, India aspires to restore 26 M ha of degraded land by 2030 (UNCCD, 2019).

The goals of LDN are to sustain and support the land resource capital and strengthen ESs. The two-pronged strategy is to reduce the rate of land degradation and increase the rate of restoration of degraded lands (Cowie *et al.,* 2018). To achieve LDN, it is important to follow the conceptual basis outlined in Fig. 1: i) establish the baseline regarding the type and extent of land degradation, ii) identify key soil parameters and establish critical threshold limits of those soil properties, and iii) determine the rate of change of these properties upon LUC or adoption of best management practices (BMPs). Establishing the baseline, or the aerial extent of degradation for different types, identifying key properties and their threshold levels, choosing site-specific BMPs, and promoting their adoption through participation of the farming communities. Nonetheless, these are among the most daunting challenges for developing countries to realizing LDN by 2030.

## 3. BASIC CONCEPTS OF ACHIEVING LDN

Since the launch of SDGs in 2015, there has been a strong interest in adoption of the concept of LDN, primarily because of the involvement of the UNCCD and other international organizations (Lal *et al.,* 2012; Tal, 2015; Stavi and Lal, 2015; Kust *et al.,* 2017, Cowie *et al.,* 2018). The philosophy of LDN and its adoption are also pertinent to realizing SDGs (#15) "Life on Land" (UN, 2015b), and especially Target 15.3. About 110 countries have voluntarily agreed to initiate the process of achieving LDN by 2030. In this context, SDG target 15.3 specifically provides a framework for creating a long-term vision to achieve multiple SDGs. Such a long-term vision involves following the response hierarchy of: Avoid > Reduce > Reverse

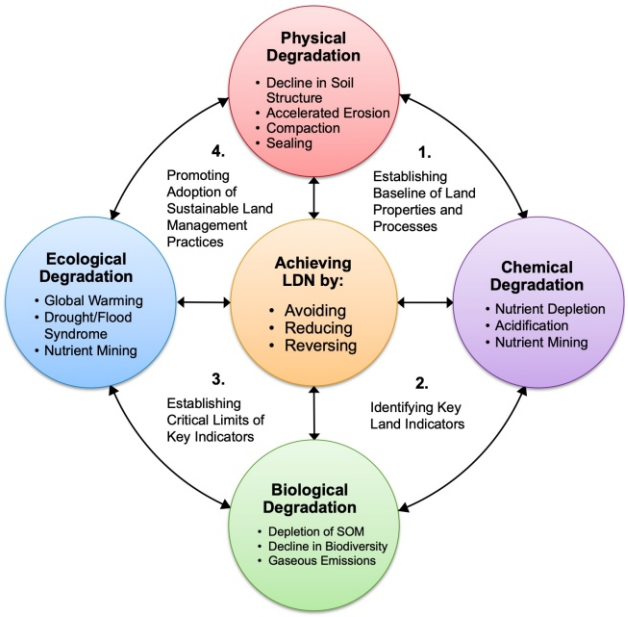


**Fig. 1. Conceptual basis of achieving Land Degradation Neutrality (LDN) by avoiding degaradation and restoring land degraded by different processes**

towards land degradation (Gilbey, 2018) and for achieving LDN. In addition to establishing the threshold limits of key soil properties, it is also important to determine (experimentally and modelling) how fast soil grows upon conversion to a restorative land use (LU) or land use change (LUC) and adoption of BMPs (Stockmann *et al.,* 2014). The rate of improvement may be slow for the initial period of 2 to 5 years and, thereafter, follow a sigmoid curve. Soil organic matter (SOM) content, being a key determinant of soil quality, establishing its critical/threshold level may be essential. The critical level of SOM (of which 50% is soil organic carbon) is 2 to 3% in soils of the tropics compared with 3 to 4% in those of temperate climates (Aune and Lal, 1997; Loveland and Webb, 2003). However, the critical level of SOM varies widely among soil types, land use and soil management practices (Lal, 2020a). SOM content in the root zone of cropland soils of developing countries (e.g., India) may be <0.5% because of the long-term use of extractive farming practices (Fig. 2), and it must be restored to realize the national LDN targets.

Realizing LDN involves developing a national road map. The latter must be based on: i) wholistic thinking, ii) a nexus approach based on inter-connectivity (Lal *et al.,* 2017), iii) nature-based solutions of restoring degraded lands, iv) sustainable land management (SLM) and, v) a soil-centric approach. Promoting adoption of these approaches may involve payment for ESs (PESs), and it may require changes in educational curricula from primary school to graduate and post graduate level, increasing awareness of the general public and of the policy makers. Once the restoration program is implemented, the impact of integrated land use planning on changes in soil properties must be assessed within i) specific land types, ii) follow like-for-like comparison, and iii) observe the strategy of Avoid > Reduce > Restore (Kust *et al.,* 2017; Cowie *et al.,* 2018; Gilbey, 2018; Matternicht and Cowie, 2018).

## 4. THE NEXUS APPROACH

The term "wholism" (or holism in Greek) is based on the concept that systems (physical, biological, social) should be considered as a whole rather than as conglomeration of its components. importance of nexus approach or inter-connectivity has been recognized for millennia by ancient civilization including Mesopotamia, Indus Valley, Vedic culture, Greek and Roman cultures (Lal *et al.,* 2017). During the 19th and 20th century, the concept of synergy; stating that the "whole is greater than sum of its parts," popularly attributed to Aristotle (SE Scholar, 2019); was widely appreciated in the western cultures (Poynton, 1987; Auyang, 1999; Oshry, 2007). Muir (1911), an American naturalist, stated that "When we try to pick out anything by itself, we find it hitched to everything else in the universe". Lovelock (1979) proposed the Gaia hypothesis that the planet Earth is one living organism. Synthesizing these ideas, Lal (2012) presented an inaugural lecture on the opening of the United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) on the theme of "Nexus approach to sustainable management of environment resources". The nexus concept is a system-based holistic approach aimed at harnessing synergisms of inter-connectivity among components realizing that the whole world is more than the arithmetic sum of its components. However, choice of components within the nexus kit must involve those which form a common denominator. In managed ecosystems and in the context of global issues, soil is the common denominator. Further, assuming a strong relation between food, energy, water (FEW) and soil, the nexus is appropriately called the FEWS Nexus (Lal *et al.,* 2017). To implement a nexus program for integrated soil management in agro-ecosystems, soil and water management for sustainable crop production must be done to sustain the resource base capital within the constraints of climate or ecological parameters. Appropriately implemented, the nexus approach to soil management can address several global issues including the followings: food and nutritional security, water purification and renewal, climate adaptation and mitigation, energy demand and supply, organic waste management, soil remediation and restoration, biodiversity, human health and well being, sustainable management of natural resources, and ecosystem security.

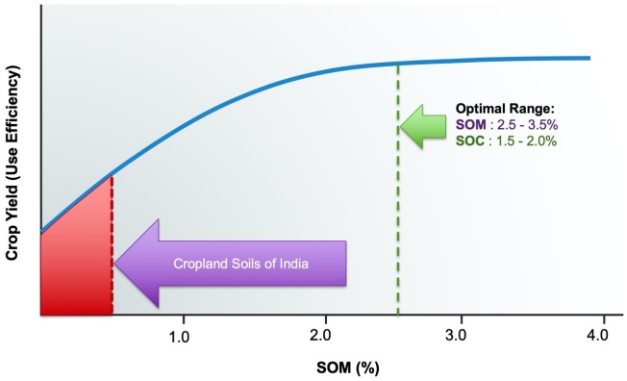


**Fig. 2. Threshold level of soil organic matter content in the surface layer of cropland soils in Inida and elsewhere in developing countries**

Some examples of nexus thinking involving translation of science into action include SDGs of the UN: achieving global food and nutritional security (SDG#2), soil carbon sequestration or 4 per 1000 (SDG#13) and realizing LDN (SDG#15). Another example of the nexus approach is that of using the soil-water-waste-energy nexus to address key issues (UNU-FLORES). In the era of urbanization, municipal waste is a resource for use as a source of energy and soil amendment. Resource use efficiency can be enhanced by material and energy recovery instead of landfill disposal of bio-waste (e.g., paper, food, wood, grass clippings). Thus, a multi-functional and integrated waste

management system is needed for inter-connectivity with agroecosystems. Such a nexus may be called soil-water-waste-energy (SWWE) nexus.

## 5. SUSTAINABLE LAND MANAGEMENT (SLM)

SLM refers to practices and technologies designed to integrate the management of land (soil, water) biodiversity, and other environmental resources to minimize the risks of degradation and optimize productivity. The goal is to protect and restore the land resource capital through a judicious management of the land capital by adopting BMPs (Fig. 3). The 1992 United Nations Conference on Environment and Development, popularly known as the Earth Summit (1992) identified SLM as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions" (Motavalli *et al.,* 2013).

Smyth and Dumanski (1993) explained the objective of SLM at harmonizing complementary goals of providing environmental, economic, and social opportunities for the benefit of present and future generations, while maintaining and enhancing the quality of land. World Bank (2006) defined SLM as "a knowledge-based procedure that helps to integrate land, water, biodiversity, and environmental management to meet rising food and fiber demands while sustaining ESs and livelihoods". TerrAfrica and FAO (2016) defined SLM as "the adoption of land-use systems that through appropriate management practices enable land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources". FAO (2017) defined SLM as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions." In essence, the term SLM refers to site-specific land use and soil/crop/animal/tree management practices which restore and sustain the land resource capital in perpetuity.

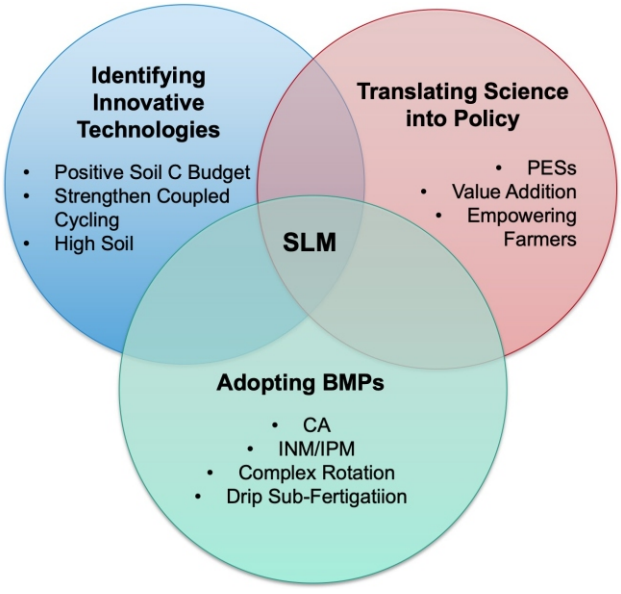


**Fig. 3. Some examples of technologies for Sustainable Land Management and synergism among them**

SLM is essential because of 1) a severe and global problem of the degradation of the land resource capital, 2) a need to eliminate food and nutritional insecurity, and 3) an urgency to mitigate climate change and improve the environment. In this context, ten tenets of SLM which must be adhered to are as follows :1) managing landscapes for effective soil and water conservation, 2) creating a positive soil /ecosystem carbon budget, 3) reducing emission of greenhouse gases (GHGs), 4) enhancing and sustaining land productivity, 5) restoring and sustaining soil quality and soil health 6) strengthening coupled bio-geochemical and bio-geophysical cycling of $H_2O$ with that of C, N , P, and S, 7) increasing above and below-ground biodiversity, 8) strengthening ESs of the land for human and nature, 9) improving quality and renewability of water, and 10) promoting nutrition-sensitive agriculture. In essence, these tenets are essential to realizing LDN at all levels.

The goal is to protect and restore the land resource capital through a judicious management of the finite and fragile land capital (Fig. 3). Some examples of SLM include conservation agriculture (CA), precision agriculture (PA), agroforestry and integration of crops with trees and livestock. While the relevance of such technologies is widely recognized, these should be implemented at landscape level with full participation of the farming community under site-specific conditions (WOCAT, 2008a; 2008b). The strategy is that of Integrated management of soil fertility, which involves judicious combination of organic fertilizers with supplemental and discriminate use of chemical fertilizers (Saginga and Woomer, 2009) so that emission of GHGs from agriculture is reduced (Smith *et al.,* 2008) and soil quality improved (Herrick, 2000; Carter, 2002).

Implementation of SLM involves three inter-related components (Fig. 3): a) identifying SLM technologies for site-specific situation, b) promoting adoption of BMPs such as CA, PA, direct seeded rice etc., and using integrated nutrient management, and c) translating science into action through policy interventions including PESs.

## 6. PAYMENTS FOR ECOSYSTEM SERVICES (ESs)

The national target of LDN of restoring 26 M ha of degraded land in India by 2030 (UNCCD, 2019) is a daunting challenge, especially in dryland eco-regions (Grainger, 2015). Further, farmers and land managers,

being the primary stakeholders, must play a critical role through an active participation in the entire process. Therefore, farmers must be rewarded through PESs for restoring degraded land and enhancing soil health. The concept of PESs, completely different than that of subsidies, must be revisited (Wunder, 2015) to ascertain that it is fair, just, transparent, and farmer friendly. It is important to design a system for PESs (Engel *et al.,* 2008) for site specific conditions. In this context, preparing the best practice guide of land and soil management practices (Wunder, 2015) may promote the adoption of BMPs and facilitate the PESs. Payments should be assessed for specific benefits of land restoration such as for improved watershed services (Porras *et al.,* 2013) and soil carbon sequestration (Lal , 2014).

Rather than direct payments (cash for adoption of site-specific BMPs), payments can also be made indirectly for providing the logistical support. For example, farmers in the Indo-Gangetic plains burn residues of rice in October and that of wheat in April to facilitate timely sowing of the next crop. Small land holders do not have the needed machinery for cutting/baling of crop residues and direct seeding of crops through the stubbles by using CA (e.g., no-till with residue retention as mulch). Thus, government or private companies could arrange machine rental services to eliminate the need for burning that would enhance soil health and improve the quality of water and air. In addition to providing machinery, farmers may also be rewarded for sequestration of carbon in soil (Lal, 2014), saving surface and ground water resources and improving their quality.

## 7. PLANNING FOR REALIZING THE NATIONAL LDN TARGET

Implementation of LDN program at national level requires a thorough planning with full participation of the farmers, land managers and community in conceptualizing a strategy (Fig. 4). Two interactive phases of the planning process involve interaction of: 1) science with policy and community, and 2) plan, implementation, and measurement and monitoring of the improvement in land/soil quality. The program can be implemented in different stages (Kust *et al.,* 2017, Cowie *et al.,* 2018): Stage 1 may involve a) establishment of a baseline for land quality by assessing types of land degradation (e.g., erosion, salinization, depletion of SOM content), b) identification of key soil properties and land parameters and delineation of their critical limits, c) development of a multi-year land use plan (for a district, region, province and nation) alongwith a time table on implementation of BMPs, and d) formulation of measurement and monitoring protocol to assess the impact of adoption of restorative land use and SLM practices. Stage 2 involves a) implementation of the chosen land use plan (for a district, region, province and nation) on annual basis, b) measurement of changes in soil properties of key parameters over the time period of 3, 5, and 10 year, and c) evaluation of net gain in land restoration for the specific region. Stage 3 comprises: a) any change in plan or choice of practices depending on the progress in rate of land restoration, and b) evaluation of the target of achieving LDN.

A well-thought out road map, encompassing these three stages, is needed to implement any regional or a national LDN program (Fig. 5). It begins with establishment of baseline with regards to the state-of-land degradation by using remote sensing techniques and ground truthing of land attributes and key soil properties. Scientific laboratories and technical personnel are needed to develop a credible protocol of measurement and monitoring of key land/soil properties, along with the establishment of their critical/threshold levels for specific land use (e.g., cropland, grazing land, forest land, national parks). Choice and implementation of site-specific SLM practices and promoting adoption of SLM through PESs and community

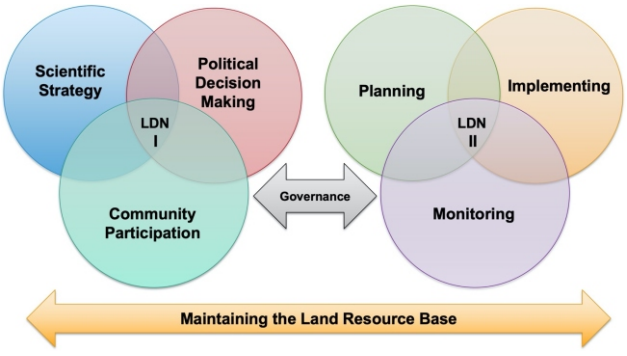


**Fig. 4. Planning for implementation of land degradation neutrality**

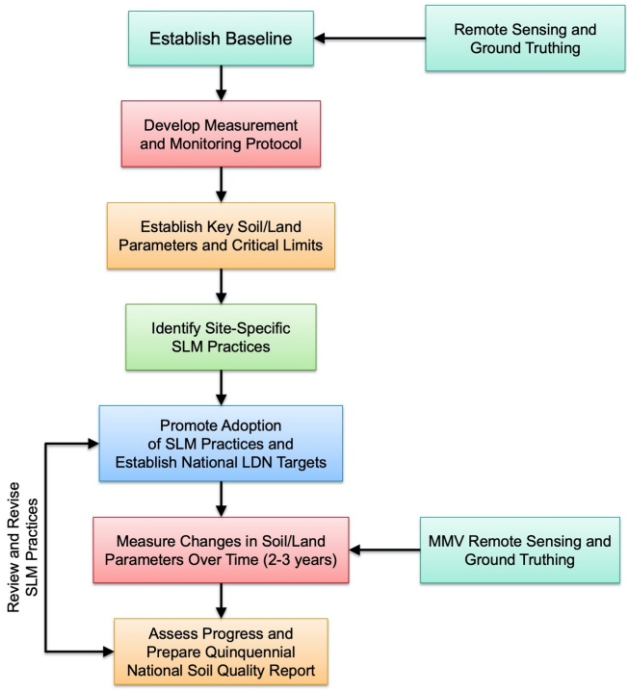


**Fig. 5. Roadmap for realizing national LDN targets**

involvement is critical component of the program. Once the SLM practices are adopted, measurement of land attributes and soil properties must be done periodically to assess progress in land restoration. Depending on the change in land quality, revisions of SLM may be required. National/ regional state-of-the-land/soil quality is needed on 5-years interval for decision makers and the community (Fig. 5). The impact of SLM may also be related to the quality of water (e.g., sediment load, concentration of plant nutrients in water), air, and vegetation cover. Community participation is essential to implementation of any LDN program. In this context, raising awareness among farmers and land managers about the serious condition of the land resources and the urgency regarding restoring degraded lands is of a critical importance. Sustainable management of natural resources must be integral part of the educational curricula from the primary and middle school to college and post graduate level. It is also important to establish channels of communication between scientist and academician on the one hand and policy makers and general public on the other.

## 8. CONCLUSIONS

Despite a range of reports on land area affected, credible estimates of the area affected by a range of land degradation processes at eco-regional and national levels are not available for India, and need to be assessed and mapped. The serious and aggravating problem of land degradation in India needs a very well conceptualized and properly implemented long-term national program(s) to reverse degradation trends. The national target of realizing LDN can be met by developing a road map to implement a program to restore degraded lands. Establishing a baseline regarding national state-of-the-land resources is the first step. State wise, road maps must be prepared to restore lands degraded by different processes by measurement and monitoring of key land/soil properties with regard to the pre-established threshold or critical level by promoting adoption of site-specific SLM practices following the holistic or the nexus approach. The nexus concept is a system-based approach aimed at harnessing synergisms of interconnectivity among components realizing that the whole world is more than the arithmetic sum of its components. A long-term program of achieving LDN follows the response hierarchy of: Avoid > Reduce > Reverse land degradation. The rate of land restoration may be slow for the initial period of 2 to 5 years and, thereafter, follow a sigmoid curve. Farmers and land managers must be rewarded for adoption of these SLM practices through PESs based on just, fair and transparent systems of payments. The goal of SLM is to protect and restore the land resource capital through a judicious management of the land by adopting BMPs. Reports on state-of-the-land/soil report, based on credible remote sensing and ground truthing methods must be prepared on a 5-years basis to document progress on realizing the national targets of LDN. A successful implementation of LDN program involves enhancing awareness of the general public about the need for reversing the land degradation trends. Increasing awareness among general public and policy makers about the urgency to restore degraded lands is essential and urgent. Environmental education must be part of the curricula from primary school to the post graduate level education.

## DISCUSSION

**Kumaraswamy Hosur,** Scientist (Biotechnology), ICAR-IIOR, Hyderabad: Is the achievement of land degradation neutrality an individual's mandate or the state's mandate? If it is state's mandate, then state must make it mandatory and should extend 100% monetary assistance to farmers / community / federal government. I want to hear the opinion of Dr Lal on this view, please.

**R. Lal.** It is responsibility of individuals and the State. Each one of us is both culprit and victim of taking soil and other natural resources for granted. Each one of us has a responsibility to adopt nature-friendly options. Even with a small gain at individual level (e.g. in saving energy and water, not wasting food, planting a tree on a denuded land, recycling biomass back to the land, protecting biodiversity), multiplied by 7.8 billion can make a major difference.

Yes, State also must play an important role in translating scientific information on land restoration into action through implementation of programs that avoid degradation, protect land, and restore degraded land. Land managers must be rewarded through payments for provisioning of ecosystem services. State must also set targets for land restoration and follow up in achieving these targets. Enhancing awareness among the general public regarding the need for land protection, avoiding land degradation and restoring land degradation is also among priorities for the State.

**Indraneel Ghosh,** Senior Advisor, GIZ, New Delhi: India Government LDN targets do not have detailed break up of degradation types, how to go about it?

**R. Lal.** Yes, there must be detailed plan on the type of land degradation that must be restored. Different types of land degradation prevalent in India include soil erosion (water, wind, ravine land, landslides, coastal and stream bank), salinization, water logging, acidification, elemental imbalance, There must be target established for each of these categories. In addition, there are other land degradation categories which are not assessed. Examples of these are depletion of soil organic matter content, decline in soil structure, soil contamination and pollution, surface sealing, land affected by brick making, mined land etc. Each category must be mapped and prioritized for implementation of the restoration plan.

**Visha Kumari V.,** PhD Scholar, Bidan Chandra Krishi Vishwavidyalaya, Mohanpur, West Bengal: Though long term experiments can help to understand the relation ship

between soil quality and degradation, I am curious to know if we have any standardized technique to measure the resilience of the soil?

**R. Lal.** I wrote an article on "Soil Resilience" and it was published in Proc. Royal Soc (B) in 1997. Reslience can be quantified and modelled for each category. For example, soil erodibilty (susceptibility to soil erosion by water and wind) can be quantified and the impact of land use and management on erodibility determined. Similarly, rate of soil organic carbon sequestration and its turnover can be measured and modelled. In severely eroded soil, which has lost its top horizon, the rate of new soil formation can be assessed and modelled when restorative land management options are adopted. However, the term "soil resilience" is more than a specific process or a property. Thus, identifying key properties and processes and then try to develop a model that integrates them into a process-specific resilience index is a priority research project.

**Boini Narsimlu,** Sr. Scientist, ICAR-CRIDA, Hyderabad : Is it possible in LDN to bring it to restoration as nature conservation?

**R. Lal.** Yes, indeed. Achieving LDN at regional or national level is an important component of nature conservation. If denuded lands of the Shiwalik hills are restored by afforestation and the land is protected, this is a great strategy of Nature Conservation from Kashmir to Tripura and Assam. You are correct, LDN is a first step in Nature Conservation.

**Shamla Rasheed,** Assistant Engineer, Department of Soil Survey and Soil Conservation, Kerala: How do we fix the target for LDN if the level of degradation is hit by a major disaster?

**R. Lal.** Severity and frequency of disaster caused by extreme events are symptoms or ramification of severe problem of land degradation. For example, when steep lands are denuded of the vegetation cover and soil is bare, we have an event of disastrous floods during the rains and drought and heat wave during the dry seasons. When the land resource capital is restored the frequency and intensity of these disasters will decrease over time. Therefore, it is important to fix the targets of LDN and stay on the track to realize these targets so that the disasters can be prevented. The prudent and an effective strategy to minimize disasters is to restore degraded lands and achieve LDN.

**Kiran Reddy,** Student, ICAR-DGR, Junagadh, Gujarat: How do we achieve LDN under rapid urbanization and Industrialization? We are releasing many harmful chemicals through our Industries like heavy metals etc. into environment. Does Artificial Intelligence and nano-technology help us in achieving LDN goals?

**R. Lal.** Yes, *ad-hoc* urbanization, conversion of prime farmland into urban and industrial land uses involving surface sealing and indiscriminate dumping of chemicals and pollutants, must be addressed as a high priority. Prime farm land must be mapped out and protected against non-agricultural uses. A few sites must be identified within each district for mining sub-soil (to deeper depths) for brick making rather than removing one meter of fertile topsoil for brick making as is being done now. Alternative sources of materials for brick making (e.g., fly ash, rice husk) must be identified. Disposal of industrial waste must be regulated and only a few suitable sites chosen (away from the major aquifers and in geologically stable landscape) for disposal of industrial waste. Environment Policy Agency must play a critical role, as should the education of general public and communities as a whole in land protection and sustainable management of natural resources.

**P. Raja,** Pr. Scientist (Soils), ICAR-IISWC, RC, Udhagamandalam: What should be the role of farmers in preventing land degradation and what should be the scientists role in creating the awareness among farmers about protecting soil resilience?

**R. Lal.** Farmers are the most important stake holders in protecting land (soil, water, vegetation biodiversity, air).They must be rewarded and supported for protecting and restoring soil, wate, air and vegetation. In-field burning of crop residues is an important example. Only farmers can stop it, provided that they are given technologies that can seed the next crop through a land which has a lot of wet residue on its surface. It can be and must be done. Farmers are also important to protecting the surface and ground water resources, and the quality of these water against pollution and eutrophication. They are also critical to protecting biodiversity.

However, small land holders and resource-poor farmers, need support to protect finite and the precious soil, water and biodiversity resources because they cannot afford to undertake the recommended management options. Therefore, payments to farmers for ecosystem services (e.g., carbon sequestration in soil and vegetation, water conservation and quality improvement, soil biodiversity enhancement). Payments must be made on the basis of fair, transparent and just systems based on the societal value of services provided.

**Pratap Ray Bhatnagar,** Pr. Scientist, ICAR-CSSRI, Karnal: LDN targets thought appropriate interventions to be implemented by Government agencies but participation by beneficiaries has to be ensured for proper implementation and future maintenance, how to make participation of locals and stakeholder more fruitful?

**R. Lal.** Community participation on any program to realize LDN is essential to its Successful implementation. Local communities, being the most important stakeholders and beneficiaries of the LDN, must be active partners in the

process from the planning stages onward. They must understand the need for LDN and be a part of the change in land use and management.

How to involve them is an important question. Planners must develop a rapport with the local communities, and win their trust. Through communication and dialogue, communities must be made to realize that LDN is in their interest. To be successful, communities must buy into the project and take its ownership. However, they must be rewarded for undertaking LDN. Trust, based on mutual respect, between community and the project managers is critical to the success of the project.

**Ranjan Paul,** Scientist, ICAR-NBSS&LUP, Nagpur: How realistic it is to adopt the concept of carbon 4 per mile concept in tropical soils of India and revert soil degradation where enhancing organic C in soil is a big challenge?

**R. Lal.** The 4 per 1000 is a slogan. It is an aspirational goal. It is an idea how to make agriculture a solution to climate change. Even if we can achieve 1 per 1000 to 40 cm soil depth, it is still a success story. The strategy to begin with is to adopt those land use and management practices which can create a positive soil and ecosystem carbon budget.

Since 2015 when 4 per 1000 was launched during COP21 in Paris, all subsequent COP meetings (Marrakech, Bonn, Warsaw and Santiago/Madrid) have endorsed land-based strategies to address climate change and make agriculture a solution to global warming and addressing other environmental issues. Policy makers have given soil scientists and agronomist an opportunity to help translate their science into actions. Soil scientists and agronomists must seize the moment and support policy makers in adopting land based solutions. This is an opportunity that agricultural scientists must never miss.

It is the journey towards 4 per 1000 which is important, and not the exact destination. Once again, farming communities must be involved in this important journey.

**P.K. Mishra,** Consultant, ICRISAT, Bhubaneswar: What is the importance and ease of data availability in public domain for planning for LDN as a national commitment? What is its status in developing world?

**R. Lal.** We must have credible data on the state-of-the-soil with regard to the extent and severity of land/soil degradation by different prococesses (e.g., erosion, salinization, depletion of soil organic matter). To do that, soil scientists must identify key soil parameters and their critical limits beyond which soil/land quality is degraded and ecosystem services are jeopardized .Once the baseline is established, then the recommended land use and soil management practices must be implemented through a community participatory approach. The impact of land use change and soil management must be assessed on restoration by periodic evaluation of key soil/land parameters.

It is appropriate that the baseline map of the state-of-the -soils of India be prepared by 2020, land/soil restoration measures adopted (e.g., no in-field burning, use of conservation agriculture, integrated soil nutrient management, drip sub-fertigation, aerobic direct seeded rice), their impact monitored on periodic basis by combination of remote sensing and ground truthing, and the national soil quality report prepared once every 5 years to assess the progress. These soil/land quality maps must be prepared on a fine scale of 1:10000 for them to be practical but never more than 1:50000.

It is true, that such data are not available for developing countries. Nonetheless, India has a large network of research institutions under ICAR to implement such a program, and India can also provide technical support to other developing countries in South Asia, Sub-Saharan Africa, Central America and. the Caribbean and elsewhere. This is the right time for India to take the leadership role among developing countries.

**M. Madhu,** Pr. Scientist and Head, ICAR-IISWC, RC, Koraput: Practically is it possible to achieve LDN? By 2030, can India achieve 26.0 M ha which required huge capital and growing population is also a great concern.

**R. Lal.** It is a daunting challenge to achieve land degradation neutrality, but, India is signatory to this agreement and must undertake the project on LDN which is in its own interest. To restore 26 M ha by 2030 may be an aspirational slogan, but it cannot be ignored and an earnest start must made toward fulfilling the commitment. Even if only 50% of the required land area will be restored by 2030, it is a path in the right direction, Further, the lessons learnt from this journey are important to understanding the processes of protecting, avoiding and. restoring finite land resources.

The question of investment is pertinent. I must state, however, many studies have shown (Nkonya *et al.,* 2016 by IFPRI) that cost of inaction is lot more than cost of restoring degraded land. Neither India nor any developing or developed nation can afford to do nothing about this serious menace of land degradation which can be justifiably called "Plague of the Land".

**Suheel Ahmad,** Scientist, ICAR-IGFRI, Jhansi: After how many years we should assess the effects of afforestation, reforestation and what importantly parameters are particularly important so far as land degradation is concerned.

**R. Lal.** Land /soil restoration, especially the building up of soil organic matter content and formation of new soil, are slow process and occur over generational and centennial scale. Strong positive impacts of land restoration on pedological processes (e.g., carbon sequestration, water runoff and sediment transport into the streams and reservoirs) is observed over a decadal scale of 10 to 20 years or more. We must exercise patience and continue the restorative process so that land resources are improved for

enhancing critical services for human wellbeing and nature conservancy. In this context, the importance of long-term soil management experiments can never be over-emphasized.

**Alka Rani,** Scientist, ICAR-IISS, Bhopal: Can soil sealing caused by rapid urbanization be considered under land degradation?

**R. Lal.** Yes, indeed, surface sealing by rapid and *ad-hoc* urbanization is a serious issue and must be assessed in terms of environment and ecological footprint, surface sealing has strong impacts on hydrological and energy balance of the urban eco-systems. It also impedes gaseous exchange and is a principal determinant of the so called "heat island effect". In addition to minimizing the land area affected, by planning for green space and urban parks etc, sealing material chosen should be permeable to water so that water runoff is minimized and there is less risk of eutrophication of agro-ecosystems. Surface sealing is a major issue in Europe and it is an important point of discussion at environmental fora.

**Trisha Roy,** Scientist, ICAR-IISWC, Dehradun: For different soils the threshold limit of the different soil properties at which the soil performs optimally will be different. So how do we understand or conclude which is the threshold value for each soil property in connection to land degradation?

**R. Lal.** Identifying key soil properties and processes which impact soil/land degradation and establishing their threshold values is essential to developing a successful LDN program. There is some literature available on this theme. USDA-NRCS commissioned a report prepared: Lal, 1994. Methods and Guidelines for Assessing Sustainable Use of Soil and Water Resources in the Tropics. USDA/SMSS Bulletin 21, Washington, DC, 78p. It has since been translated into Spanish and Portuguese for use in Latin America.

This report provides some examples of key soil properties and their threshold limits. It is important to identify these properties for site/region specific situations in India and also their threshold levels with regard to land use, bio-physical and socio-economic factors.

**Debashis Mandal,** Pr. Scientist (Soils) and ICAR National Fellow, ICAR-IISWC, Dehradun: For achieving land degradation neutrality with respect to soil erosion two sets of information is very important; i) the present status of degradation in quantitative term (only erosion rate is not sufficient) and ii) its potential to be restored. There is a need to assess those soils/land which may be recoverable. To what extent does current understanding of soil processes allow this identification?

**R. Lal.** Yes, you are correct about both requirements listed by you. India has a strong research network under ICAR, State Agricultural Universities and other NGOs. While additional research is needed, we have sufficient knowledge about soil properties and processes and the impact of sustainable land management (SLM) on land restoration. Thus, the LDN process can be implemented at the state. Level for key processes such as soil erosion by water and wind and restoration of eroded. Land Reclamation of salt affected soils can be another project ready for implementation to protect, avoid and restore salinized soils. We understand a lot about soil organic carbon dynamics in agro-ecosystems. Re-carbonization of the terrestrial biosphere (soil and vegetation) is another process that merits implementation. While, new research is continued, it is of utmost important that the known scientific. Information is translated into action to achieve LDN at district, state and national level.

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