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Soil health management in relation to climate change: A review

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Abstract

Climate change refers to any change in climate over time due to natural variability or as a result of human activity. The main cause of climate change is the increased emission of green house gases like CO2 (70%), CH4 (27%), N2O (3%), CFCs etc. The major effects of climate change influence the productivity of natural ecosystem. The fourth assessment report of Intergovernmental Panel on Climate Change (IPCC) made it clear that the global average temperature has increased by 0.74 0C over last 100 years and projected to increase about 1.1 to 6.4 0C by 21st century. Climate change and agriculture are interrelated processes and global warming is projected to have significant impact on agricultural by influencing through direct and indirect effect on crops, soil, livestock and pests.

Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land-use boundaries. These functions are able to sustain biological productivity of soil, maintain the quality of surrounding air and water environments, as well as promote plant, animal, and human health. Soil health indicators are a composite set of measurable physical, chemical and biological attributes which relate to functional soil processes and can be used to evaluate soil health status, as affected by management and climate change drivers. Defining soil health in relation to climate change should consider the impacts of a range of predicted global change drivers such as rising atmospheric carbon dioxide (CO2) levels, elevated temperature, altered precipitation (rainfall) and atmospheric nitrogen (N) deposition, on soil chemical, physical and biological functions. Elevated CO2 concentration, increasing temperature, atmospheric N deposition and changes in total and seasonal distribution of rainfall and extreme events such as droughts and floods will impact on soil biological processes, C and N cycling, and consequently on soil structure and erosion events, nutrient availability and plant diseases, and hence on ecosystem functionality and agricultural productivity. Increasing soil organic carbon (SOC) is a key process in mitigation practice to climate change as most recommended management practices.

Management strategies that sequester carbon in soil, reduce soil erosion and green house gas emission, conserve soil moisture, maintains soil temperature and enhance soil fertility should be adopted to cope up the impact of climate change on soils.

Keywords: Soil health, climate change, nutrient management, conservation, biochar

Introduction

According to the IPCC (2007) [14], global temperature is expected to increase between 1.1 and 6.4 °C during the 21st century and precipitation patterns will be altered. Soils are intricately linked to the atmospheric/climate system through the carbon, nitrogen, and hydrologic cycles. Because of this, altered climate will have an effect on soil processes and properties. Recent studies indicate at least some soils may become net sources of atmospheric C, lowering soil organic matter levels. Soil erosion by wind and water is also likely to increase. Soils are important to food security and climate change has the potential to threaten food security through its effects on soil properties and processes. Understanding these effects, and what we may do to adapt to them, requires an understanding of how climate and soils interact and how changes in climate will lead to corresponding changes in soil.

Soil health indicators are a composite set of measurable physical, chemical and biological attributes which relate to functional soil processes and can be used to evaluate soil health status, as affected by management and climate change drivers. Defining soil health in relation to climate change should consider the impacts of a range of predicted global change drivers such as rising atmospheric carbon dioxide (CO_2) levels, elevated temperature, altered precipitation (rainfall) and atmospheric nitrogen (N) deposition, on soil chemical, physical and biological functions (French *et al.* 2009) [8]. Many studies have progressed for relationships

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Between particular soil properties and climate change drivers, e.g. responses to temperature, CO_2 or rainfall. Low soil health is often a yield limiting factor for crop production and increases the potential for runoff, erosion and other environmental losses, as well as drought. These problems are anticipated to become more severe with climate change. Thus more holistic soil health management will become increasingly necessary as an adaptation and mitigation strategy. N fertilizer is a significant input cost. Conversely, yield potential is lost in some wet seasons. These scenarios result in decreased farm profits and high environmental losses related to GHG impacts, ground- and surface water degradation, and estuary hypoxia problems. Improving soil health, carbon and nitrogen management therefore provides win-win opportunities, to increase profits and decrease environmental losses. India is faced, today, with stagnation in crop productivity and slowdown in agricultural growth. Declining soil health is considered as one of the factors for such a decline. The restoration of soil health is, therefore, a formidable challenge before us to ensure higher productivity, profitability and national food security.

Climate change

Climate change is a long-term shift in the statistics of the weather (including its averages). For example, it could show up as a change in climate normals (expected average values fortemperature and precipitation) for a given place and time of year, from one decade to the next.

Causes of climate change

Natural variability

Climate change is a normal part of the Earth’s natural variability, which is related to interactions among the atmosphere, ocean, and land, as well as changes in the amount of solar radiation reaching the earth. The geologic record includes significant evidence for large-scale climate changes in Earth’s past. This includes solar variability, volcanic dust levels, internal variability and geological change.

Human-induced change

Greenhouse Gases certain naturally occurring gases, such as carbon dioxide (CO_2) and water vapour (H_2O), trap heat in the atmosphere causing a greenhouse effect. Burning of fossil fuels, like oil, coal, and natural gas is adding CO_2 to the atmosphere. The current level is the highest in the past 650,000 years. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change concludes, “that most of the observed increase in the globally averaged temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. ”Human induced changes include greenhouse gases, aerosols, ozone depletion and land use change.

Global climate change

- Global mean temperatures have increased by 0.74°Cduring last 100 years
- GHG (CO2, methane, nitrous oxide) increase caused by fossil fuel use and land use changes, main reasons.
- Temperatures increase by 1.8-6.4 °C by 2100 AD.
- Precipitation likely to increase in *kharif*
- Snow cover is projected to contract
- More frequent hot extremes, heavy precipitations
- Sea level to rise to be 0.18 - 0.59 m.

Evidences

- **Sea level rise:** Global sea level rose about 17 centimetres (6.7 inches) in the last century. The rate in the last decade, however, is nearly double that of the last century.
- **Global temperature rise:** All three major global surface temperature reconstructions show that Earth has warmed since 1880. Most of this warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years. Even though the 2000s witnessed a solar output decline resulting in an unusually deep solar minimum in 2007-2009, surface temperatures continue to increase (Fig.1).

Fig 1: Evidences of Global Warming

- **Ocean acidification**

Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30 percent. This increase is the result of humans emitting more carbon dioxide into the atmosphere and hence more being absorbed into the oceans. The amount of carbon dioxide absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year.

- **Shrinking ice sheets**

The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost 150 to 250 cubic kilometres (36 to 60 cubic miles) of ice per year between 2002 and 2006, while Antarctica lost about 152 cubic kilometres (36 cubic miles) of ice between 2002 and 2005.

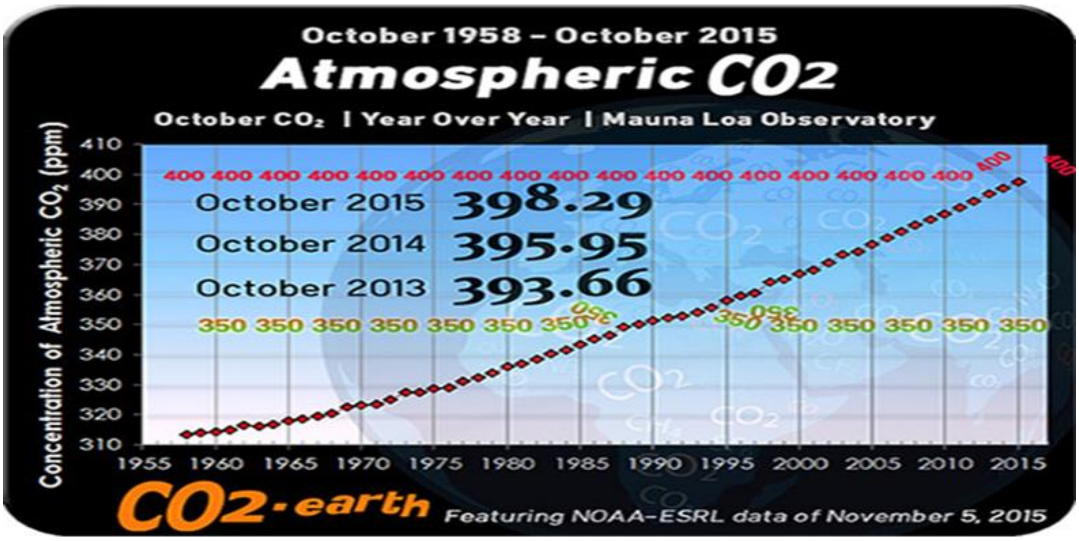


Fig 2: Global Carbon Dioxide Growth

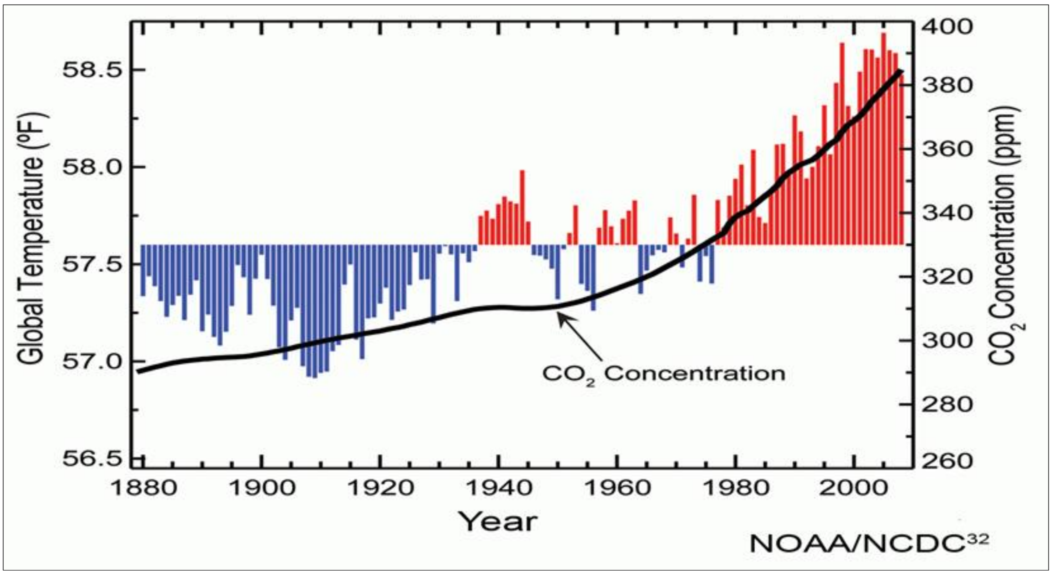


Fig 3: Global Increase of Temperature

The average global temperature fluctuates every year (Fig.3). However, when you look at a snapshot of the global temperature trend, it's on the rise - particularly since 1970. The main cause is Carbon dioxide and other greenhouse gas emissions from human activities. There are plenty of factors that influence temperatures in different regions across the globe. El Niño is one of the biggest drivers of year-to-year variability, increasing the likelihood of warm weather in the Pacific Northwest and cooler weather in the Southeast as well as a host of other global impacts. Longer-term fluctuations such as the Pacific Decadal Oscillation and aerosols from natural and human sources can further affect regional climate. Solar cycles also have global temperature implications, although on a much smaller scale. These shifts taken individually and together account for the year-to-year variability seen in the global average temperatures. They can’t fully explain why the globe has warmed about 1.6°F since 1880, though. Overlaying the amount of carbon dioxide in the atmosphere (Fig.2) shows a clear correlation with that rise in temperatures.

Soil health

Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land-use boundaries (Doran and Zeiss, 2000) [7]. These functions are able to sustain biological productivity of soil, maintain the quality of surrounding air and water environments, as well as promote plant, animal, and human health (Doran *et al.*, 1996) [6].

Soil health parameters

Major soil physical, chemical and biological properties which may indicate the status of soil health in relation to climate change impacts are listed below.

Physical parameters

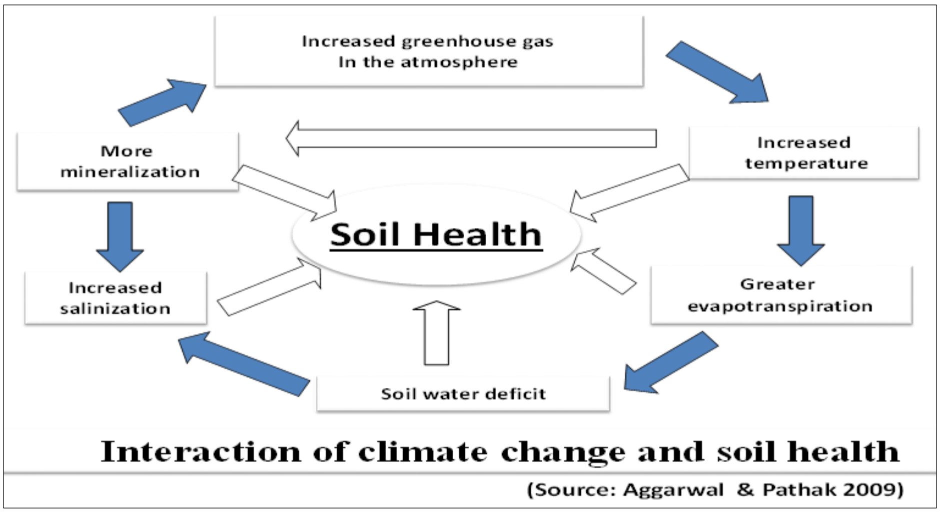
- Porosity
- Aggregate stability
- Infiltration
- Bulk density
- Soil & rooting depths
- Soil available water & distribution

Chemical parameters

- Soil surface pH; rate of acidification or alkalisation
- Electrical conductivity; leachable salts
- Adsorption & cation exchange capacity
- Plant available N, P, K, S

Biological parameters

- Soil organic matter
- Respiration
- Soil biota biomass
- Microbial biomass C & N
- Potentially mineralizable N
- Enzyme activity



Interaction of climate change and soil health

(Source: Aggarwal & Pathak 2009)

Fig 4: Interaction of Climate Change and Soil Health

Impacts of climate change

- Global warming
- Ozone depletion
- Storms
- Sea level rise
- Precipitation
- Droughts
- Floods
- Shrinking water sources
- Ocean acidification\
- Melting glaciers
- Forest fire
- Soil health
- Pest and disease out break
- Loss of wetlands
- Rapid continued loss of biodiversity

Challenges of climate change to soils

With global warming, rainfall levels are expected to decline in many places, and/or to occur in more intense events, and evaporation and transpiration rates are projected to increase. These changes will reduce the availability of soil moisture for plant growth (Fig.4). The higher temperatures will also increase the rate of SOM decomposition (mineralization), especially near the soil surface, which will affect the soil's potential capacity to sequester carbon and retain water. In the scientific literature, there is common consensus that the effect of higher concentrations of carbon dioxide (CO_2) in the atmosphere and increases in temperature on photosynthesis and net primary production, and hence on carbon fixation in the biomass, will not be sufficient to counterbalance the GHG emissions due to the mineralization of SOM. In cropping, grazing and forest systems, in particular, climate change and variability may affect soil health for plant growth through:

- Reduced or erratic rainfall and more frequent and severe periods of drought that lower the capacity of soils to make water and nutrients available to plants;
- More intense rainfall and storms that increase the risk of soil erosion by water and wind (through rain splash, accelerated runoff, strong winds)
- Increased soil surface temperatures and greater rates of mineralization of SOM.

Projected impact of climate change on soils

- Soil formation
- Increased carbon loss due increased Temp.
- Decline in soil health/ quality
- Alteration in nutrient transformation and acquisition by plant
- Changes in soil physical properties – water content
- Decrease soil biodiversity
- Increased droughts and floods will accelerate soil erosion
- Increase in soil salinity in coastal regions

Strategies for soil health management in relation to climate change

- Preventing and mitigating land degradation
- protecting vulnerable lands to high SOM losses
- Improving soil water storage
- Controlling soil erosion
- Improving soil structure with organic matter
- Managing soil organic matter for soil carbon sequestration
- Boosting nutrient management
- Biochar

Preventing land conversion and protecting vulnerable lands to high SOM losses

Intensive land uses are expanding into areas where SOC stocks are less resilient. For example, semi-arid savannas and grasslands, tropical rainforests and peat lands are all being converted to arable land at an increasing rate. Soil carbon stocks in semi-arid environments can decrease by 30 percent in less than five years when native vegetation or pastures are converted to cropland (Zach *et al*., 2006) [25]. Cultivation of tropical forest soils causes losses of more than 60 percent of original SOC stocks in just a few years (Brown and Lugo, 1990) [2]. Tropical peat lands converted to cropland or plantations are a hotspot of carbon emissions. Draining peat soils to introduce commercial production systems in tropical environments causes ongoing losses of up to 25 tonnes of carbon per hectare per year (Jauhiainen *et al*., 2011) [15]. Although drylands have lower mitigation potential per hectare than humid lands, their overall contribution could be highly significant since dry and sub-humid lands cover 47 percent of the Earth's land surface. Moreover, many dryland regions affected by land degradation and are sub-optimally managed could rapidly respond to improvements in management. Assessments of land resources are needed to understand trends in land conversion; the type, extent and severity of various land degradation processes; and the extent and effectiveness of existing improved or sustainable land management measures. Such assessments will identify hotspots and bright spots in terms of land degradation (soil, water and biodiversity) and climate change. Land use planning can then be used to determine suitable land uses and provide policy support or incentives to reduce land conversion and promote the adoption of sustainable practices, with particular attention given to peatlands and drylands that are more vulnerable to climate change.

Preventing and mitigating land degradation

Soils that have been degraded are at much greater risk from the damaging impacts of climate change. Degraded soils are vulnerable due to serious losses of SOM and soil biodiversity, greater soil compaction and increased rates of soil erosion and landslides. In addition, land degradation is itself a major cause of climate change. It estimated that overall, land use and land use changes account for around 31 percent of total human-induced GHG emissions. In the 1990s, 56 percent of the world's cropland (65 percent in Africa, 38 percent in Asia and 51 percent in Latin America and the Caribbean) and 73 percent of rangelands were estimated to be degraded (Oldeman, 1992) [19]. Unsustainable land management practices that are degrading soils include: continuous cropping with reductions in fallow and rotations, repetitive tillage and soil nutrient mining; overstocking, overgrazing and burning of rangelands; and the overexploitation or clearance of wooded and forest lands. During a time of rising demand for food, fibre, fuel, freshwater, fodder, timber and household energy, these practices are reducing the productive capacities of the world's croplands, rangelands and forests. There is a need for greater policy support and investment in identifying and promoting appropriate production systems and management practices that simultaneously reverse or minimize degradation, conserve above-and belowground biodiversity, sequester carbon, reduce GHG emissions and at the same time ensure sustained productivity.

Controlling soil erosion

Soil erosion is a widespread and serious degradation process. Intense rains can cause devastating soil erosion on cultivated lands on moderate to steep slopes where runoff rates are high and the ground has inadequate vegetative cover. Even on gradual slopes, alkaline soils may suffer from dispersion or crusting that will increase soil erosion risk. Runoff and resulting soil erosion can be substantially reduced through the adoption of minimum to no tillage techniques combined with optimizing soil cover (cover crops, residues, mulch). On steeper slopes, soil erosion can also be reduced by planting cross-slope vegetation; using soil and water conservation structures, such as terraces, earth bunds and tied ridges to optimize water capture and infiltration; and creating grassed waterways to convey excess water safely off the slopes. Increased incidence of windstorms could also accelerate soil erosion as the blown sand may be deposited on productive land or sand dunes may encroach on these lands. Measures to reduce erosion by wind include optimizing vegetation cover with drought-resistant species, using rotational grazing to sustain rangeland vegetation quality, and planting windbreaks perpendicular to the prevailing winds.

Improving water storage

Water storage in the soil depends on many factors, including rainfall, soil depth, soil texture (clay content) and soil structure. Soil management can influence rainwater infiltration and the capacity of the soil to reduce soil water evaporation and store water in the soil. Groundcover management can have highly beneficial effects on soil surface conditions, SOM content, soil structure, porosity, aeration and bulk density. Improvements in these properties influence infiltration rates, water storage potential and water availability to plants. These improvements also increase the effectiveness of rainfall and enhance productivity. They also reduce rates of erosion, the dispersion of soil particles and the risks of waterlogging and salinity in drylands.

Crop management systems that reduce soil disturbance (e.g. ploughing and hoeing) and bring about a high accumulation of organic matter should be introduced. Mulching is a simple technique that buffers soil temperature and helps the soil-crop system reduce evaporation and the mineralization of organic matter. Mulching also counteracts the nutrient loss. Precision farming is a more sophisticated management strategy based on observing and responding to intrafield variations to optimize returns on inputs while preserving natural resources. For example, precision agriculture is used to optimize the quantities of water and nutrients required by providing these inputs directly to the plant when needed through scheduled sprinkler irrigation or drip irrigation systems. Implicit in this type of management is an increased level of knowledge of crop requirements and local soil, terrain and climatic conditions (e.g. soil, slope, aspect).

Improving soil structure with organic matter

Many clay or loamy soils are compacted due to repetitive hoeing or ploughing. In mechanized systems, soil compaction is caused by the passing of heavy machinery through the fields for tillage. In grazing lands, soil is compacted by the trampling of livestock or wildlife. Compaction reduces airspaces in the soil and decreases the penetration of plant roots. Only stronger roots are able to penetrate the soil. The growth of lateral roots or fine root hairs, which are important for moisture and nutrient uptake, is restricted. Compacted soils and shallow soils are seriously affected by dry spells that limit root growth and the plant's access to moisture and nutrients. Sub-soiling to break up compacted layers can have a huge beneficial effect on root growth and soil productivity.

Managing soil organic matter for soil carbon sequestration

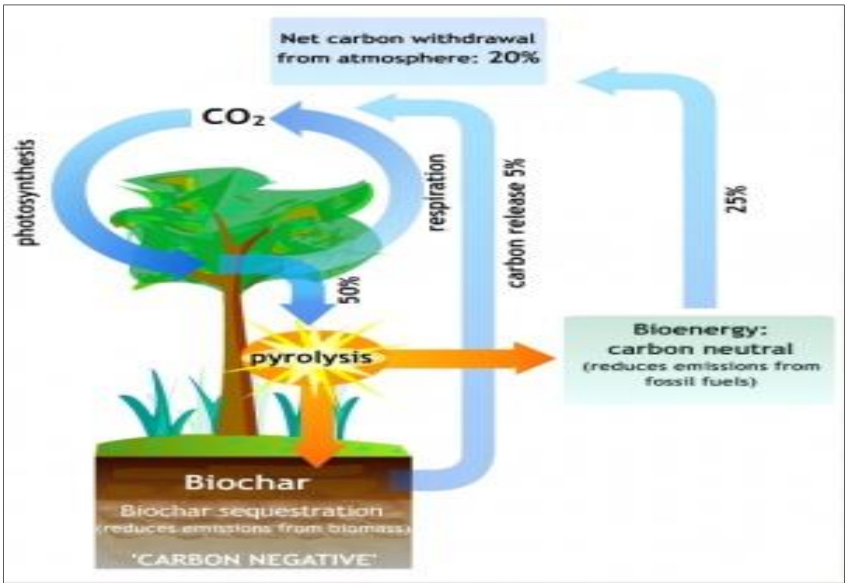
Soil carbon stocks and the mitigation potential they provide depend on the agro-climatic zone, the land use type and the intensity of use. The rate of SOM decomposition and turnover depends primarily on the combined effects of the soil biota, temperature, moisture and its chemical and physical composition. It is also affected by the previous land use and natural resource management practices (particularly the mechanical disturbance of the soil). The monoculture of cash crops and the high use of external inputs have been an approach farmers have adopted to achieve the highest possible yields with minimal labour. However, fossil fuel prices have increased, and the production of energy-intensive mineral fertilizers and pesticides is a major source of GHG emissions. Moreover, when incorrectly applied, these inputs leach into water resources and the resulting water contamination has serious deleterious effects on ecosystems and human health. Diversified crop rotations and improved techniques for the management of fertilizer, seeds and pesticides can make the application of inputs more efficient. This reduces the wastage of external inputs and thereby reduces the amount of inputs needed. Greater efficiency in this area can also potentially lower GHG emissions. By improving soil structure and increasing soil biodiversity, no-till cultivation and the control of soil compaction will also reduce GHG emissions, which result mainly from anaerobic soil conditions.

Boosting nutrient management

With agricultural intensification, organic fertilizers (manure, compost and plant residues) are increasingly supplemented by inorganic or synthetic fertilizers, which provide required crop nutrients. Nitrogenous fertilizers are the most widely used fertilizers and deliver huge benefits in terms of productivity, especially in nutrient-depleted soils. However, these fertilizers also have a high potential for environmental damage in terms of GHG emissions and nitrate pollution: These GHG emissions can be reduced by making changes in the rates, timing and type of nitrogen fertilizer applications; using slow release fertilizers that control the formation of nitrates; and adding nitrification inhibitors containing ammonium to fertilizer. These practices will help synchronize the demand and supply of nitrogen. Agronomic management can also control the biological processes that cause nitrate leaching and produce GHG emissions. Cropping patterns should provide enough structural carbohydrates (e.g. lignin) along with nitrogen to allow the nitrogen produced from decaying surface residues to be released slowly and contribute to the growth of the following crop while minimizing losses (Huggins *et al*., 1998; Gregorich *et al*., 2001) [13, 9]. There is common consensus that zero tillage and conservation agriculture systems will considerably reduce nitrate leaching (Macdonald *et al*., 1989) [17]. This is because, unlike mechanical tilling practices, zero tillage and conservation agriculture leave the soil undisturbed, which decreases mineralization and the subsequent production of nitrates. Cover crops take up the nitrogen and reduce its loss from the soil. At the same time, unused mineralized nitrogen remains distributed within smaller pores and is not washed out of the soil (Bergström, 1995; Davies *et al.*, 1996) [1, 3]. However, where no-till is used without cover crops and with herbicides to manage weeds, the effects on nitrogen uptake and reduced leaching, as well as on yields, may be less evident. The positive effects of the above principles will be optimized and losses minimized by integrating soil-crop water management practices, identifying the spatial variability within the given land area and fields, and using precision-farming techniques to apply fertilizer and water in ways that are highly efficient and site-specific.

Biochar

Biochar is a carbon-rich charcoal-like substance produced by heating plant material under low oxygen conditions by a process known as pyrolysis. During pyrolysis, around 50% of the biomass carbon is converted into biochar and of the other 50%, around two-thirds can be released as useful energy (Fig.5). Land application of biochar is not a new concept. It traces its roots to observations made by 19th century naturalists. In recent times, biochar gained importance after the observation of black carbon in *Terra Preta* soil in the Amazonian basin of Brazil by late Wim Sombroek, a distinguished Pedologist. The radiocarbon dating studies have revealed them to originate from 500 years to 7000 years. They provide a visually compelling proof for the longevity of biochar carbon in soil.



Sohi *et al*., 2009 [23].

Fig 5: Biomass to Biochar Production

Biochar being a highly carbonized, aromatic long chain compound is extremely resistant to decomposition by microbes in soil. This led to the concept of using biochar for long-term carbon sequestration for mitigating climate change. Nevertheless, biochar can be used as a soil amendment to improve soil health and increase crop production. In this regard, an obvious positive attribute of biochar is its nutrient value, supplied either directly by providing nutrients to plants or indirectly by improving soil quality, with consequent improvement in the efficiency of fertilizer use. Surface chemistry and C/N ratio are the two properties which make biochar to change the behaviour of nutrients in soil. Nutrient composition and availability of biochar depend upon the nature of feedstock and the pyrolysis conditions. In the Indian context, the study has tremendous implications as India has biochar production potential of 309 million tonnes annually (equivalent to 154 Mt of biochar carbon), the application of which might offset about 50% of carbon emissions from fossil fuels. It is a matter of concern that in the Indian state of Punjab alone, some 70-80 Mt straws of rice and wheat are burnt annually, releasing approximately 140 Mt of CO_2 into the atmosphere, in addition to methane, nitrous oxide and air pollutants (Punia *et al*., 2008) [20]. Under this scenario, biochar offers a significant, multi-dimensional opportunity to transform large-scale agricultural waste streams from a financial and environmental liability to valuable assets.

Practices adopted for soil health management

Mechanical measures

Ridges and furrows, graded furrows, broad bed furrow, broad bed and tied furrows, raised and sunken bed system etc are important in *in situ* rainwater conservation and prevent soil loss. Gabion structures, graded bunds, water diversion bunds, bench terracing, grassing of waterways, stabilization of washes, provision of drainage between waterways etc are important erosion control measures.

Table 1: Effect of different mechanical measures on soil erosion

Mechanical measure	2% slope		4% slope		8% slope	
	Runoff	Soil loss	Runoff	Soil loss	runoff	Soil loss
Contour maize cultivation	40.4	16.08	100.8	23.90	175.6	43.08
Graded bunding	15.3	4.24	33.6	6.87	75.6	14.33
Contour bunding	8.5	3.14	20.1	4.85	32.4	8.75
Bench terracing	5.7	1.65	9.6	2.05	18.2	3.11

(***Source***: Narain *et al*., 1992) [18].

Contour maize produced the highest runoff and soil loss and bench terracing reduced. At 8% slope the runoff and soil loss were at 175 mm and 43.08 tons/ha respectively in the case of contour maize, 75.6 mm and 14.33 tons/ha for graded bunding, 32.4 mm and 8.75 tons/ha for contour bunding and 18.2 mm and 3.11 tons/ha for bench terracing (Narian *et al*, 1992) [18]. Contour cultivation reduced runoff by 20.6% and soil loss by 43.51% and improved maize yield by 23% in Shiwalik hills (Mittal *et al*, 1986) [27].

In-situ moisture conservation and water harvesting

Harvesting water for the time when it is needed is an important constraint for farming in India. In the rain fed system water harvesting is a major tool used to cater the needs of agriculture. Small scale operations like ponds, stop dams percolation tanks can help to cope up this problem (Fig.6).

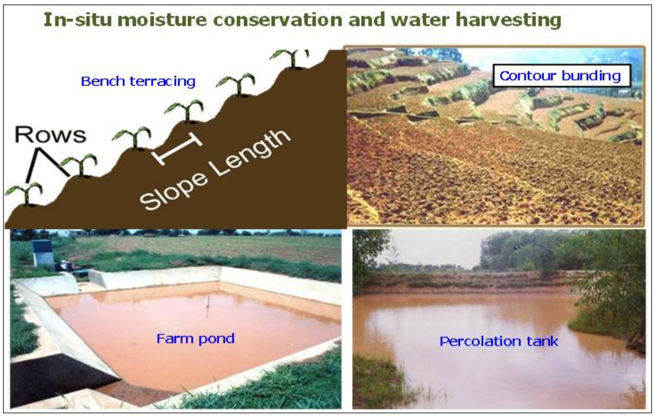
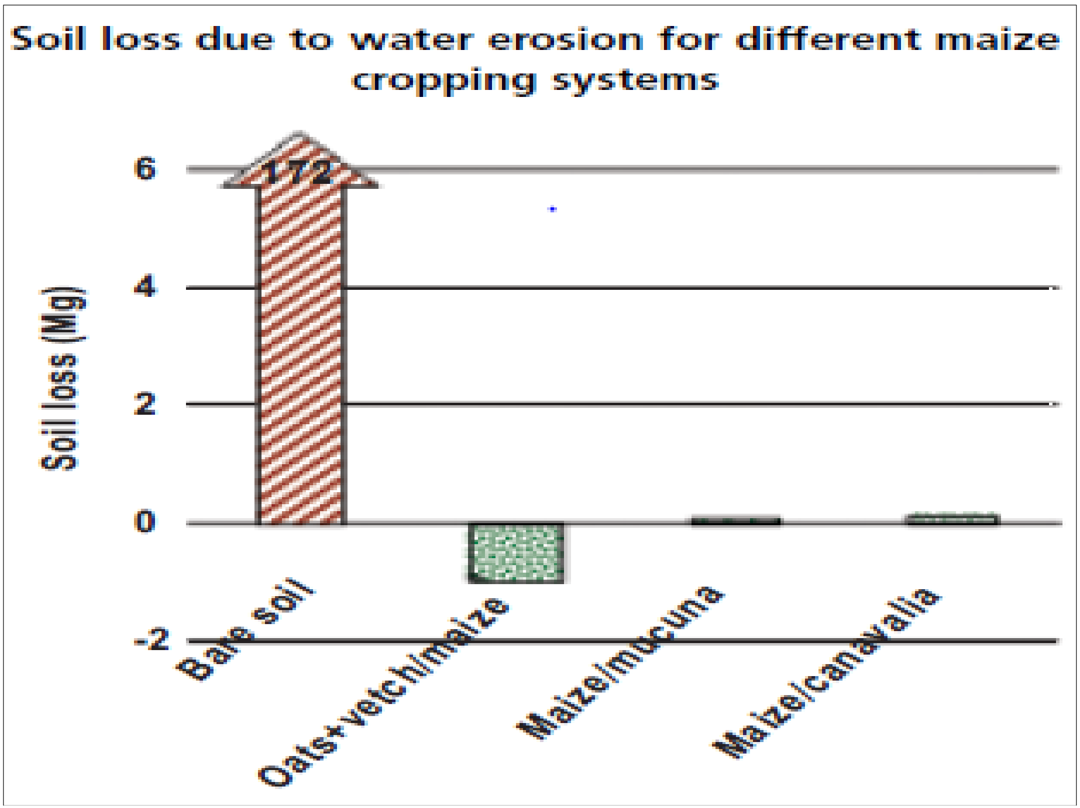


Fig 6: Water Harvesting and Moisture Conservation Techniques

Agronomic measures

Agronomic measures like contour cultivation, contour strip-cropping, mixed cropping, tillage and surface mulching, zero tillage and living mulch form important components of SWC measures. The contour bunding reduced the runoff to the range of 8.5-32.4 mm depending on the slope and soil loss to 3.14-8.75 tons/ha the hill AES (Sastry, 1994) [28]. Green manuring, weed management, growing appropriate cropping systems and grasses are the other cover management measures, which help in conservation of soil. Inter planting of erosion resistant leguminous crops, such as cowpea, soybean etc., which develop quick canopy cover has been found efficient in reducing soil erosion from corn. The cultivation of pure maize on 8 per cent slope at Dehradun lost 33.3% of rainfall as runoff and produced 25.1 tons/ha of soil loss.Inter planting cowpea reduced the runoff and soil loss to 26% and 20.6% tons/ha, respectively (Khybri, 1988) [16]. Inter cropping of maize and soybean resulted in the maximum production and reduced soil and runoff losses (Singh *et al*, 1981) [22]. The less the soil is covered with vegetation, mulches, crop residues, etc., the more the soil is exposed to the impact of raindrops. When a raindrop hits bare soil, the energy of the velocity detaches individual soil particles from soil clods. These particles can clog surface pores and form many thin, rather impermeable layers of sediment at the surface, referred to as surface crusts. They can range from a few millimetres to 1 cm or more; and they are usually made up of sandy or silty particles. These surface crusts hinder the passage of rainwater into the profile, with the consequence that runoff increases. This breaking down of soil aggregates by raindrops into smaller particles depends on the stability of the aggregates, which largely depends on the organic matter content.

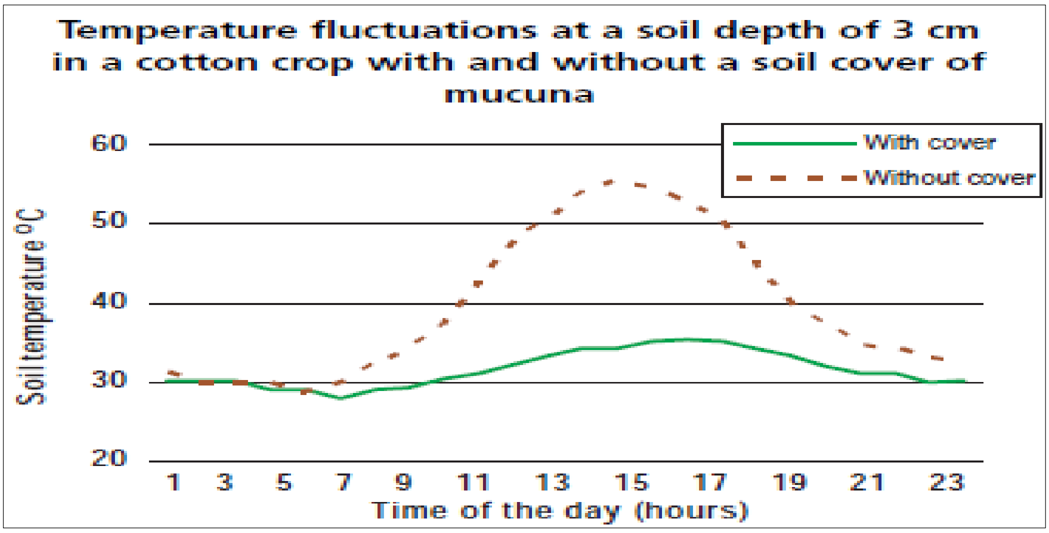


Source: Debarba and Amado, 1997 [4].

Fig 7: Effect of Cropping System on Soil Loss

Less the soil is covered with vegetation, mulches, crop residue, etc., the more the soil is exposed to impact of rain drops. Increased soil cover can result in reduced soil erosion rate or even lower, as reported by Debarba and Amado (1997) [4] for an oats and vetch/maize cropping system (Fig.7).

Soil cover protects the soil against the impact of raindrops, prevents the loss of water from the soil through evaporation, and also protects the soil from the heating effect of the sun. Soil temperature influences the absorption of water and nutrients by plants, seed germination and root development, as well as soil microbial activity and crusting and hardening of the soil



Source: Derpsch, 1993.

Fig 8: Effect of Soil Cover on Soil Temperature

Roots absorb more water at higher soil temperatures up to a maximum of 35 °C. Higher temperatures restrict water absorption. Soil temperatures that are too high are a major constraint on crop production in many parts of the tropics. Maximum temperatures exceeding 40 °C at 5 cm depth and 50 °C at 1 cm depth are commonly observed in tilled soil during the growing season, sometimes with extremes of up to 70 °C. Such high temperatures have an adverse effect not only on seedling establishment and crop growth but also on the growth and development of the micro-organism population. Mulching with crop residues or cover crops regulates soil temperature. The soil cover reflects a large part of solar energy back into the atmosphere, and thus reduces the temperature of the soil surface. The results in a lower maximum soil temperature in mulched compared with unmulched soil and in reduced fluctuations are shown in Fig8.

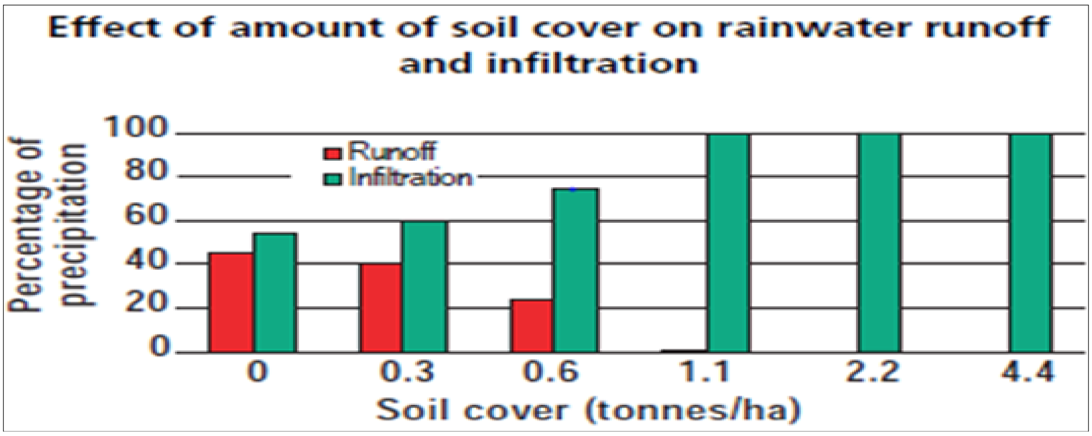


Fig 9: Effect of Soil Cover on Runoff and Infiltration

The proportion of rainwater that infiltrates into the soil depends on the amount of soil cover provided. The figure (Fig.9) shows that on bare soils (cover = 0 tonnes/ha) runoff and thus soil erosion is greater than when the soil is protected with mulch. Crop residues left on the soil surface lead to improved soil aggregation and porosity, and an increase in the number of macropores, and thus to greater infiltration rates. Increased levels of organic matter and associated soil fauna lead to greater pore space with the immediate result that water infiltrates more readily and can be held in the soil. The improved pore space is a consequence of the bioturbating activities of earthworms and other macro-organisms and channels left in the soil by decayed plant roots.

Soil management practices

By minimizing soil disturbance, conservation tillage practices such as no tillage and reduced tillage increase the build up of soil organic matter and thereby mitigate GHG emissions, especially if combined with the retention of crop residues (Fig.10). Storing carbon in soils reduces atmospheric levels of carbon.

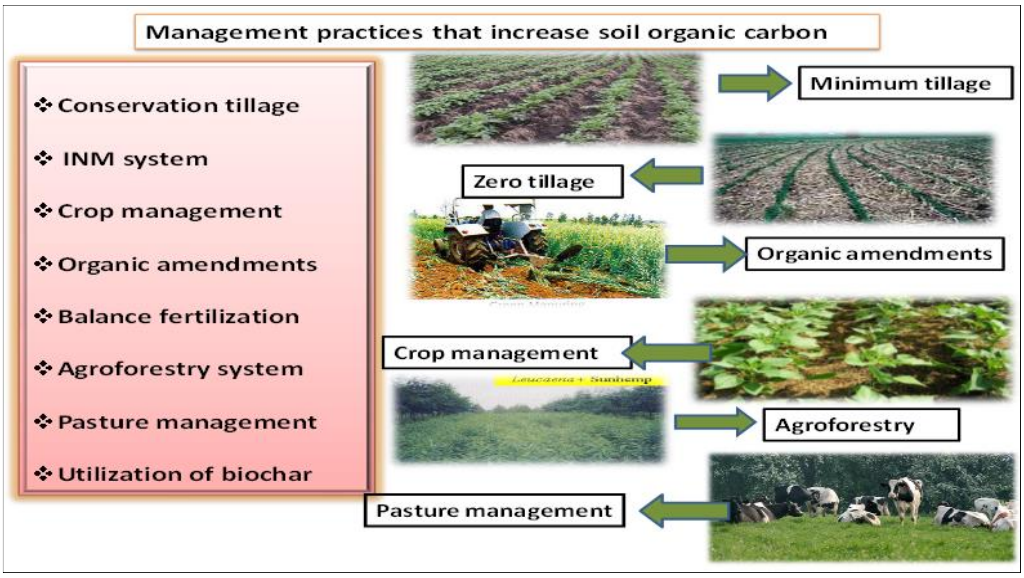


Fig 10: Management Practices for Improving Soil Health

The amount of carbon released from soils depends directly on the volume of soil disturbed during tillage operations. Therefore, the less soil is disturbed, the better the conservation of soil carbon. No-till (NT), zero till (ZT) and direct seeding (DS) 4are often used interchangeably to denote minimum soil disturbance and are associated with many environmental benefits.

Table 2: Annual changes in SOC content in soil layers as affected by different combined fertilizer and manurial treatments

Treatment	Annual changes in SOC (kg C ha^{-1}) at different soil depth		
	0-15 cm	**15-30 cm**	**30-45 cm**
Control	33.0	27.9	23.5
NP	114.4	88.0	34.5
NK	17.6	80.7	68.2
NPK	82.1	154.7	64.5
N+ FYM	359.3	244.2	123.9
NPK+ FYM	398.9	306.5	258.9
LSD (P=0.05)	12.9	12.6	8.3

Kundu *et al.* (2008) [26].

Kundu *et al.* (2008) [26] studied the relationship between carbon addition and storage under long-term (27 years) soybean wheat cropping system in sandy loam soils of North – West Himalayas. They reported that the treatments which were receiving 20 kg N+34.9 kg P +32.2 kg ha^{-1} K + 10 t FYM ha^{-1} (NPK + FYM) showed higher input of organic carbon in all the tree layers of soil which was 398 kg C ha^{-1}for 0-15 cm, 306.5 kg C ha^{-1} for 15-30 cm and 258.9 kg C ha^{-1} for 30-45 cm and it was due to higher biomass addition to soil from soybean crop from leaf fall, root biomass and nodule biomass over control and other treatments (NP,NK,NPK,N +FYM).

Table 3: Soil Quality Indicators after Three Years of Study as Influenced by Organics

Treatments	Bulk density(Mg m^{-3})	Organic carbon (%)	Soil respiration(mg CO_2 24 h^{-1} g^{-1} soil)
T_1: Inorganic fertilizers alone	1.31	0.63	0.167
T_2: Straw(5 t ha^{-1})	1.17	0.86	0.254
T_3: Greengram(10 t ha^{-1})	1.18	0.78	0.258
T_4: Dhanchia (10 t ha^{-1})	1.16	0.76	0.256
T_5: Greengram(5 t ha^{-1}) +Straw(2.5 t ha^{-1})	1.19	0.82	0.280
T_6: Dhanchia(5 t ha^{-1}) +Straw(2.5 t ha^{-1})	1.20	0.87	0.288
Mean	1.2	0.77	0.241
CD at 5%	0.06	0.105	0.025

Surekha and Rao (2009) [24].

Surekha and Rao (2009) [24] reported that soil quality parameters showed significant improvement with organic sources over chemical fertilizers alone and maximum benefit was from paddy straw when added either alone or in combination with green manures compared to the green manures alone in irrigated rice–rice system. Very high SOC increases are achieved by the application of external organic inputs to the soil, suggesting a high potential for carbon storage in the soil. There was a significant improvement in physical properties such as bulk density under application of organic sources. Bulk density ranged from 1.16 to 1.20 Mg m^{-1} in treatments where organic sources had been added compared to 1.30 Mg m-3 in control with inorganics alone. The decrease in bulk density in these treatments was 8 to 11% over control. The organic carbon (SOC) content increased significantly in all treatments with organics (0.760.87%) over control (0.63%). Higher SOC values were recorded where straw had been added either alone or in combination with green manures compared to the green manures alone. Soil respiration rate was also significantly higher in all the treatments with organics by 52-72% compared to control and maximum values were obtained in the straw + green manure-added plots. Application of organics stimulates and increases the living microorganisms in the soil involved in biochemical activity of importance to soil fertility and plant nutrition. Thus, the increased microbial biomass could have resulted in increased soil respiration rate. Here, interestingly, paddy straw contributed to the maximum extent in the improvement of some soil health indicators.

Eco friendly soil health management

The eco-friendly approaches inspire a wide range of application of plant growth promoting rhizobacteria (PGPRs), endo-and ecto mycorrhizal fungi, cyanobacteria and many other useful microscopic organisms led to improved nutrient uptake, plant growth and plant tolerance to abiotic and biotic stress (Fig.11). Biological soil fertility management is an ecological approach for sustainable crop production. Different soil micro-organisms play an important role in transformation of nutrients for plant use. Some micro-organisms are capable of fixing nitrogen, while some can increasethe availability of nitrogen and phosphorus. Bio-fertilizers are the products containing living cells of micro-organisms that have the ability to mobilise the nutrients from non-usable form through biological processes.

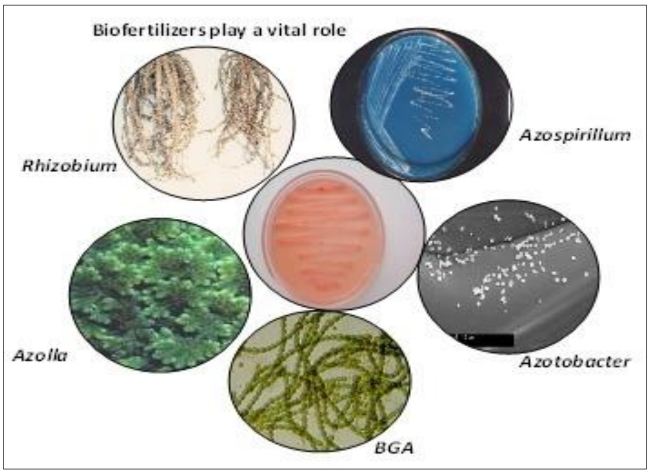


Fig 11: Bio-fertilizers for Improving Soil Health

Major focus in the coming decades would be on safe and eco-friendly methods by exploiting the beneficial micro-organisms for sustainable crop production and soil health. Such microorganisms, in general, consist of diverse naturally occurring microbes whose inoculation to the soil ecosystem advances soil physicochemical properties, soil microbes biodiversity, soil health, plant growth and development and crop productivity.

Conclusions

A healthy soil is fundamental for sustained agricultural productivity and the maintenance of vital ecosystem processes. To cope with climate change, the different types of production systems (crop, livestock and forest) and the specific practices used to manage them need to be adapted to take into account the diversity and current status of soils (e.g. sand, loam and clay soils, peat soils, sodic soils, shallow soils, nutrient depleted soils) and terrain (e.g. steep and flat lands, wetlands) and climatic conditions (e.g. short rainy seasons, erratic rains, high temperatures, storms). Diversified production systems and land uses will conserve the diversity of plant and animal species and varieties in the agro-ecosystem; provide diverse habitats for beneficial predators and pollinators; and reduce farmers' risk and vulnerability if one or more crops fail or if other farming enterprises collapse. Management practices that do not deplete SOC content, but rather increase it from year to year through organic matter management, will bring win-win-win benefits. They will create productive soils that are rich in carbon, require fewer chemical inputs and maintain vital ecosystem functions, such as the hydrological and nutrient cycles. There is a need to shift away from specialized high-input systems towards the design and adoption of more integrated production systems (crop-livestock, agroforestry, agropastoral) that will reduce inorganic fertilizer use and the resulting GHG emissions. Integrated production systems also diversify farm outputs, sustain yields and reduce vulnerability to climate change and other shocks.

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