Soil security and policy

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Soil policy has been addressed in several articles, but only at the textual level and without integrating the two key aspects: soil threats and soil security. Soil threats have been a topic of discussion, leading to the concept of soil security. Soil security is important, as many authors have recommended framing a soil policy to protect soils, with special reference to threats arising from global warming. The present article aims to frame a soil policy model using the concepts of 4Es (exploration, education, extension, and empowerment) and 7Cs (capacity, connectivity, communication, condition, capital, codification, and care) respectively.

Keywords: Global warming, model, soil policy, soil security, soil threats.

ANY civilised nation thinks positively about preserving natural resources. Conserving nature is more challenging these days, given both natural and anthropogenic influences on national resources, such as soil, on which a significant portion of the population will rely. These soil threats prompt us to take soil security more seriously. To secure soils against threats, a sound soil policy with a framework and parameters for protection, sustainable use, and management is necessary. Soils require safeguards to enhance their vitality and productivity through scientific research and advancement. Such research efforts would require developing a comprehensive strategy to increase the adoption of soil health management systems, incorporating a soil health reference for farmers and stakeholders.

Soil conservation, from an overall perspective, protects soils from harmful impacts, restores degraded soils, improves awareness of the value and sensitivity of soils, and strengthens international commitment. There is a great demand to balance immediate needs with long-term investments, build a business case model with cost-benefit analysis, and provide a clear roadmap to frame the terms of reference for soil use without harming the Earth. Gaps in science related to climate change, data infrastructure, and soil health indicators are crucial to address the need for soil monitoring frameworks that develop soil policy that takes these issues into account.

In framing a soil policy, international collaborations are key to success, alongside the collection of reliable, robust data from available soil information systems[1,2]. Soil policy framing also requires data-sharing platforms. Multiple benefits for food production, climate resilience, carbon storage, and water management, as well as numerous environmental benefits such as biodiversity and ecological balance, should be incorporated into soil policy. Planners should also ensure that the soil policy is understandable to stakeholders[3]. The information gap, if any, can be addressed through academic discussions and deliberations, with excellent institutional coordination. An inclusive approach will involve greater community input, such as from the gram panchayat, in the national decision-making process.

In the Indian context, soil degradation and depletion have long been addressed, underscoring the importance of soil health in mitigating soil productivity loss through natural farming (NF). This chemical-free traditional farming method[4] integrates crops, trees, and livestock to sustain biodiversity[5]. Several studies[4,5] indicate that, for more coordinated action in soil governance, various schemes and programmes in India need to be better aligned. A stand-alone soil policy could be the first step in catalysing actions to mainstream sustainable soil management practices. Such a policy would recognise the soil jurisdiction to connect the national vision with the regional and local participants.

At the local, regional, and international levels, the benefits of soils are well appreciated. The benefits of soil are important because they transcend human life, expertise, and experiences over many generations and even centuries. The soil is situated at the interface between the atmosphere, biosphere, hydrosphere, and lithosphere. It is the ultimate result of the interaction of various factors, including climate (atmosphere, hydrosphere), relief, biosphere, organisms, parent material (natural rocks and minerals), lithosphere, and time. A range of services essential to our health and the well-being of society, in general, and the environment, in particular, are provided by the soils. Soils are under pressure due to the demand of the burgeoning global population. By 2050, soils will be required to support, regulate, and provide cultural services for ~9.6 billion people, supporting essential services for all ages[6,7]. The soil, a finite natural resource, is under threat in several dimensions[8] to provide a range of essential services for our health and well-being.

Several significant existential environmental challenges have been identified as crucial to the sustainable development of humanity and the planet, encompassing

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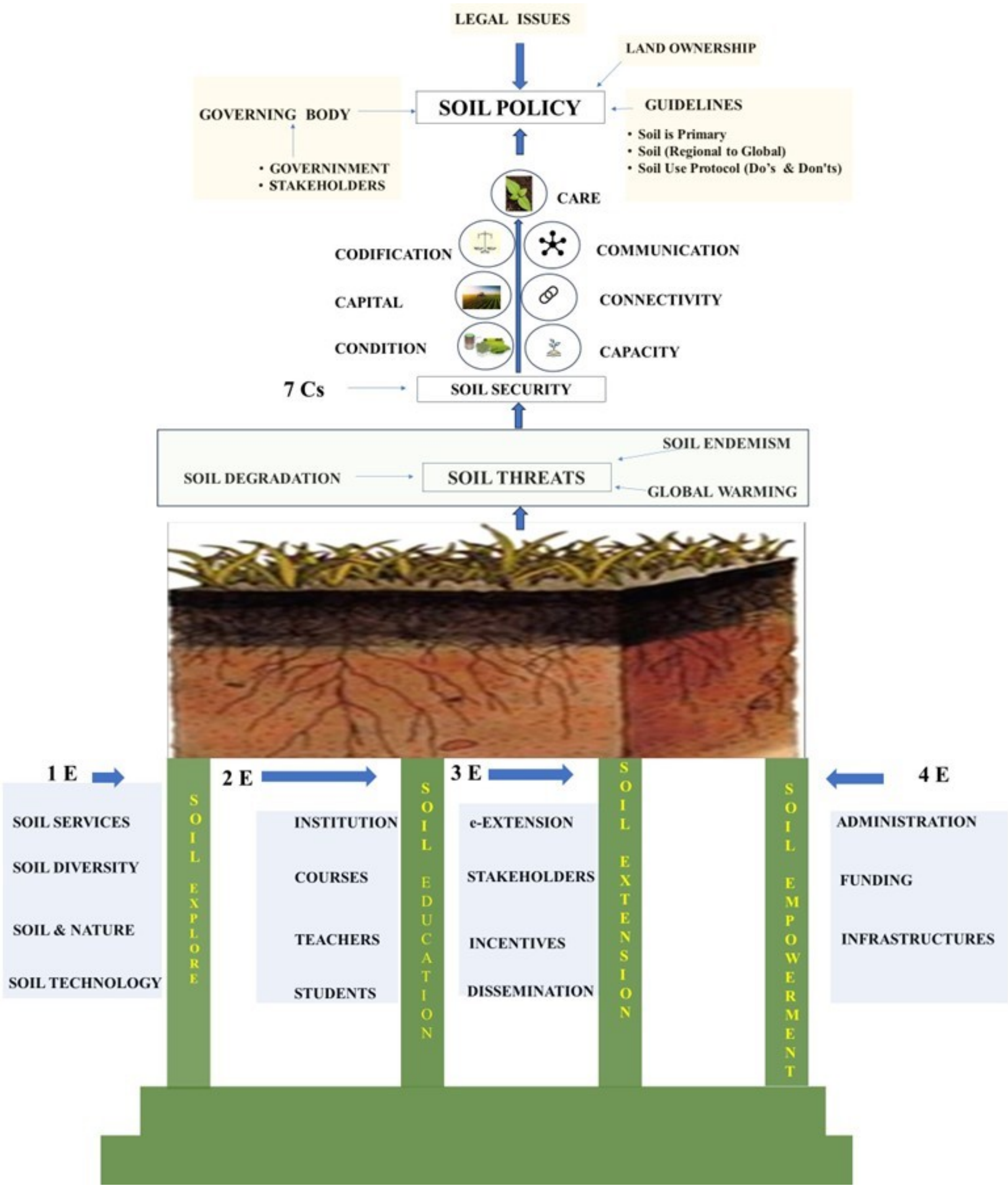

Figure 1. A suggested soil policy showing its interconnectedness with soil threats and soil security.

interrelated issues such as food, water, energy, climate, biodiversity, and soil ecosystem services. Available literature indicates various issues related to soil threats, soil security, and biodiversity, suggesting the need to develop a soil policy model to safeguard nature[1,3,4,5,8–12]. These challenges indicate a need for a comprehensive soil security plan that is multidimensional in its approach to the social, economic, and environmental aspects[10]. Soil security attempts to integrate the existential challenges concurrently through the seven factors of capacity, connectivity, communication, condition, capital, codification, and care. The present article suggests a soil policy model based on the 4Es (exploration, education, extension, and empowerment) and 7Cs (capacity, connectivity, communication, condition, capital, codification, and care).

4Es of soil policy

There is a demand for soil-centric policy to protect soils and ensure soil security. Soil security is achieved through an understanding of the soil ecosystem, highlighting the multifunctionality of soils and underscoring the need for an effective soil policy. The soil security concept helps understand the basic principles of soil threats and soil endemism, and recognises soil resources as a gift of nature, thereby helping develop a policy framework to realise the importance of the four Es (4Es) as briefly described below (Figure 1).

Exploration

Exploration encompasses soil services, soil diversity, the interplay between soil and nature, and soil technology for the ecosystem. Soil services include:

- Provisional services to predict soil carbon reserves and soil quality, thereby controlling food, fuel, fibre, raw materials, and freshwater reserves.
- Regulating services for soil carbon sequestration, pedoclimate, gas regulation, water regulation, water purification, soil erosion, and flood control.
- Supporting services to affect soil formation, influencing nutrient cycling, biodiversity, and human health, and
- Cultural services that are used to maintain cultural heritage, maintain soil in good health for a progressive nation, and vice versa.

Soil diversity: Soils are diverse throughout the globe. Terrestrial diversity, in most cases, centres on the above-ground flora and fauna. The terrestrial ecosystem warrants special mention for its diverse soil systems, which are linked to pedodiversity and biodiversity and provide the ecosystem services mentioned above. Studies have shown a strong relationship between soil diversity and biodiversity, with implications for various regional and global planning contexts[4].

Soil and nature: The importance of combining modern science and technology with traditional farming as a way to overcome agricultural poverty and help develop villages was recognised by our predecessors. This requires an understanding of the science and the application of advanced technologies based on recent research findings on soils and soil carbon, as well as the latest trends in climate change, which are leaving carbon footprints in nature.

Soil is often referred to as *Dhartī/Bhoo Mata* (Mother Earth), which is closely related to the cosmic elements. Scientists and professors are striving to uncover the truth about soils for the benefit of posterity and future generations. This understanding necessitates revisions to the educational system, the research agenda, and related areas. Our ancient knowledge of the basics of soils and land always helps us comprehend the essence of natural resource management.

Soil technology: Soil technologies encompass various aspects of soil organic and inorganic carbon sequestration to maintain soil quality and health, as well as soil restoration to control erosion and degradation. Soil compaction control, fertility management, modern irrigation techniques, and soil monitoring should be integrated to maintain soil quality. Agronomic practices include soil amendment application, optimisation of tillage and cultivation methods, and planting high-quality crop varieties developed through biotechnology. Manure application, bi-otillage, cover crop planting, and diversified cropping systems are integral to modern agricultural technologies. The application of remotely sensed data for soil monitoring is also an important aspect of modern techniques (Figure 1).

Education

This includes various issues such as:

- Good educational institutions to impart education on soil and natural resources.
- Studies on soils, informed by the knowledge of our predecessors, will be beneficial. This may necessitate the formulation of soil courses for primary, secondary, college, and postgraduate studies, with the involvement of quality teachers[12,13].
- Good-quality teachers signify both the number and the quality of teachers and professors. Increased teaching loads require trained staff at schools, colleges, and universities. Quality experts should select quality teachers based on merit and performance[12].
- For research and academic purposes, students with better academic performance should be segregated at the school level. Students selected in this manner must possess an aptitude for the profession and creativity. A rigorous selection process is necessary (Figure 1) (ref. 12).

Extension of soil information

This can be carried out using various methods:

- Via electronic media (e-Extension) for disseminating the information on soils to the local and global audiences using Information and Communication Technologies (ICT) with all available modern facilities[13].
- Information for stakeholders, including teachers, students, other staff, and farm families in the rural sector, sends a positive signal to users of soil, helping make soil policy more effective.
- Incentives to help performers make their efforts rewarding through the process of extension activities.
- Publication to reach stakeholders through the dissemination of information[14], using the print media as a valuable tool for informing people about soil security and soil policy.

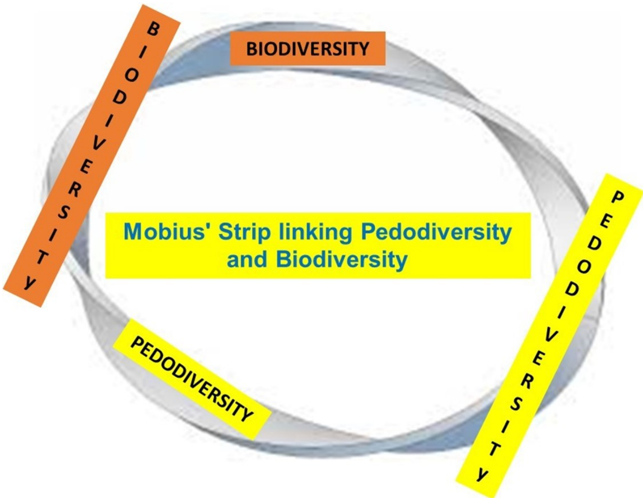

Figure 2. Mobius strip linking pedodiversity and biodiversity: two important aspects to frame soil policy.

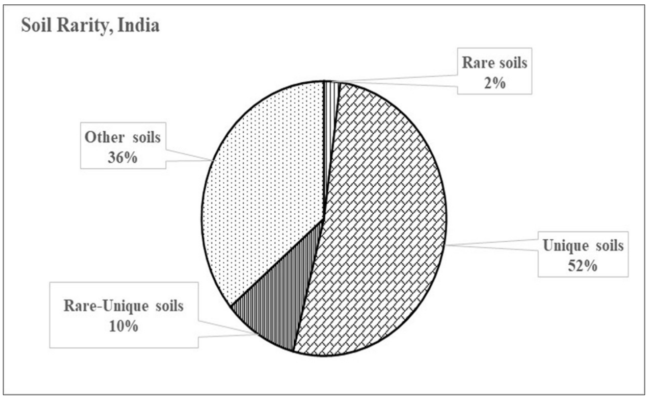

Figure 3. Soil diversity and rarity for Indian soils (at soil family level of soil taxonomy[6,19]).

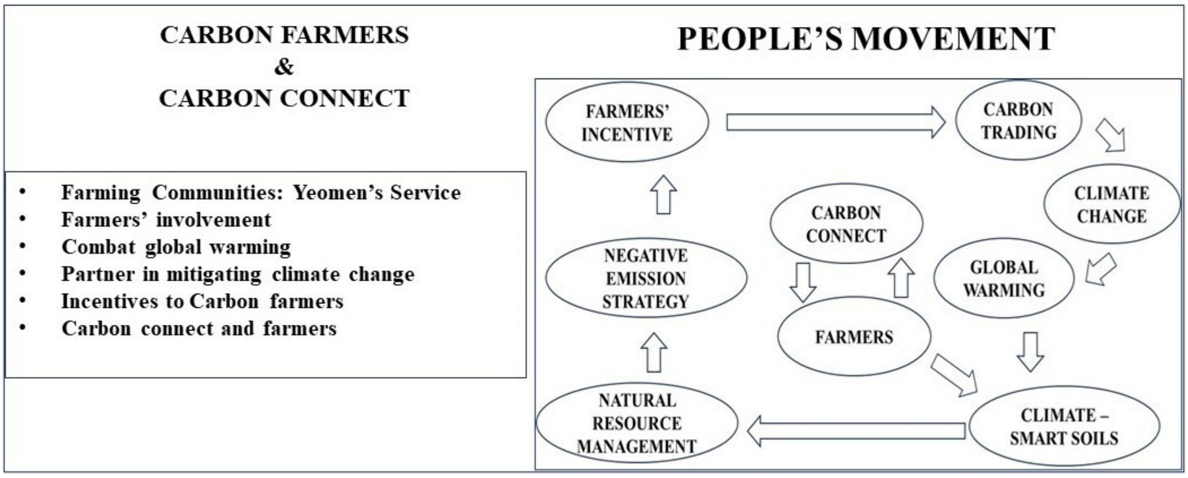

Figure 4. Soil carbon connecting farmers as participants to fight global warming.

Empowerment

This consists of the following:

- *Administration*: As part of soil policy, soil security needs to be administered within the system with the active participation of natural resource managers.
- *Funding*: Finance is necessary to implement the 4Es of soil policy. Proper investment in research and the development of new technologies, including AI-driven software, is required to mitigate soil degradation and ensure soil conservation. Funding is also necessary to improve the quality of education, recruit quality teachers, and offer scholarships and fellowships to attract the best students to study soils.
- *Infrastructures:* Infrastructure is the foundation of all the institutions that carry out soil research, education, and extension. In the modern age of communication technologies, an educational institution, other than the building, requires many other infrastructural facilities (hostels, roads, student-staff health care, and many other facilities) (Figure 1).

The literature suggests that soil carries the physical and cultural history of our civilisation, which will be useful information for framing soil policy. The 4Es of soil information help in understanding soil threats, which are again connected through three important issues (Figure 1), such as:

- *Soil degradation*: This is due to natural and human-made factors, with special reference to chemical degradation. Chemical contamination, soil erosion, sodification, salinization, and acidification form other aspects of soil threats.

- *Soil endemism*: According to their importance and the gradual process of extinction, plants, trees, animals, soil types, and biodiversity are reported to face the danger of extinction. Pedodiversity and biodiversity are two interrelated aspects of natural diversity, and their relationship is often depicted as a Möbius strip. This curious and intriguing object can be created with a strip having only one surface. Once created, it will give the illusion of a single continuous surface. The concept of diversity has been widely used in ecological studies in connection with biodiversity (Figure 2) (ref. 15). They are distinctly different, yet once we understand their link, it becomes difficult to consider them as two separate surfaces. We can infer the richness of either of these from the richness of the other. Thus, a region rich in biodiversity can be safely assumed to have a high pedodiversity. Biodiversity can be a mechanism behind the performance of an ecosystem, particularly in communities of above-ground organisms. Soils, which occur below ground, are not well understood in terms of their impact on biodiversity.

  As in plants and animals, soils exhibit endemism, a key concept in ecology referring to plant or animal species that occur naturally and are confined to a specific geographic area. Soil endemism has been defined as the taxonomic richness of soil communities (types), which is quantified using soil data. An understanding of soil endemism helps identify rare, unique, and rare-unique soils. Soil endemism is influenced by broad climatic and vegetational effects, resulting in zonal soils (mature soils developed under optimal soil drainage conditions over a prolonged period). Unusual conditions of parent material or topography form intrazonal soils (indicating a lack of distinct horizon boundaries between soil layers) and azonal soils (poorly developed soils), which exhibit weak endemism. There is no accepted standard for defining soil rarity in the literature, except for Amundson *et al.*[16], who suggested a few guidelines for the United States. Zonal and intrazonal soils are generally endemic (rare and unique soils).

  In contrast, azonal soils (other soils, Figure 3) are neoendemic. The modified areal extent for Indian soils includes rare (occupying an area of < 500 ha), unique (existing only in one state), and rare-unique soils (covering a total area of < 5000 ha in one state)[8]. The quantitative definition of these three classes (rare, unique and rare-unique) is the first approximation for evaluating soil diversity in India. Amundson *et al.*[16] defined endangered soils, which were qualitatively assessed for the rare and/or unique soils that have lost more than 50% of their area to various land disturbances. The diversity and rarity of Indian soils are illustrated in Figure 3, where other soils indicate multiple soil types spread across different states to a considerable extent.

- *Global warming:* Global warming, with special reference to soils, is leading to a decline in organic carbon reserves, accompanied by a concomitant increase in soil inorganic carbon (due to the formation of pedogenic calcium carbonates), which renders the soils sodic and unfit for agriculture. The role of soil as a crucial natural resource for sequestering and storing atmospheric CO_2 to mitigate the effects of climate change has been addressed by many researchers. There has been a considerable interest in mitigating climate change through the sequestration and storage of carbon in soil. Soils provide important ecosystem services at both local and international levels and are the mainstay for crop production. Soils act both as sources and sinks of carbon.

7Cs of soil policy

Appropriately addressed, the soil threats might also lead us to secure soils for a soil policy model using the revised 7C approach[8], as detailed below.

- *Capacity*, including soil biomass production and other intrinsic properties of soil (cation exchange capacity and available water-holding capacity).
- *Condition* that is dependent on soil physical, chemical, mineralogical, and biological properties.
- *Capital* that demands addressing the values of the soil produce, involving the estimation of the values of food, fibre, feed, and other farm products to help build a robust soil policy.
- *Connectivity* indicates social involvement in terms of awareness among a diverse range of consumers.
- *Codification* suggests developing codes for the evaluation of soil quality (with special reference to soil C storage in the face of the global warming threat, which may be used as a legal instrument to arrive at a soil policy. Linking soil quality and the stakeholders might benefit the farmers in three ways:
  (i) It will make them more vigilant about soil quality (in terms of soil parameters such as bulk density (BD), soil organic carbon (SOC), and soil inorganic carbon (SIC)) while doing a periodic monitoring of soil quality with the state agricultural universities' (SAUs) supervision,
  (ii) This will also incentivize the farmers to maintain both the forms of soil carbon (SOC and SIC)[17], and
  (iii) Make them proud participants in mitigating climate change in the overall battle of combating global warming (Figure 4) (ref. 17).
- *Communication* indicates the use of ICT and AI to understand soil threats and combat soil security. There is an urgent need to transform knowledge-delivery systems by strengthening the science of delivery, which has been overlooked by researchers, development workers, and policymakers. Availability of new technologies such

Table 1. Themes of World Soil Day by the Food and Agriculture Organization (FAO)

Year	Theme
2015	Healthy Soils for a Healthy Life
2016	Soils & Pulses: Symbiosis for Life
2017	Caring for the soils starts from the ground
2018	Be the Solution to Soil Pollution
2019	Stop Soil Erosion, Save our Future
2020	Keep soil alive, protect soil biodiversity
2021	Halt soil salinization and boost soil productivity
2022	Soils: Where food begins
2023	Soil and Water: A Source of Life
2024	Caring for Soils: Measure, Monitor, Manage

as information technology (IT), internet of things (IoT), audio and video communications through mobile, geographical information system (GIS), simulation modelling, remote sensing (RS), and artificial intelligence (AI) opens up new vistas for effective knowledge delivery for achieving the impacts on the ground. Awareness creation through formal and informal methods facilitates mass communication for skill building, knowledge, and practices via e-Extension (eE). The eE is envisioned to operate primarily through web portals, social media, and mobile apps and to offer several benefits over traditional extension approaches. The methodologies are portable, cost-effective, and can reach a larger section of people in real-time. Most of these technologies are interactive, allowing stakeholders to connect online or offline and provide quick feedback. The major benefit of e-Extension is its ability to integrate various farm and extension media, including text, pictures, videos, and animations. The eE provides opportunities to improve the lives of vulnerable populations, including women and unemployed youth. There is scope to foster public-private-expert partnerships among farmers through eE. Resources, such as finance and insurance, can also be mobilised more easily through this technique. The eE stands on four interconnected bonds, namely e-learning, e-extension, e-farming, and e-trading. Initiatives to map remote villages online will further enhance the e-learning process for farmers.

- *Care*: The soil is the heart of the Earth. It maintains Earth's overall balance and fosters a relationship between the Earth, atmosphere, hydrosphere, and biosphere. It possesses physical, chemical, mineralogical, and biological properties essential for crop and tree production, as well as soil microbial growth. Thus, soils maintain a sustainable balance between environmental elements and biodiversity, which demand utmost care. Caring for soil is more necessary due to the growing population, which makes the carrying capacity of soils for sustenance increasingly difficult. Furthermore, climate change and the associated problems discussed above suggest that soil care should be a crucial component of a viable soil policy. Soil care, therefore, is of utmost importance and should be a part of soil security to foster an interconnectedness with the natural resources, nature, biodiversity, and ecology[15,16].

Soil policy

Soil threats and soil security necessitate the development of a comprehensive soil policy with clear guidelines, making soil a primary natural resource for establishing a protocol for its use. These protocols, with clear dos and don'ts, should be made compulsory, accompanied by stringent rules from the regulatory body to prevent soil abuse and protect agricultural land from being used for non-agricultural purposes. Soil is important, and if not protected locally and regionally, it might impact global soil resources. A governing body may be established in collaboration with the appropriate organisations and stakeholders, involving farmers and legal landowners. The governing body will develop guidelines to examine the legal issues and create a soil-centric policy that protects our planet for future generations (Figure 1).

Way forward

We must secure positive behavioural change on farms, delivering multiple public benefits, empowering farmers to make better-informed decisions, securing consensus, and promoting integrity and transparency to inform soil policy. Our food system has prioritised short-term production and profit over long-term environmental sustainability. The modern agricultural system has led to significant soil contamination, degradation, and erosion in many areas, resulting in a long-term decline in productivity. This suggests conserving soils to achieve the Sustainable Development Goals (SDGs). Three relevant land management indicators of SDG have important connections with the soil policy, such as (i) proportion of land degraded over total land area (15.3.1), (ii) terrestrial protected areas as a percentage of total land area (15.3.2), and (iii) ratio of land consumption rate to population growth rate (11.3.1) (ref. 1).

Land and resource management policies have been successful in areas where (i) local community participates in the programme, (ii) private investment in soil and water conservation is supported by public, (iii) roads are improved and well maintained, (iv) macroeconomic management is ensured without any bias, (v) organized NGOs (non-governmental organizations) are involved, and (vi) governmental efforts help developing awareness programmes on environmental problems with possible solutions at local levels[18].

Soil policy, although it appears complex, seems to be evolving through the active participation of individual countries and/or groups of nations. At the global level, the Food and Agriculture Organisation (FAO), through its various programmes, has been emphasising the importance of soils each year (Table 1) to raise awareness of soils and their role in sustaining life. These efforts of the FAO could also focus on soil policy to achieve global impact.

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