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THE GLOBAL SOIL HEALTH CRISIS: IMPLICATIONS FOR SUSTAINABLE AGRONOMY AND HORTICULTURE UNDER CLIMATE CHANGE

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ABSTRACT

Over decades, international awareness and activity has increased, from first soil conservation during the Dust Bowl years of the 1930s through to today's United Nations' Land Degradation Neutrality objectives (SDG 15.3) and national soil health initiatives. But improvement still is unequal. This study synthesizes the existing evidence for a crisis in soil health, focusing on the historical patterns, present day condition, and future estimates under climate change. It lists the primary indicators of soil health (chemical, physical, and biological) and methods for their measurement. We then discuss agronomic and horticultural practices that can either mitigate soil degradation or adapt systems to maintain productivity, such as no-till farming, cover cropping, organic amendments, agroforestry, precision nutrient management and more, discussing the advantages, limitations and scalability of each practice. Policy and institutional interventions are discussed in a broad context ranging from international frameworks (e.g., UNCCD, Bonn Challenge) to effective local initiatives (e.g., Malawi's fertilizer subsidy, China's reforestation, India's soil-health card).

Keywords **:** International, soil, organic, policy, local.

Introduction

Soil health is fundamentally its ability to operate as a living ecosystem that nurtures plants, animals and people, and is vital to global food security and environmental quality. Healthy soils store carbon, clean the water, sustain biodiversity and provide the nutrients and physical support that plants require (Behera, 2007). On the other hand, low soil health erodes agricultural production, water supply and resistance to climatic extremes (Carlisle, 2016). Alarming appraisals are pointing to a 'silent crisis' under our feet with almost one third of the soils of the globe already moderately to severely deteriorated (CTIC and SARE, 2013). In many areas, decades of intense agriculture, deforestation, overgrazing and poor irrigation methods have removed the organic matter from the soil, degraded the topsoil layers, compacted the surface and altered biological communities (Gao, 2015). Global estimates reveal that more than 18 million square kilometres of land - mostly agricultural and pasture area are degraded. More sobering, human-induced degradation is already reducing crop yields by some 10% on 1.7 billion hectares of farmland globally, affecting some 1.7 billion people (including nearly 50 million undernourished children) and costing tens of billions of dollars in lost productivity each year (HuQ, 2023).

The key factors differ between regions (Table 1). For example, in sub-Saharan Africa, overgrazing and deforestation on sloping ground have caused fast erosion, and an estimated 65 percent of agriculture in sections of the area is now moderately to severely degrade. In South Asia, the drivers are various, such as extensive yearly cropping on steep terraces, flood irrigation leading to salinization, and the burning of crop wastes, which combined erode soils and deplete nutrients in many of the densely populated plains (Joyce, 2022). In Europe and North America, decades of intensive plowing, monocultures and industrial inputs have resulted to a widespread loss of organic carbon and soil biodiversity (over 60% of soils are classified "unhealthy" in areas of Europe) and increased runoff and compaction (Kaspar, 2012). Even drylands and desert areas are not immune: inadequate water management has salinized as much as 50% of irrigated lands in certain parts of the Middle East and North Africa, while climate-driven extremes (droughts, floods) increase erosion worldwide. The strongest message is that soils are eroding quicker than they can recover under present practice (Kirchner, 2000). The advantages of organic amendments and cover cropping are described in classical books from China, India and Europe (e.g. Roman and medieval agronomy). However, these systems have been continually pressured by population demands and technological changes (Sainju, 2006). During the Industrial Revolution, the development of artificial fertilizer (late 1800s) and technology enabled farmers to plow increasingly wider areas, frequently without regard to the need to replace organic matter. The Dust Bowl tragedy (1930s) was a brutal lesson in erosion. In the early 20th century, the marginal areas of North America were over cultivated. With no vegetative cover or conservation tillage, the rains promptly washed away the nutrient-rich topsoil, converting agriculture into desert. The problem gave rise to regulations like the U.S. Soil Conservation Act (1935) and extensive soil survey programs, beginning the era of modern soil research and conservation. Simultaneously research on bulk soil organic matter by personalities such as Liebig and Power (1800s-1900s) created a scientific basis by associating humus with fertility (Saleem, 2020).

The post-World War II "Green Revolution" innovations (high-yield crop types, synthetic fertilizers and pesticides) greatly increased yields but frequently sped up the clock of deterioration. The intensive tillage and monocultures exacerbated erosion and dependence on external inputs. By the 1980s-90s, the soil fertility was diminishing to the point of becoming a bottleneck even for intensive agriculture. Awareness of worldwide desertification increased, resulting in the UN Convention to Combat Desertification (UNCCD, 1994) and subsequently the Land Degradation Neutrality objective (SDG 15.3, aiming for no net loss of productive land by 2030). During this period organic agriculture, conservation tillage and integrated farming started to expand, heralding today's soil friendly technologies (Vaughan, 1994).

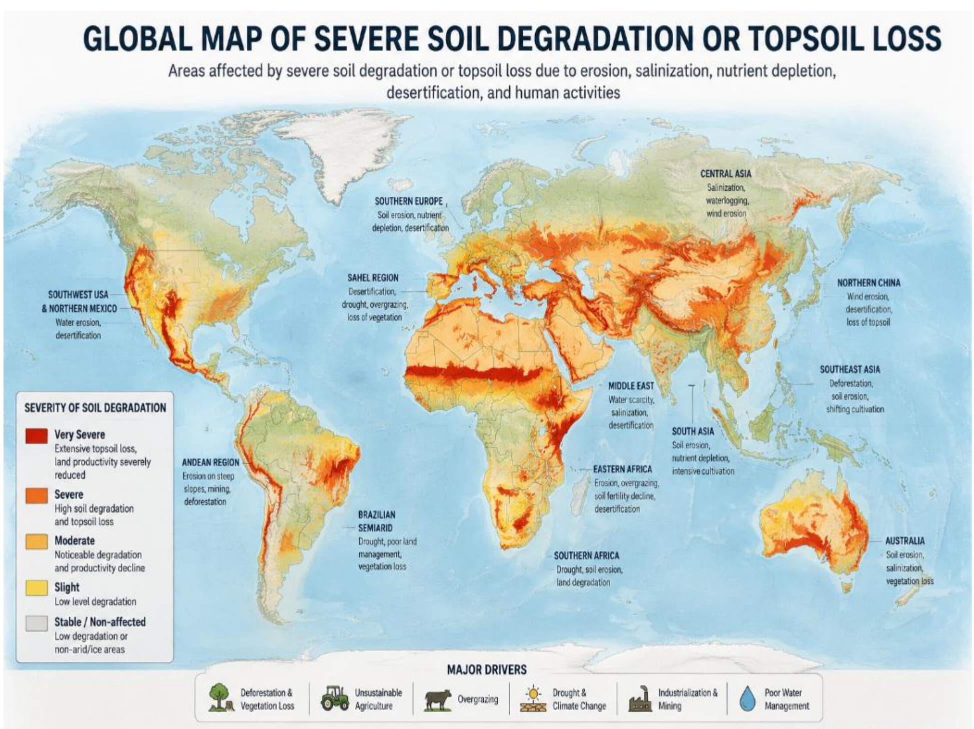

Fig. 1 : A world map highlighting regions of severe soil degradation or topsoil loss

Global Trends in Soil Degradation and Drivers

Extent of degradation: Existing evidence suggests a serious decline in global soil health. About one third of soils are considered deteriorated (moderate or worse). In sub-Saharan Africa, soil losses may exceed 50-100 tons per hectare per year, and an estimated 65% of farmed land has been damaged due to erosion or loss of nutrients (Zhang, 2016). More than 60% of European soils are in sub-optimal conditions due to intensive agriculture and acid deposition (reduced organic carbon, loss of biodiversity and decrease of peatlands). Degradation is concentrated in Asia where land constraints and population pressure have led to steeper cultivation, flood irrigation (leading to salt build-up) and residue burning (Mitchell, 2017). South Asia (India, Pakistan, Bangladesh etc) is losing on the order of $10b per year in reduced productivity. In Latin America, erosion is a problem in portions of the Amazon and Andes, especially due to deforestation. In North America, the Great Plains suffer from wind erosion, and intensively cultivated zones from nutrient imbalances. Arid and semi-arid areas are especially vulnerable: it is estimated that 2050% of irrigated soils globally are salt-affected owing to inadequate irrigation and evaporation (primarily in the Middle East, North Africa and Central Asia). Around half of the world's population lives in regions affected by soil degradation, showing how pervasive this catastrophic is climate change (Martínez-Valderrama, 2024).

Drivers by Region: In humid tropics (Amazon, Central Africa, Southeast Asia) deforestation for cattle ranching or oil palm plantations and consequent erosion dominate (SanyalD., 2020). In intensively farmed humid subtropics and temperate zones (e.g. Northern India, Eastern China, Midwest US) the culprits include excessive ploughing, monocultures without breaks, abuse of chemical inputs and compaction by heavy equipment. Dry sub-tropics (Sahel, Central America) with overgrazing and wind erosion of bare soils. Mountainous locations (Himalayas, Andes, Ethiopian highlands) lose soil from their slopes when plant cover is removed. Agricultural intensification frequently “mines” soil minerals Nitrogen, phosphorus and micronutrients (zinc, boron etc.) are cropped out without replenishment in many low resource contexts, creating a hidden hunger of the soil. These human impacts are superimposed atop climate-driven processes, with torrential downpours stripping soil more rapidly and severe droughts reducing plant cover, exacerbating degradation (U.S. Department of Agriculture, 2024).

Implications for Soils: The influence of these factors may be seen in many soil health indicators. The topsoil is becoming shallower, and some estimates say that half of the world’s arable topsoil has been lost since the beginning of intensive agriculture. Soil organic carbon (SOC), an important measure of fertility and structure, has decreased dramatically. Many croplands have lost 20-60% of their original soil carbon (Montanarella, 2016). Loss of SOC reduces soil aggregation and the ability of soil to retain water and nutrients. Likewise, soil biology is impacted: microbial biomass, earthworms and root networks are reduced by disturbance and chemical overload, which impairs nutrient cycling. Heavy tractors compact the soil, increasing bulk density and decreasing penetration rates; runoff of nutrients and pesticides pollutes streams. Overall, damaged soils have a worse ability to sustain crops and to cushion climatic shocks (Li, 2019).

Climate Change Forecasts: Many soil affected changes concerns will be more worsened by climate change. Higher temperatures speeds up organic matter decay and so further reduce SOC. Changing rainfall patterns, more violent storms and longer droughts may lead to increased erosion and less time for farmers to undertake restorative methods at larger scale (Jian, 2020). For example, a two-fold increase in rainfall intensity may nearly quadruple erosion rates on sensitive soils. High latitude permafrost melting will release stored carbon and alter local hydrology. In certain places (boreal woods, Mediterranean) higher wildfire frequency may burn stored soil carbon. Soil structure will be impaired. However, some favourable benefits could arise (e.g. extended growing seasons in cold places), but they are unlikely to outweigh numerous detrimental effects on soil (Iowa State University (2018). And degraded soils are also less resilient: a drought on a soil rich in organic matter has significantly more limited consequences on yields than on depleted soil. Climate trends and soil degradation thus influence each other and may generate positive feedback loops for CO_2 in the atmosphere (see Conceptual Diagram below). The cumulative impact is that, if left unchecked, climate change would likely exacerbate the worldwide soil health issue, endangering the supply of food and fiber in the next several decades (Follett, 2015).

Table 1 : Global soil degradation drivers by region and approximate magnitude.

Region	Primary Drivers	Magnitude/Impact
Sub-Saharan Africa	Overgrazing; deforestation for fuelwood and shifting farming; droughts and extreme rains	Up to 65% of cropland moderately degraded; soil erosion ~100 t/ha/yr in hotspots; low inputs
North Africa & Middle East	Unsustainable irrigation (salinization); overgrazing; desert expansion	2050% of irrigated soils salt-affected; moderate semi-arid deforestation
South Asia	Intensive monocultures on steep lands; flood irrigation (salinity); residue burning; nutrient depletion	Cropping lands ~10%+ lower yields from degradation; ~$10B/yr lost in production
Southeast Asia	Deforestation (palm oil, logging); slash-and-burn farming; tropical rain erosion	Significant peat soil loss; recurring haze from fires; unclear aggregated loss estimates
East Asia (China, etc.)	High chemical input; heavy tillage; terracing erosion; mining pollution	China: >28 million ha returned from cropping to forest (Grain-for-Green); many acidified soils
Europe	Intensive tillage; fertilizer/pesticide overuse; acid rain; peatland drainage; compaction	~60% soils “unhealthy” (organic C loss); severe erosion hotspots; policies (Nitrates Directive)
North America	Mono-cropping (e.g. corn-soybean); industrial tillage; wind erosion; urban sprawl	Plains wind erosion reduced yields; portions of US Midwest soils depleted of organic matter
Latin America (incl. Amazon andes)	Deforestation (cattle, soy); hillside farming; fires; mining	Amazon deforestation ~17% (Brazil); Andean erosion; large-scale cattle ranching contributes erosion and greenhouse gases
Central Asia (Arid zones)	Irrigation withdrawal (Aral Sea); salinization; overgrazing; desertification	Aral Sea basin: large-scale salinization after reservoirs drained; substantial loss of productive land
Australia/Oceania	Dryland salinity (former irrigation); overgrazing; bushfires; low organic matter	~20% of agricultural soil salinized; pasture acidity in 6.7M ha; Great Barrier Reef sediments from farming

Soil Health Indicators and Monitoring

To evaluate soil health a set of physical, chemical and biological indicators reflecting the main soil activities (nutrient cycling, structure, water storage, biodiversity, etc.) is needed. Chemical indicators are soil pH (field probe or laboratory meter), electrical conductivity (salinity proxy, measured in a soil-water extract), total organic carbon (laboratory combustion or oxidation tests), and available nutrient concentrations (e.g., soil N, P, K via standard extraction methods). Chemical fertility may alternatively be expressed as cation exchange capacity or base saturation, although they are less often studied (Gaffney, 2019). Physical indicators are linked to structure and hydrology. Bulk density (mass of dry soil per unit volume) gives an indication of compaction and is determined by taking a core of known volume. Aggregate stability can be assessed particularly by wet-sieving or slaking tests. Water infiltration rate (measured using single or double-ring infiltrometers) shows how quickly soils absorb rainfall. Texture (% sand/silt/clay) is the foundation for many soil processes. It is commonly assessed by sedimentation or laser methods. The moisture retention of soil (field capacity or permanent wilting point) may be tested in pressure-plate equipment in the laboratory (Korucu, 2019). Biological indicators measure the living part. For example, microbial biomass carbon (measured by fumigation-extraction procedures) indicates the size of the soil microbial community and microbial respiration (CO_2 generated by incubated soil) measures overall activity . Enzyme tests (e.g. dehydrogenase, phosphatase) reflect the metabolic capability for nutrition cycling. Biological diversity indicators (e.g., bacterial or fungal diversity by DNA sequencing) are increasingly being examined but are less standardized (Van Eerd, 2014). The health of soil fauna may be assessed by counts of soil macrofauna (e.g., earthworms or nematodes) in field samples. Other promising indications include active (labile) carbon fractions, determined by permanganate oxidation, and soil protein (glomalin) from mycorrhizal fungus. At larger scales remote sensing indicators such as plant cover, normalized difference vegetation index (NDVI) or surface reflectance may be used as proxy for soil health (particularly erosion risk and organic matter) (Kassam, 2022).

Table 2 : Soil health indicators and measurement methods.

Indicator	**Measurement Method**
Soil Organic Carbon (SOC)	Laboratory oxidation (WalkleyBlack) or combustion analyzer; infrared spectroscopy
Total Nitrogen (N)	KCl extraction for nitrate/ammonium; Dumas combustion
Available Phosphorus (P)	Olsen or Bray extract with colorimetry or spectroscopy
Exchangeable Potassium (K)	Ammonium acetate extraction with flame photometry
pH (acidity)	Electrode in soil-water or CaCl₂ suspension
Electrical Conductivity (Salinity)	EC meter in 1:5 soil-water extract
Cation Exchange Capacity (CEC)	Ammonium acetate or barium chloride extraction (lab)
Bulk Density (compaction)	Cylinder or core sample method (dry weight/volume)
Aggregate Stability	Wet sieving test (shaking soaked soil through sieves)
Water Infiltration Rate	Double-ring or single-ring infiltrometer in field
Water-Holding Capacity (Field Capacity)	Pressure plate apparatus (lab)
Soil Texture	Hydrometer or pipette method (particle-size distribution)

Agronomy and Horticulture Mitigation and Adaptation Practices

- **Conservation Agriculture (CA):** The integrated strategy, eliminates ploughing, which decreases erosion and increases the organic carbon and microbiological life in the soil. Cover crops and leftovers protect the soil from rain and weeds. (Lienhard P., 2020) Legumes fix the nitrogen in the ground. CA systems may give comparable or superior yields than conventional systems, especially under environmental stress. The CA systems have enhanced carbon sequestration and water infiltration performance. Even at warmer temperatures, a recent experiment performed at wide scale showed that conservation practices increased a composite soil health score by almost 21 percent over time. ... However, this did not affect the volume of agricultural production (HuJ. 2525). CA is scalable and made feasible by the widespread adoption of no-till technology, with more than ten percent of the world's arable land farmed using CA. However, there are substantial drawbacks, for example, the use of pesticides to control weeds in the areas that have not been plowed, the late warming of the soil in spring, and the early problems with the production (DixitA., 2015).

- **Reduced or No-Tillage**: Simply decreasing tillage (or removing it) inside CA may provide significant benefits: it reduces degradation of aggregates and organic matter and preserves root pathways. Bulk density (a disadvantage) is often higher in no-till fields, but the benefits of increased surface residue and earthworm activity generally outweigh the compaction. Farmers have to adjust weed and fertilizer management. No-till is very scalable prevalent in places like Brazil, USA, Canada yet its adoption may need incentives or training in areas habituated to plowing (Collins, 2013).
- **Cover Cropping:** Planting non-harvested crops (cover crops) during fallow periods or intercropping (e.g. winter rye, vetch and clover) avoids bare soil, scavenges leftover nutrients and contributes organic matter when terminated. Leguminous coverings may provide biologically fixed nitrogen. Cover crops help improve soil structure and minimize erosion by retaining dirt with their roots. The primary disadvantages are the expense of the seed, the necessity to control the cover (time of termination) and potential competition for water under dry circumstances. Cover cropping is a reasonably scalable practice on medium to large farms, although it is less frequent in smallholder systems unless subsidized (Boyer, 2013).
- **Crop Rotation and Diversification**: Growing diverse crops particularly in climate change affetcedt areas includes legumes or deep-rooted species can breaks pest/disease cycles, improves soil nitrogen balance and naturally reduce weeds at greater extent. Diversification (intercropping, agroforestry layers) also replicates natural ecosystems, increasing biomass return to soil & biodiversity. These measures are typically good, with few disadvantages, and may boost average yields and soil stability (BergtoldJ. 2019).
- **Organic amendments (Manure, Compost, Biosolids):** Among the advantages include modifications to the structure of the soil, as well as increases in the carbon and fertility of the soil over a longer period of time. Raw manure has the potential to be a source of infections or nutrient runoff if it is not handled in an effective manner. The logistics are difficult to manage since the procurement, transportation, and distribution of

heavy organic materials may be costly. Scalability is restricted since there is a limitation on the availability of these inputs. For the most part, these inputs are only feasible inside the confines of an agricultural system (for instance, dairy farms) or in close proximity to metropolitan areas (for compost). On the other hand, studies have shown that the application of compost in even low concentrations has the potential to dramatically increase the ability of microorganisms to retain water and the amount of microbial activity (Agomoh; 2021).

- **Biochar Amendment:** Biochar is a kind of carbon that is stable, and it is produced by burning biomass, which is required for its production. The incorporation of this substance into the soil has the ability to enhance the retention of nutrients and the storage of water for a large length of time. Biochar has the potential to store carbon for centuries, which is another possibility. It has been shown via experiments that there is the potential for cation exchange increases as well as decreases in leaching consequences. The production of biochar, which needs pyrolysis, which consumes a lot of energy, is one of the disadvantages. Other disadvantages include the high cost per ton and the unpredictability of the effects on various soils. According to BescansaP (2026), there is now a lack of scalability; thus, it is recommended to wait for manufacturing that is more cost-effective.
- **Agroforestry and Tree Integration:** Deep tree roots seek nutrients and water leaf litter provides organic substances and roots assist keep soil on slopes. Shade and windbreaks may help prevent erosion. These systems greatly enhance total farm resilience and biodiversity. The major disadvantage is the land trade off. Trees take up area and light that might go to annual crops, and the advantages come over years . High are the establishment expenses (seedlings, labour). However, agroforestry is geographically scalable (e.g. hedgerows in Europe, Faidherbia intercropped acacia in Africa) and typically doubles or triples overall land production when correctly managed (CarlisleL. (2015).
- **Mulching:** In horticulture, covering the surface of the soil with organic material (straw, wood chips, grass clippings) or plastic. Mulches preserve moisture, adjust soil temperature, control weeds and contribute organic matter as they break down. Mulching is almost typical in horticulture (orchards, vineyards, vegetable beds). Downside is labor or material expense (transporting mulch) and Potential for disease if not handled. However, mulching is particularly scalable in high value systems. For example, a deep layer of straw mulch would greatly increase penetration and nutrient cycling in organic orchards with minimal negative impact other than expense (FAO. (2003).
- **Contour Farming and Terraces:** Sloping ground may be planted in rows following the contour or made into terraces (steps). This greatly minimizes downhill flow and erosion. They are labour demanding to construct but may reduce soil loss by orders of magnitude. They support fertility on mountainous fields (e.g. rice terraces in Asia or bench terraces in the Andes) and enable sustained production when flat ground is limited. The downside is that terraces might collapse if not maintained and mechanisation is more difficult on terraced fields. Nevertheless, they are among the few means of preventing soil wash-out in hilly places and have been utilized efficiently for centuries (GaskinJ. 2016).
- **Controlled Traffic Farming (CTF):** Restricting heavy equipment to permanent traffic lanes decreases the amount of compacted soil. The tractor wheels are restricted to established tracks, leaving the remainder of the field free. This approach maintains soil structure, root penetration and porosity throughout much of the field. Downsides include the necessity for GPS guidance, specific equipment (narrower machines or tracks) and changing management. CTF is relatively scalable and has been applied in areas of Europe, Australia and North America, increasing yields on compact-prone soils (KarG., 2009).
- **Precision fertilizer and Irrigation Management**. With precision agricultural technology such as soil maps, GPS-guided applicators and variable-rate applicators, the application of fertilizer and water may be tailored to the demands of the crop. This is a good way of farming. One of the advantages of this is that it limits the amount of excess application which in turn reduces the amount of leaching and run off. Also nutrients are dispersed in areas where roots have access to them. Examples of precision irrigation methods include sub-surface or drip irrigation systems. These may assist save water and also aid the environment by avoiding waterlogging and salinization. A few pros include it is efficient and it is good to the environment. The disadvantages include the high initial cost and the necessity for certain talents. The dropping prices of technology, especially for big and high-value farms, are making scalability grow while smallholder farmers in low-income countries

may be left far behind (LuoZ., 2010). Costs of technical advances decrease scalability.

- **Biological Amendments (Biofertilizers):** Application of beneficial microorganisms (e.g. Rhizobia, mycorrhizal fungus and nitrogen-fixing bacteria) may enhance nutrient absorption and soil life. For example, inoculation of legumes with particular Rhizobia enhances N fixation while mycorrhizal inoculants may enhance P absorption. They are relatively minimal danger (mostly simply natural creatures) and may help plants grow better in weak soils (JordonM., 2023).
- **Phytoremediation and Cover Planting :** The usage of certain plant species for the purpose of soil cleansing or stabilization such as grasses or trees with deep roots that may absorb excess salts or heavy metals or species that grow fast and can replenish organic matter. This category is already covered with cover crops that may be grown between rows of crops or during the winter. As an illustration, the salt-tolerant barley cultivated in irrigated locations to absorb sea salt is a good example of this. However, phytoremediation is often slow (it may take years or even decades) and is also site specific although it has its benefits. Although it is scalable since it uses land that has been farmed, it requires crop selection and typically early economic help (GarbaI., 2022).
- **Resting and Fallow Land:** Modern efforts improve this with cover crops or managed pasture fallows. Pros include easy soil recovery. Cons are loss of revenue from field. It is employed on a lesser scale (e.g. as a yearly fodder break) and as a last resort if no other crop can be grown. Resting of grazing pastures is a typical practice in broad pastoral regions and has been shown to restore damaged grazing soils (IwerieborE. E. G. (2011).

Policy and Institutional Interventions

Addressing the soil crisis also requires policy, education and investment. A number of national and international initiatives have been launched. Table 4 compares key interventions, their scales and outcomes. Notable examples include:

- Global Pledges (UNCCD Land Degradation Neutrality, SDGs) More than 130 nations have committed to “land degradation neutrality” (LDN) under the UN Convention to Combat Desertification (UNCCD) by 2025, in line with Sustainable Development Goal 15.3 (No Net Loss of productive land by 2030). These are more aims than actions, however several countries are creating national plans to attain LDN (e.g., Ethiopia’s green legacy initiatives, China’s Great Green Wall program for dust belt). However, the effectiveness of these pledges is varied, they have mobilized awareness and financing (FriedrichT, 2022).
- China's 'Grain for Green' Program: A nationwide strategy launched in 1999 that pays farmers to put trees or grasses on steep, erodible fields. As of 2017, the initiative has restored more than 28 million hectares of degraded agriculture to forest. Overall, Grain-for-Green is widely described as the greatest land restoration effort in history, while there have been concerns (a subsequent research indicated that only ~37% of the newly wooded area remained forest after 18 years, with some reverting to agriculture). It has also enhanced livelihoods in several uplands communities (DelgadoA, 2016).
- Saudi Green Initiative (KSA) In 2026, Saudi Arabia declared the restoration of 1 million hectares of damaged land under its national Saudi Green Initiative, even in dry desert circumstances. The story illustrates that even in water-scarce conditions, large-scale restoration is doable using a combination of cloud seeding, drought-resistant plants and protected areas (Jaziri S. M’hamed H, 2022) if there is a strong backing of policies and investments.
- South Korea Reforestation (Korea’s Green Revolution of the 1970s): In the 1970s and 1980s, the Korean government launched an ambitious reforestation campaign to counteract the effects of deforestation caused by the conflict. State-led planting of fast-growing trees on slopes and incentives to farmers greatly improved Korea’s forest cover (now acknowledged by UNESCO as a restoration achievement). This has restored soil and water quality across huge regions and newer projects like the Changwon Initiative are exporting the lessons worldwide (Lin B. B. (2011).
- India’s Soil Health Card Scheme: India launched in 2015 to provide every farmer a soil-health card indicating the nutrient level and fertilizer recommendations. By 2020, more than 150 million cards had been issued. Independent studies have shown that fields maintained according these principles have substantial productivity improvements (e.g. ~30% more wheat and rice output) and cost savings due to decreased misuse of fertilizer. The national strategy highlights the effect of mass soil testing and extension in boosting fertilizer efficiency and soil fertility (FAO. (2012).

- Malawi Fertilizer Subsidies. In the mid-2000s, Malawi actively subsidized fertilizers for smallholder corn producers. This approach is widely considered as a success. It is said that corn yields doubled or quadrupled for many farmers and that there was excess which could be sold. Higher food supply also increased rural earnings and had knock-on impacts on labor and wages. The initiative demonstrated how access to nutrients may rapidly increase food security, but the long-term sustainability (cost and soil health) is still under investigation (LiP., 2023).
- African Union and Regional Plans: the African Union's Agenda 2063 and the related New Partnership for Africa's Development (NEPAD) projects, have frequently prioritized soil fertility. For instance, the African Fertilizer Summit (2013) resulted in an aim to increase the usage of fertilizer in sub-Saharan Africa fourfold, while the subsequent Nairobi Declaration (2024) has set an ambitious goal to restore 30% of Africa's damaged soils by 2034. In certain countries, such as Ethiopia and Rwanda, these aims have been incorporated into national land-use strategies, with initiatives being implemented to promote terracing, agroforestry, and irrigation (Saleem, 2009).

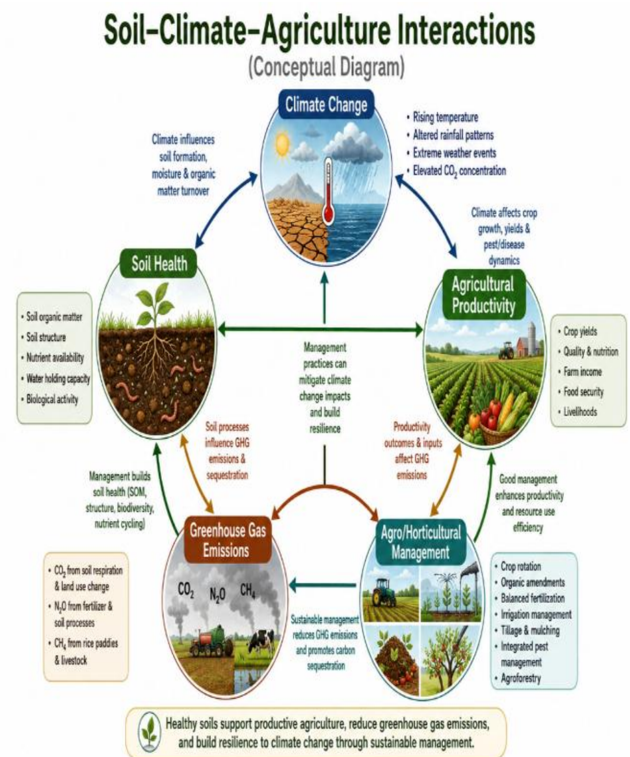

Fig. 2: Soil Climate Agriculture Interactions

Conclusion

Climate change is causing a major deterioration in the health of the earth's soils and offers a major challenge for sustainable agriculture and horticulture. Findings of the research indicate that millions of hectares of land are damaged by such causes as erosion, salinity, loss of nutrients and biological deterioration, frequently worsened by changes in climatic patterns. The effects are huge. Many countries will see flat or declining agricultural yields without immediate action, jeopardizing the food security of an expanding population already under pressure from deterioration. Therefore, the restoration of soil health is vital for climate change adaptation and mitigation, sustainability of agricultural practices and the achievement of international development goals. But the answers are there. Various soil management practices have been shown to improve soil structure, fertility and resilience. These practices include conservation tillage, cover cropping, organic additions, agroforestry, integrated nutrient management, and many more. Such techniques may prevent and even reverse soil degradation. The best systems incorporate these methods and adapt them to the individual requirements of the local environment. It is thus very important to set up legal and institutional framework providing incentives for good management of soils. Case studies from throughout the globe show how political will and commitment may achieve extraordinary results. The case studies span from community-led contour farming, to government subsidy schemes and multinational forestry initiatives. Further study is needed to enhance indicators of soil health, measurement techniques (remote sensing and rapid field testing) and knowledge of soil-climate feedbacks. Farmers will require training and support to transition to regenerative techniques, and markets may need to reward soil-conscious agriculture. Governments and development organizations need to integrate soil health in planning for climate and agriculture. In essence, the soil health situation is a serious one, yet it is a situation that can be addressed. If we can combine the historical knowledge with the present scientific understanding, use ecologically sound and economically realistic methods and create a link between policy and grassroots action, we can preserve the fundamental resource of soil for future generations.

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