NABARD

National Sectoral Paper
Land Development

Farm Sector Development Department
National Bank for Agriculture and Rural Development
Mumbai

NABARD's Vision

Development Bank of the Nation for fostering rural prosperity

NABARD's Mission

Promote sustainable and equitable agriculture and rural development through participative financial and non-financial interventions, innovations, technology and institutional development for securing prosperity

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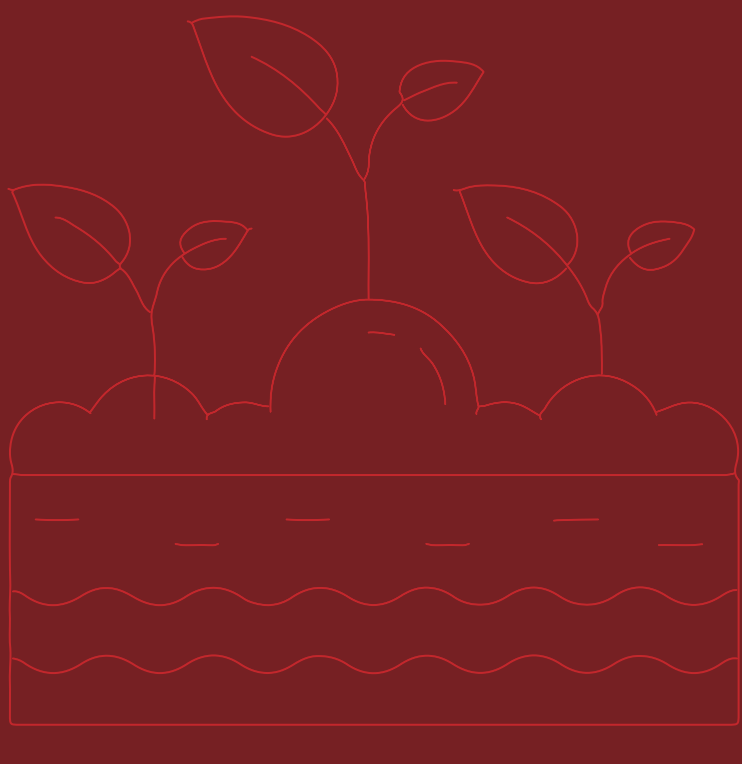

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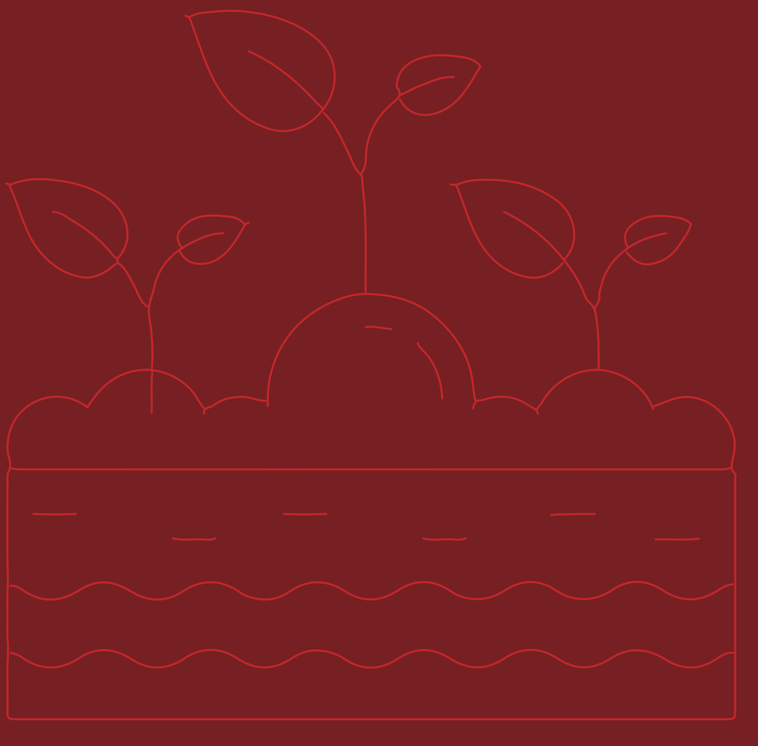

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Foreword

At present there is tremendous pressure on land resources due to increasing population and competing demands of various land uses. Land is used for the largest primary private industry in our country i.e. agriculture. In view of the decreasing land-man ratio and continued dependence of a high proportion of the population on agriculture, it is important to take proper care of this finite resource. Unfortunately it is a widely neglected and misused resource. The results are ominous in the form of high degradation and declining productivity. The situation demands everyone's attention and immediate correction. Land resource includes soil, water, bio-diversity, and micro climate.

Recognizing the critical challenges faced by rainfed and dryland farming communities, NABARD has been at the forefront of watershed development in India since 1992, beginning with the Indo-German Watershed Development Programme in Maharashtra. This pioneering initiative laid the foundation for a participatory, community-led approach to watershed development. The establishment of the Watershed Development Fund (WDF) in 1999-2000, with equal contributions from the Government of India and NABARD, marked a significant milestone in institutionalizing support for integrated watershed development. NABARD has sanctioned 3,747 watershed projects, covering over 27 lakh hectares across 28 states. These efforts have not only improved soil and water conservation but also enhanced livelihoods and climate resilience in some of the most vulnerable regions of the country.

In recent years, NABARD has expanded its vision through innovative programs such as JIVA, an agroecological transformation initiative promoting natural farming and climate-resilient practices, Climate-proofing of completed watersheds, to reduce vulnerability to climate change, Spring-shed development in the North Eastern Region, addressing the drying of springs due to climate variability, Pilot projects for reclamation of alkaline soils in Punjab and Haryana and Soil restoration under the SEWOH initiative.

These initiatives reflect NABARD's commitment to integrating ecological sustainability with rural development, ensuring that communities not only survive but thrive in the face of environmental challenges. Our efforts are further strengthened by the use of geospatial technologies in collaboration with the National Remote Sensing Centre (NRSC), enabling real-time monitoring, geo-tagging of assets, and impact evaluation of watershed projects. Total 1,173 projects have been digitized, with over 1.95 lakh assets geo-tagged and 718 impact studies conducted.

As we look ahead, the focus will be on scaling up agroecological models, mainstreaming climate adaptation, and deepening community participation. I am confident that the insights and experiences captured in this Sectoral Paper will serve as a valuable guide for policymakers, practitioners, and development partners.

Shaji K V
Chairman
National bank for Agriculture and Rural Development
Mumbai
July 2025

Message

Food is fundamental to life, and feeding over 1.4 billion people places immense pressure on India's finite natural resources. With just 2.4% of the world's land and 4% of its freshwater resources, India must support 18% of the global human population and 15% of the world's livestock

This imbalance underscores the urgent need for sustainable land and water management.

India is currently facing a serious challenge of land degradation, with an estimated 115–120 million hectares—about 33% of the country's total geographical area—affected by various forms of degradation. Water erosion alone accounts for nearly 94 million hectares, followed by acidification, salinity, wind erosion, and flooding These issues are exacerbated by unsustainable agricultural practices, overuse of chemical inputs, deforestation, and the growing impacts of climate change.

The degradation of soil and water resources directly threatens food security, biodiversity, and rural livelihoods. Soil and water conservation is no longer optional—it is essential. These resources are inextricably linked to agricultural productivity, climate resilience, and ecological balance.

The solution lies in a paradigm shift toward sustainable agriculture, including Agroecological practices, Organic and natural farming, Efficient water management, Soil health restoration, and Climate-resilient land use planning.

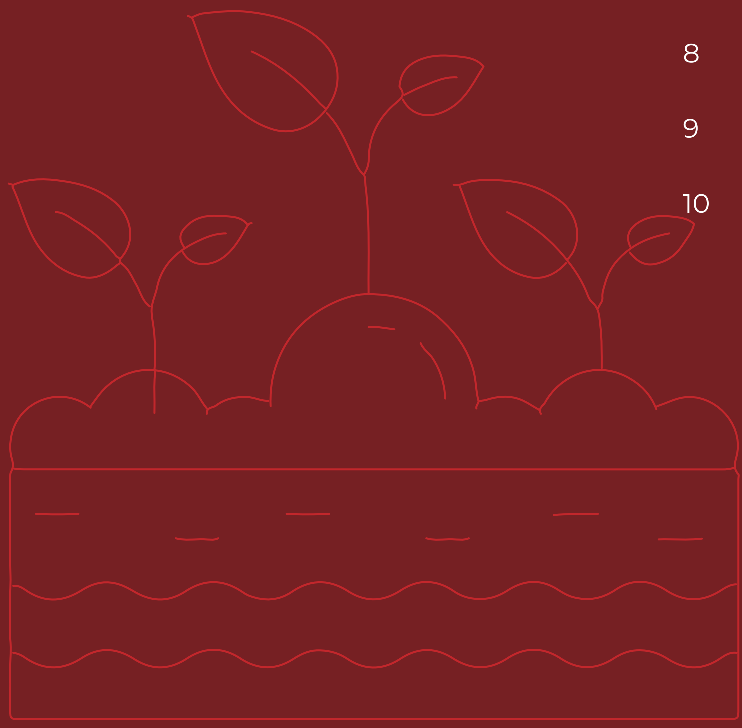
In this context, NABARD has been playing a pivotal role in promoting integrated natural resource management through watershed development, agroecological transformation, and climate-proofing initiatives. Our efforts are aligned with national priorities and global sustainability goals.

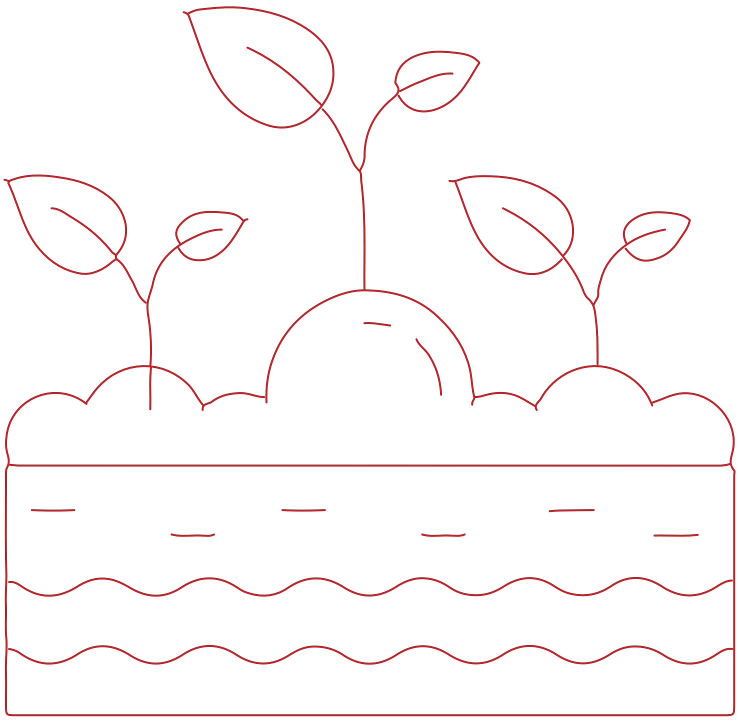
This Sectoral Paper on Land Development and Soil Science brings together critical information on soil, water, and crop production systems. It aims to serve as a comprehensive resource for all stakeholders—policymakers, researchers, financial institutions, and development practitioners—to plan, implement, and scale up effective strategies for conserving natural resources and enhancing farm productivity and incomes.

I commend the C-TAG Coordinator and team members for their dedicated efforts in preparing this insightful document. NABARD welcomes feedback and suggestions to further enrich this initiative and strengthen our collective commitment to sustainable land management and rural prosperity.

Dr A K Sood
Deputy Managing Director
National bank for Agriculture and Rural Development
Mumbai
July 2025

Contents





01

Introduction

Soil is the loose surface material that covers most land. It consists of inorganic particles and organic matter. Soil provides the structural support for plants used in agriculture and is also their source of water and nutrients. Soils vary greatly in their chemical and physical properties. Processes such as leaching, weathering and microbial activity combine to make a whole range of different soil types. Each type has strengths and weaknesses for agricultural production.

Physical characteristics of soil: The physical characteristics of soil include all the aspects that you can see and touch, such as texture, colour, depth, structure, porosity (the space between the particles), stone content etc.

Good soil structure contributes to soil and plant health, allowing water and air movement into and through the soil profile. Soil stores water for plant growth and supports machine and animal traffic. While some soils are naturally better structured than others, some physical characteristics of soils can be changed with good management. It is important to monitor the physical characteristics of soil to understand soil conditions.

It is also important to ensure that management practices are not contributing to the decline of the soil. An example of this is excessive traffic causing compaction and reducing the amount of macropores, or spaces between the aggregates, therefore reducing the amount of air and water into and through the soil.

Soil texture, structure, drainage characteristics

The combination of mineral fractions (gravel, sand, silt and clay particles) and organic matter fraction give soil its texture. Texture grades depend upon the amount of clay, sand, silt and organic matter present.

1.1 Sandy soil

The solid part of the soil is made up of particles such as organic matter, silt, sand and clay which form aggregates. Aggregates are held together by clay particles and organic matter. Organic matter is one of the major cementing agents for soil aggregates. The size and shape of aggregates give soil a characteristic called soil structure. Soil structure influences plant growth by affecting the movement of water, air and nutrients to plants.

Sandy soils have little or no structure but are often free draining. With higher clay content, the soil structural strength increases, but its drainage ability often decreases.

Heavy clays can hold large amounts of water and, as infiltration rates are slow, they tend not to be well drained, unlike sand or loam soils with no or a lower clay content.

1.2 Loam type soil

The number of soil pores and the pore size relate to the drainage capacity of the soil. The larger size and fewer the number of pores the easier it is for water to move through the soil profile.

It is not just the soil type that affects structure and drainage but also the activities or environmental factors occurring to them. Root and earthworm activity can improve soil structure through creating large pores. Excessive cultivation, removal of crop residues and increased traffic contribute to soil structural decline, through compaction of soils, reducing pore size and breaking down of soil aggregates.

The chemical make-up of soils also determines structure. When high amounts of sodium are present (>6% exchangeable sodium percentage) clay particles separate and move freely about in wet soil. These soils are known as sodic soils. When sodic soils come in contact with water, the water turns milky as the clay disperses and when the soil dries out a crust is formed on the surface. Sodicity can be overcome by applying gypsum.

1.3 Clay soil

Slaking is the breakdown of aggregates on wetting, into smaller particles. Slaking generally occurs when intense rainfall hits dry soil, the aggregates collapse as a result of the pressure created by the clay swelling and the trapped air expanding and escaping. This process can block up pore spaces and when the soil dries a crust is formed, causing infiltration and seedling emergence problems.

Soil colour:

Soil colour can indicate the organic matter content of soil, the parent material soil is formed from, the degree of weathering the soil has undergone and the drainage characteristics of the soil.

The colour of the soil is the main indicator of how soils drain.

Table 1: Soil colour indications

S. No.	Soil Colour	Indication
1	Black	Humus
2	Red	Presence of iron Phosphorous may be less available to the plant Free draining
3	Yellow	Moist conditions Restrictive drainage Less weathering
4	Grey, Blue/ green hues	Poor drainage Waterlogging

Lighter coloured soils can generally indicate low fertility, for example, white sands. While darker soils (like black clays) are quite fertile. There is a large range in between.

Soil drainage:

The drainage of a soil is an important characteristic to assess, as many plants prefer well-drained soils. If a soil is poorly drained, sufficient oxygen cannot get to the plant roots, which can stunt or kill the plant. Soils that are very well drained can limit plant capture of water in drier environments or in dry years due to insufficient water holding capacity.Other important indicators are:

- texture of the soil
- presence of buckshot and stones
- dispersibility and friability of the soil.
- Inorganic component of soils

Inorganic component of soils

Inorganic material is the major component of most soils. It consists largely of mineral particles with specific physical and chemical properties which vary depending on the parent material and conditions under which the soil was formed. It is the inorganic fraction of soils which determines soil physical properties such as texture. This has a large effect on structure, density and water retention.

Soil texture

The texture of soil is a property which is determined largely by the relative proportions of inorganic particles of different sizes. The following sizes are used to describe the inorganic fraction of soils:

- Gravel — particles greater than 2mm in diameter
- Coarse sand — particles less than 2 mm and greater than 0.2 mm in diameter
- Fine sand — particles between 0.2 mm and 0.02 mm in diameter
- Silt — particles between 0.02 mm and 0.002 mm in diameter

- Clay — particles less than 0.002 mm in diameter.

Sand

Quartz is the predominant mineral in the sand fraction of most soils. Sand particles have:

- a relatively small surface area per unit weight
- low water retention
- little chemical activity compared with silt and clay.

Silt

Silt has a relatively limited surface area with little chemical activity. Soils high in silt may compact under heavy traffic. This affects the movement of air and water in the soil.

Clay

Clays have very large surface areas compared with the other inorganic fractions. As a result, clays are chemically very active and able to hold nutrients on their surfaces. These nutrients can be released into soil water to be used by plants. Like nutrients, water also attaches to the surface of clay but this water can be hard for plants to use.

There are many different types of clays. Clays are distinguished from sand and silt by their ability to swell and retain a shape they have been formed into — as well as by their sticky nature.

Soil textural class

The relative proportion of sand, silt and clay particles determines the physical properties of soil, including the texture. The surface area of a given amount of soil increases significantly as the particle size decreases. Consequently, the soil textural class also gives an indication of soil chemical properties.

The exact proportions of sand, silt and clay in a soil can only be determined in a laboratory. However, a naming system has been developed to approximately describe the relative proportions. This classification of soil can be undertaken in the field where particular properties indicate possible textural classes.

To estimate the texture in the field, crush a small sample of soil (10 to 20 g) in one hand. After removing any gravel or root matter, work the soil in the fingers to break down any aggregates. With the sample moist but not sticky, the textural class can be estimated by the feel of the sample between the fingers.

Textural class descriptions for soil

A simple way to determine a soil texture and its characteristics is by hand texturing. When texturing soil, it is important to understand the behaviour feel, colour, sound and cohesiveness of the soil, which is achieved by making a bolus (wetting the soil and forming a ball). For example, a sandy loam will only just stick together (slightly coherent) and there will be noticeable sand grains which can be seen and felt and heard if you place the bolus close to your ear and squeeze it.

It is then important to form a ribbon from the bolus to determine the clay content of the soil. The longer the ribbon the higher the clay content. The length of the ribbon is measured against a ruler and along with the behaviour of the soil can be compared with the descriptions on the soil texture table. This table will help you to assess soil texture.

Table 2: Guide to common soil textures

Texture grade	Behaviour of moist bolus (ball formed in palm of hand)
Sand	Coherence, nil. Single sand grains adhere to fingers. If you press the bolus between your fingers, holding close to your ear, you will hear the sand grains rubbing against each other.
Loamy sand	Slight coherence. Discolours fingers with dark organic stain. Ribbon length 1.0cm.
Clayey sand	Slight coherence; sticky when wet. Many sand grains stick to fingers. Discolours fingers with clay stain. Ribbon length 1.0cm.
Sandy loam	Bolus just coherent but very sandy to touch. Ribbon length 1.3 to 2.5cm. Can hear sand grains (see Sand description).
Fine sandy loam	Bolus coherent. Sand can be felt and heard when manipulated. Ribbon length 1.3 to 2.5cm.
Fine sandy loam	Bolus coherent. Sand can be felt and heard when manipulated. Ribbon length 1.3 to 2.5cm.
Light sandy clay loam	Bolus strongly coherent but sandy to touch. Ribbon length 2 to 2.5cm.
Loam	Bolus coherent and spongy. Smooth feel, may be greasy. Ribbon length 2.5cm.
Loam fine sandy	Bolus coherent and slightly spongy. Fine sand can be felt and heard when manipulated. Ribbon length 2.5cm.
Silt loam	Coherent bolus, very smooth to silky when manipulated. Ribbon length 2.5cm.
Sandy clay loam	Strongly coherent bolus sandy to touch. Medium sand grains visible. Ribbon length 2.5 to 3.8cm.
Clay loam	Coherent plastic bolus, smooth to manipulate. Ribbon length 4 to 5cm.
Silty clay loam	Coherent smooth bolus, plastic and silky to touch. Ribbon length 4 to 5cm.
Fine sandy clay loam	Coherent bolus, fine sand can be felt and heard. Ribbon length 4 to 5cm.
Sandy clay	Plastic bolus, fine medium sands can be seen, felt or heard in clay matrix. Ribbon length 5 to 7.5cm.
Silty clay	Plastic bolus, smooth and silky to manipulate. Ribbon length 5 to 7.5cm.
Light clay	Plastic bolus, smooth to touch; slight resistance to shearing between thumb and forefinger. Ribbon length 5 to 7.5cm.
Light medium clay	Plastic bolus, smooth to touch, slightly greater resistance to ribboning. Ribbon length 7.5cm.
Medium clay	Smooth plastic bolus, handles like plasticine. Has some resistance to ribboning. Ribbon length 7.5cm.
Heavy clay	Smooth plastic bolus, handles like stiff plasticine. Has firm resistance to ribboning. Ribbon length 7.5cm or more.

It should always be remembered that soil texture often varies with depth and that the properties of the topsoil are affected by the properties of the subsoil.

Structure

Structure is the arrangement of soil particles and pore spaces between. Soil with a structure beneficial to plant growth, has stable aggregates between 0.5 and 2mm in diameter. Such soils have good aeration and drainage.

Chemical properties

The inorganic minerals of soils consist primarily of silicon, iron and aluminium which do not contribute greatly to the nutritional needs of plants. Those in the clay fraction have the capacity to retain nutrients in forms which are potentially available for plants to use.

Organic component of soil

The organic matter of soil usually makes up less than 10% of the soil. It can be subdivided into living and the non-living fractions. The non-living fraction contributes to the soil's ability to retain water and some nutrients and to the formation of stable aggregates.

Organic matter fraction of soils

The organic matter fraction of soils comes from the decomposition of animal or plant products such as faeces and leaves. Soil organic matter contributes to stable soil aggregates by binding soil particles together.

Plants living in soil continually add organic matter in the form of roots and debris. Decomposition of this organic matter by microbial activity releases nutrients for the growth of other plants.

The organic matter content of a soil depends on the rates of organic matter addition and decomposition. Soil microorganisms are responsible for the decomposition of organic matter such as plant residues. Initially, the sugars, starch and certain proteins are readily attacked by a number of different microorganisms. The more resistant structural components of the cell wall decompose relatively slowly. The less easily decomposed compounds, such as lignin and tannin, impart a dark colour to soils containing a significant organic matter content.

The decomposition rate of organic materials depends on how favourable the soil environment is for microbial activity. Higher decomposition rates occur where there are:

- warm, moist conditions
- good aeration
- a favourable ratio of nutrients
- a pH near neutral
- freedom from toxic compounds.

Soil organisms

The soil contains numerous organisms ranging from microscopic bacteria to large soil animals such as earthworms. The soil microorganisms include – bacteria, fungi, actinomycetes, algae, protozoa, nematodes, etc.

The diversity of soil organisms can both assist and hinder plant growth. Beneficial activities include:

- organic matter decomposition
- nitrogen fixation
- transformation of essential elements from one form to another

- improvement in soil structure through soil aggregation
- improved drainage and aeration.

Under some circumstances, soil organisms compete with plants for nutrients.

Bacteria are the smallest and most numerous microorganisms in the soil. They make an important contribution to organic matter decomposition, nitrogen fixation and the transformation of nitrogen and Sulphur.

The fungi and actinomycetes contribute beneficially to organic matter decomposition. The group of large soil animals includes earthworms, which incorporate organic matter into the soil as well as improve aeration and drainage by means of their channels. Some soil fungi, nematodes, and insects feed on roots and lateral shoots to the detriment of plants.

02

Soils of India - Major soil deposits of India

There are seven types of soil deposits in India. They are alluvial soil, black soil, red soil, laterite soil, or arid soil, and forest and mountainous soil, marsh soil. These soils are formed by various geographical factors. They also have varied chemical properties. Sundarbans mangrove swamps are rich in marsh soil.

2.1 Alluvial Soil:

Alluvial soils have been deposited by the Indus, Ganges and Brahmaputra rivers. The entire northern plains are made up of alluvial soil. This soil also extends in Rajasthan and Gujarat through a narrow corridor. It is also found in the eastern coastal plains particularly in the delta region of Mahanadi, Godavari, Krishna and Cauvery rivers.

Alluvial soil is generally fertile. Mostly these soils contain adequate proportion of potash, phosphorus and lime which are ideal for growth of all sorts of crops especially sugarcane, paddy, wheat, and pulse crops.

2.2. Black Soils :

Black soil is typical of the Deccan trap (Basalt) region spread over northwest Deccan plateau and is made up of lava flows. They cover the plateaus of Maharashtra, Saurashtra, Malwa, Madhya Pradesh, and Chhattisgarh and extend in the south-east direction along the Godavari and the Krishna valleys.

Also known as regur soil, black soil is ideal for growing cotton and is rich in soil nutrients, such as calcium, magnesium, potash etc. These soils are generally poor in phosphorus content.

The black soils are made up of clayey soil, well known for their capacity to hold moisture. Because of their high clay content, black soils develop wide cracks during the dry season, but their iron-rich granular structure makes them resistant to wind and water erosion. They are poor in humus yet highly moisture-retentive, thus responding well to irrigation. Those soils are also found on many peripheral tracts where the underlying basalt has been shifted from its original location by fluvial processes. The sifting has only led to an increased concentration of clastic contents.

2.3. Red and Yellow soils :

Red soil develops on crystalline igneous rocks in areas of low rainfall in the eastern and southern parts of the Deccan plateau. Yellow and red soils are also found in parts of Odisha, Chhattisgarh, West Bengal, Maharashtra, southern Karnataka, Tamil Nadu and Madhya Pradesh. Red and yellow soils develop a reddish colour due to diffusion of iron in crystalline and metamorphic rocks. It looks yellow when it occurs in a hydrated form.

2.4 Laterite Soils:

Laterite soils are mainly found in Karnataka, Kerala, Tamil Nadu, Madhya Pradesh, Andhra Pradesh and the hilly areas of Odisha and Assam. After adopting appropriate soil conservation techniques particularly in the hilly areas of Karnataka, Kerala and Tamil Nadu, this soil is very useful for growing tea and coffee. Red laterite soils in Tamil Nadu, Andhra Pradesh and Kerala are more suitable for crops like cashew nut.

The laterite soil develops in areas with high temperature and heavy rainfall. This is the result of intense leaching due to heavy rain. The name “Laterite” is derived from the Latin word “later” which means a brick. Its red colour is due to the iron oxide. When this soil becomes wet, it becomes smooth like butter and when it is dry, it becomes very hard. It is formed due to the change of dry and moist climate and due to the prevention of silica-based material. Humus content of the soil is low because most of the microorganisms, particularly the decomposers, like bacteria, get destroyed due to high temperature and lack of organic matter which is food, shelter and protection for the microorganisms from the high temperatures. Laterite soils are suitable for cultivation.

2.5. Arid Soils:

Arid soils range from red to brown in colour. They are generally sandy in texture and saline in nature. In some areas the salt content is very high and common salt is obtained by evaporating the water. Due to the dry climate, high temperature, evaporation is faster and the soil lacks organic matter and moisture which is the raw material needed for humus. The lower horizons of the soil are occupied by Kankar because of the increasing calcium content downwards. The Kankar layer formations in the bottom horizons restrict the infiltration of water. After proper irrigation these soils become cultivable as has been in the case of western Rajasthan.

2.6. Forest Soils:

Forests soils are found in the hilly and mountainous areas where sufficient rainforests are available. The soils texture varies according to the mountain environment where they are formed. The soil is loamy and silty in valley sides and coarse-grained in the upper slopes. It is acidic with low humus content in the snow-covered areas.

2.7. Mountain Soils:

Mountain soils are found in the valleys and hill slopes of the Himalayas at altitudes of 2500 m to 3000 m. These soils are often the vegetation cover helps in their classification. The carbon nitrogen ratio is very wide. They are silty loam to loam in texture and dark brown in colour.

03

Importance of Soils in Indian Agriculture

Throughout human history, our relationship with the soil has affected our ability to cultivate crops and influenced the success of civilizations. This relationship between humans, the earth, and food sources affirms soil as the foundation of agriculture.

Agriculture and Human Society

Human use and management of soil and water resources have shaped the development, persistence, decline, and regeneration of human civilizations that are sustained by agriculture. Soil and water are essential natural resources for our domesticated animal- and plant-based food production systems. Although of fundamental importance today, agriculture is a relatively recent human innovation that spread rapidly across the globe only 10,000 to 12,000 years ago, during the Agricultural Revolution. This short, yet highly significant period of time, represents less than 0.3 % of the more than four million years of human evolution as bipedal hominids and ultimately Homo sapiens. In agriculturally-based societies during the last ten millennia, humans have developed complex, urban civilizations that have cycled through periods of increasing complexity, awe-inspiring intellectual achievement, persistence for millennia, and, in some instances, perplexing decline. In many cases, stressed, declining civilizations adapted, or reemerged, into new or similar complex cultures. Through such fluctuations, we have remained dependent on a relatively small number of crop and animal species for food, and on integrated soil-water systems that are essential for their production. There is no doubt that our modern human society has developed to the point that we cannot exist without agriculture.

It is clear that agriculture sustains and defines our modern lives, but it is often disruptive of natural ecosystems. This is especially true for plant communities, animal populations, soil systems, and water resources. Understanding, evaluating, and balancing detrimental and beneficial agricultural disturbances of soil and water resources are essential tasks in human efforts to sustain and improve human well-being. Such knowledge influences our emerging ethics of sustainability and responsibility to human populations and ecosystems of the future.

Although agriculture is essential for human food and the stability of complex societies, almost all of our evolution has taken place in small, mobile, kin-based social groups, such as bands and tribes. Before we became sedentary people dependent on agriculture, we were largely dependent on wild plant and animal foods, without managing soil and water resources for food production. Our social evolution has accelerated since the Agricultural Revolution and taken place synergistically with human biological evolution, as we have become dependent on domesticated plants and animals grown purposefully in highly managed, soil-water systems.

Soil Fertility and Crop Growth

The early use of fire to flush out wild game and to clear forested land provided the first major anthropogenic influence on the environment. By burning native vegetation, early humans were able to gain access to herbivores grazing on the savanna and in nearby woodlands, and to suppress the growth of less desirable plant species for those easier to forage and eat. These and other factors (e.g., population pressures, climate change, encouraging / protecting desirable plants), help to lay the groundwork for the Agricultural Revolution and caused a dramatic shift in the interactions between humans and the earth. The shift from hunter-gatherer societies to an agrarian way of life drastically changed the course of human history and irreversibly altered natural nutrient cycling within soils. When humans sowed the first crop seeds at the dawn of the Neolithic Period, the soil provided plant-essential nutrients and served as the foundation for human agriculture.

Plant Nutrients

Throughout Earth's history, natural cycling of nutrients has occurred from the soil to plants and animals, and then back to the soil, primarily through decomposition of biomass. This cycling helps to maintain the essential nutrients required for plant growth in the soil. Complex nutrient cycles incorporate a range of physical, chemical, and — most importantly — biological processes to trace the fate of specific plant nutrients (e.g., N, P, C, S) in the environment. For a thorough analysis of these cycles, additional reference materials are available (Bernhard 2010, Brady & Weil 2008, Troeh & Thompson 1993). For the purpose of this article, a simplified version of nutrient cycling in natural and agricultural systems is shown in Figure 1.

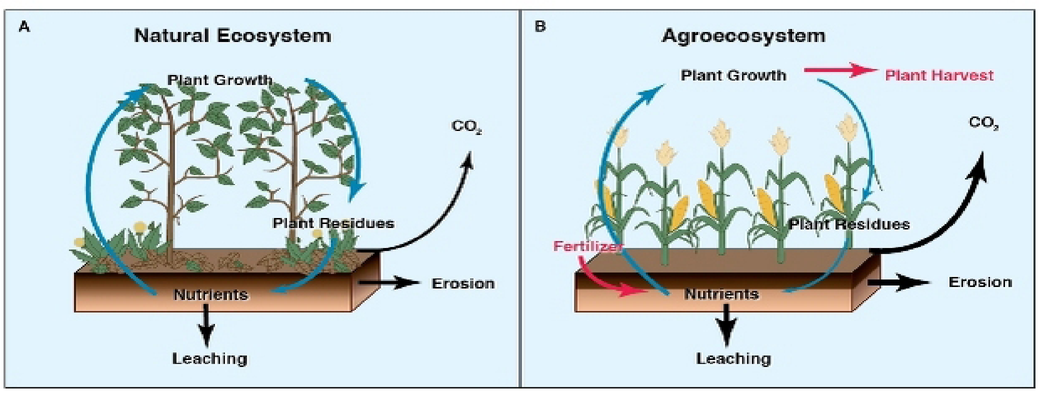


Figure 1: Simplified nutrient cycling schemes for (a) a natural ecosystem and (b) an agroecosystem.

The thickness of arrows corresponds to the relative amounts. The blue arrows represent basic nutrient pathways such as plant uptake, biomass decomposition, and nutrient return to soil. In the agroecosystem fertilizer (e.g., manure, compost, chemical) is applied and nutrients are removed through plant harvest (red arrows). Greater potential leaching (e.g., nitrate), erosion (e.g., soil, phosphate), and CO_2 emissions in the agroecosystem are indicated via thick black arrows.

It is generally accepted that there are 17 essential elements required for plant growth. The lack of any one of these essential nutrients, listed in Table 1, can result in a severe limitation of crop yield — an example of the principle of limiting factors. Of the mineral elements, the primary macronutrients (N, P, and K) are needed in the greatest quantities from the soil and are the plant nutrients most likely to be in short supply in agricultural soils. Secondary macronutrients are needed in smaller quantities, are typically in sufficient quantities in soil, and therefore are not often limiting for crop growth. The micronutrients, or sometimes called trace nutrients, are needed in very small amounts and, if in excess, can be toxic to plants. Silicon (Si) and sodium (Na) are sometimes considered to be essential plant nutrients, but due to their ubiquitous presence in soils they are never in short supply.

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Table 1. : Essential plant nutrients and their primary form utilized by plants.

Essential plant element		Symbol	Primary form
Non-Mineral Elements			
	Carbon	C	CO_2 (g)
	Hydrogen	H	H_2O (l), H^+
	Oxygen	O	H_2O (l), O_2(g)
Mineral Elements			
Primary Macronutrients	Nitrogen	N	NH_4^+, NO_3^-
	Phosphorus	P	HPO_4^{2-}, $H_2PO_4^-$
	Potassium	K	K^+
Secondary Macronutrients	Calcium	Ca	Ca^{2+}
	Magnesium	Mg	Mg^{2+}
	Sulphur	S	SO_4^{2-}
Micronutrients	Iron	Fe	Fe^{3+}, Fe^{2+}
	Manganese	Mn	Mn^{2+}
	Zinc	Zn	Zn^{2+}
	Copper	Cu	Cu^{2+}
	Boron	B	$B(OH)_3$
	Molybdenum	Mo	MoO_4^{2-}
	Chlorine	Cl	Cl^-
	Nickel	Ni	Ni^{2+}

Agriculture alters the natural cycling of nutrients in soil. Intensive cultivation and harvesting of crops for human or animal consumption can effectively mine the soil of plant nutrients. In order to maintain soil fertility for sufficient crop yields, soil amendments are typically required. Early humans soon learned to amend their fields with animal manure, charcoal, ash, and lime ($CaCO_3$) to improve soil fertility. Today, farmers add numerous soil amendments to enhance soil fertility, including inorganic chemical fertilizers and organic sources of nutrients, such as manure or compost, often resulting in surplus quantities of primary macronutrients. The efficiency of fertilizer application and use by crops is not always optimized, and excess nutrients, especially N and P, can be transported via surface runoff or leaching from agricultural fields and pollute surface- and groundwater.

Soils for Agriculture

While soil is frequently referred to as the "fertile substrate", not all soils are suitable for growing crops. Ideal soils for agriculture are balanced in contributions from mineral components (sand: 0.05–2 mm, silt: 0.002–0.05 mm, clay: <0.002 mm), soil organic matter (SOM), air, and water. The balanced contributions of these components allow for water retention and drainage, oxygen in the root zone, nutrients to facilitate crop growth; and they provide physical support for plants. The distribution of these soil components in a particular soil is influenced by the five factors of soil formation: parent material, time, climate, organisms, and topography. Each one of these factors plays a direct and overlapping role in influencing the suitability of a soil for agriculture.

Inorganic Soil Components

As one might expect, contributions from each mineral size fraction help to provide the physical framework for a productive soil. Loamy-textured soils are commonly described as medium textured with functionally-equal contributions of sand, silt, and clay. These medium-textured soils are often considered ideal for agriculture as they are easily cultivated by farmers and can be highly productive for crop growth.

The mineral components of soil may exist as discrete particles, but are more commonly associated with one another in larger aggregates that provide structure to soil. These aggregates, or peds, play an important role in influencing the movement of water and air through soil. Sandy soils have large pore spaces and increase water drainage, but do not provide soils with many nutrients. Clay-rich soils, on the other hand, increase water holding capacity and provide many essential nutrients. A common measure of soil fertility is obtained by measuring the cation exchange capacity (CEC). The CEC is a measure of a soil's ability to exchange positive ions between the soil particles and solution surrounding these particles.

Due to their high surface area, clay particles can exert a large influence on various soil properties (e.g., CEC, structure, water-holding capacity), even when the percent clay content is low. Clay minerals are colloidal particles, having high surface area, with charged surfaces; permitting binding of many essential plant nutrients. The most prevalent clay-sized particles in soils fall into the class of layer-type aluminosilicates that commonly have permanent negative charge with a high CEC. Positively charged clay particles, which bind anions, include those which have pH dependent charge. The most common classes of these minerals in soils are the iron (Fe), aluminium (Al), and manganese (Mn) hydroxides.

Soil Organic Matter (SOM)

SOM comprises the partial or well-decomposed residues of organic biomass present in soil. SOM gives topsoil its deep black colours and rich aromas that many home gardeners and farmers of grassland soils are familiar with. Surface soils are composed of approximately 1 to 6% organic matter, with SOM decreasing with depth (Brady & Weil 2002). Figure 2 is a photograph of an organic matter-rich soil (Mollisol) formed under prairie vegetation in the United States. The thick dark upper layers in this soil reflect the high SOM content. The presence of SOM is crucial for fertile soil as it provides essential plant nutrients, beneficially influences soil structure, buffers soil pH, and improves water holding capacity and aeration. The presence of organic, ionizable functional groups (e.g., carboxyl, alcoholic/phenolic OH, enol, quinone, and amine) impart charge to SOM (Sparks 1995), contributing high CEC, and pH buffering capacity.

Soil pH

Often referred to as the master variable of soil, pH controls a wide range of physical, chemical, and biological processes and properties that affect soil fertility and plant growth. Soil pH, which reflects the acidity level in soil, significantly influences the availability of plant nutrients, microbial activity, and even the stability of soil aggregates. At low pH, essential plant macronutrients (i.e., N, P, K, Ca, Mg, and S) are less bioavailable than at higher pH values near 7, and certain micronutrients (i.e., Fe, Mn, Zn) tend to become more soluble and potentially toxic to plants at low pH values (5–6) (Brady & Weil 2008). Aluminium toxicity is also a common problem for crop growth at low pH (<5.5). Typically, soil pH values from 6 to 7.5 are optimal for plant growth; however, there are certain plants species that can tolerate — or even prefer — more acidic or basic conditions. Maintaining a narrow range in soil pH is beneficial to crop growth. SOM and clay minerals help to buffer soils to maintain a pH range optimal for plant growth (Havlin et al. 2005). In instances where the pH is outside a desirable range, the soil pH can be altered through amendments such as lime to raise the pH. Ammonium sulphate, iron sulphate, or elemental sulphur can be added to soil to lower pH.

Soil Degradation and Crop Production

Soil forms from fresh parent material through various chemical and physical weathering processes and SOM is incorporated into soil through decomposition of plant residues and other biomass. Although these natural soil building processes regenerate the soil, the rate of soil formation is very slow. For this reason, soil should be considered a non-renewable resource to be conserved with care for generations to come. The rate of soil formation is hard to determine and highly variable, based on the five factors of soil formation. Scientists have calculated that 0.025 to 0.125 mm of soil is produced each year from natural soil forming processes. Because of the time required to generate new soil, it is imperative that agricultural practices utilize best management practices (BMPs) to prevent soil erosion. The soil which is first eroded is typically the organic and nutrient enriched surface layer which is highly beneficial for plant growth. Thus, the primary on-site outcome is reduced crop yield as only the less fertile subsurface layers remain. Soil erosion also pollutes adjacent streams and waterways with sediment, nutrients, and agrochemicals creating serious off-site impacts.

Today, agricultural fields are not immune to the forces of nature (e.g., moving water, blowing wind, extremes of temperature) that caused soil erosion in the past. Implementation of agricultural best management practices (BMPs), and through the practice of conservation agriculture, the rate of soil loss can be reduced to approximately equal the rate of soil formation, although often still greater than that in natural systems. In addition to soil erosion, intensive land use has resulted in deforestation, water shortages, and rapidly increasing desertification of vast areas of the globe, all of which threaten the sustainability of our agricultural systems.

Sustainable Soil Management

It is evident that, in order to maintain and increase food production, efforts to prevent soil degradation must become a top priority of our global society. Current population models predict a global population of between 8 and 10 billion in the next 50 years and a two-fold increase in food demand. If mismanagement of soil resources continues to diminish the fertility of the soil and the amount of productive arable land, then we will have lost a precious and essential pillar of sustainable agriculture. Sustainable agriculture is an approach to farming that focuses on production of food in a manner that can be maintained with minimal degradation of ecosystems and natural resources. This sustainable approach to agriculture strives to protect environmental resources, including soil, and provide economic profitability while maintaining social equity. The concept of sustainable agriculture is often misinterpreted to mean that chemical fertilizers and pesticides should never be used. This notion is incorrect, as sustainable agriculture should embrace those practices that provide the most beneficial services for agroecosystems and encourage long-term production of food supplies in a cultural context of the region. It cannot be overstressed that sustainable practices should not only consider crop production and profit, but must include land management strategies that reduce soil erosion and protect water resources. By embracing certain modern-day technologies and learning from the past, our society will be able to continue to conserve soil resources and produce food supplies sufficient to meet current and future population demands.

04

Land Use Pattern and Land Conversion

The geographical area of the country is 328.7 million hectares. As per the latest published 'Land Use Statistics-at a Glance 2012-13 to 2021-22', the area under agricultural land in the country has marginally reduced from 180.62 million hectares in 2018-19 to 180.11 million hectares in 2021-22.

Land Utilization and Land Use Pattern in India: Land use pattern refers to the arrangement or layout of the uses of land which may be used for pasture, agriculture, construction, etc., and factors that mostly determine this are relief features, climate, the density of population, soil and socio-economic factors. The effective and efficient development of natural resources without damaging the environment or human existence is referred to as resource development. Resource development helps future generations as well as current ones.

Land Use Pattern in India

In India, the land is primarily used for agricultural purposes, with nearly 60% of the country's land area devoted to farming. India is one of the world's leading producers of food, and agriculture accounts for a significant portion of the country's economy.

Other uses of land in India include forestry and grazing, which make up about 15% of the country's total land area. Less than 5% of India's land is urbanized, although this figure is growing as the country's population continues to increase.

Land Resources in India

India is one of the world's most populous countries, with over 1.4 billion people, and its land area is correspondingly large. India's land resources are important not only for the country's own citizens but also for the global community. India has a diverse range of land resources, including arable land, forests, and minerals.

Arable land in India amounts to about 60% of the total land area. Most of this arable land is used for agriculture, which is the mainstay of the Indian economy. About half of India's workforce is engaged in agriculture, and the sector contributes around 15% to the country's GDP. The main crops grown in India are rice, wheat, pulses, sugarcane, and cotton. India is also a major producer of spices, tea, coffee, and tobacco.

Forests cover about 21% of India's land area. The country has a rich variety of flora and fauna, and its forests are home to many endangered species of animals. Forests play an important role in the Indian economy, as they provide timber and fuelwood for industries and households. They also help to regulate the water cycle and protect against soil erosion.

India has significant reserves of minerals such as iron ore, bauxite, manganese ore, copper ore, zinc ore, limestone, and mica. These minerals are exploited for various purposes such as construction materials

One of the most valuable natural resources is land. Our living system is supported by the land. As a result, rigorous land resource management is required. There are several different types of land in India. Mountains, plateaus, plains, and islands are all examples.

1. Mountains cover around 30% of India's geographical area. Mountains help rivers flow year after year, carrying fertile soils, facilitating irrigation, and providing drinking water. Mountains provide excellent opportunities for tourism and adventure sports, as well as cash generating.

2. Plains: Plains cover around 43 percent of India's geographical area. Plains provide land for agriculture, industry, and housing, among other things.

3. Plateau: Plateaus cover over 27% of India's area, providing a diverse range of minerals, fossil fuels, and forests.

Land Utilization and Land Use Pattern

Both physical and human factors influence how land is used. Climate, terrain, and soil type are all physical influences. Population, technology, skill, population density, tradition, competence, and other human characteristics are all important considerations.

This means that the net sown area accounts for around 44% of the total land available. If we include fallow (4%) and current fallow (7%), we get to around 54% of the land being used for agricultural or associated activities. Wasteland is too low in quality to be transformed into cultivable land. Furthermore, the pattern of net planted areas differs from state to state. Punjab has a fairly high rate, although hilly states have a very low rate. The percentage of land covered by forest is 23% much below the national forest policy's target of 33% (1952). Illegal deforestation, road and building development, human population pressure, and other factors all contribute to this. The following are the most common forms of land use in the country:

Sown Area Net (NSA)

The cropped area in the year in question is referred to as the net sown area. This sort of land use is crucial since the agricultural output is heavily reliant on it.

This accounts for around 6% of India's total reported area, or 141.58 million hectares, compared to the global average of 32%. The amount of farmed land per capita has decreased dramatically, from 0.53 ha in 1951 to 0.11 ha in 2011-12, necessitating population control. Rajasthan has the biggest NSA, with 18.35 million hectares, accounting for 12.96 percent of India's total reported NSA; Maharashtra is second.

Due to the gentle slope of the terrain, fertile alluvial and black soils, a large amount of the Sutlej, Ganga plains, Gujarat lowlands, Kathiawar plateau, Maharashtra plateau, and West Bengal basin is farmed. Climate-friendly Irrigation facilities that are second to none. Because of its rough topography, adverse climate, and barren soils, the mountainous area and dryer tracts have lower NSA.

More than Once Sown Area

This land is utilized to cultivate more than one crop every year, as the name implies. This sort of land is important because, nearly all arable ground has been cultivated, and the only method to enhance agricultural productivity is to raise cropping intensity, which may be accomplished by expanding the area seeded many times. This group includes a substantial portion of the land in Punjab, Haryana, Uttar Pradesh, and Bihar, as well as the coastal areas.

Forest land

This covers any property that is legally designated as forest or is managed as forest, whether it is state-owned or privately held, and whether it is forested or kept as prospective forest land. The forest area includes the area of crops cultivated in the forest and grazing fields or areas open for grazing within the forest. More forest land is being reported in Madhya Pradesh, Arunachal Pradesh, Odisha, Maharashtra, Andhra Pradesh, and the Andaman Nicobar Islands. Heavy rains and relief characteristics are to blame.

Land that cannot be Cultivated

Land not available for cultivation includes barren and unculturable land, as well as land put to non-agricultural uses. Non-agricultural land comprises land occupied by communities, cities, highways, railways, or land under water, such as rivers, lakes, canals, tanks, ponds, and other bodies of water. All barren and uncultivated lands on steep and hill slopes, deserts, and rocky places are classified as barren land. And these places cannot be ploughed without incurring significant input costs and perhaps minimal returns. Rajasthan, Madhya Pradesh, Maharashtra, Gujarat, Himachal Pradesh, Uttar Pradesh, and Bihar are the states with the most acreage in this category. Chandigarh, Andaman and Nicobar, Dadra and Haveli, and Sikkim, on the other hand, have a smaller proportion of their land in this category.

Grazing fields and Permanent Pastures

Permanent pastures and other grazing fields cover a total of 10.3 million hectares. This accounts for around 4% of the country's overall reporting area. Given the enormous number of cattle in the country, the current area under pastures and other grazing sites is insufficient. Pastures cover around a third of the reporting area in Himachal Pradesh. In Madhya Pradesh, Karnataka, Gujarat, Rajasthan, Maharashtra, and Odisha, the percentage ranges from 4 to 10%. In the remaining sections of the country, it is less than 3%.

Land Covered in a Variety of Tree Plantations and Groves

This covers any cultivable land that is not covered by the NSA yet is used for agricultural purposes. This category includes land under casuarina trees, shrubs, thatching grass, bamboo, and other fuel groves that are not classified as orchards.

Agricultural Waste

This is land that is accessible for agriculture but is not being utilized for one reason or another. Due to limitations such as a shortage of water, soil salinity or alkalinity, soil erosion, and waterlogging, it cannot be used. Agriculture was once practiced in the Reh, Usar, Bhur, and Khola tracts of Uttar Pradesh, Punjab, and Haryana, as well as other regions of the country, but it had to be abandoned due to soil shortages caused by poor agricultural techniques. Due to several land reclamation programs conducted in India after independence, wasteland has decreased. Gujarat (13.6 %), Madhya Pradesh (10.2%), Uttar Pradesh (6.93 %), and Maharashtra (6.93 %) are the states with the most cultivable wasteland (6.83 %).

Vacant Land

This category contains all land that was once cultivated but is currently uncultivated. Current fallow lasts one year, but fallow that lasts two to five years is categorized as 'fallow other than current fallow.' Rajasthan has the biggest area of 'fallow other than present fallow,' with 2040 hectares, followed by Maharashtra & Andhra Pradesh. Andhra Pradesh has the most land that is currently fallow.

Land Conversion

The agricultural lands are being

converted into non-agricultural lands unabated. There is no control or limit for conversion of agricultural land into non-agricultural land.

In the long term, the change in agricultural land use into other purposes will threaten the food security. Indeed, another problem arises for the low farmer exchange value for production so that most of the farmers tend to be hopeless in cultivating their land. This practice reduces the availability of land for food production, potentially impacting food security and agricultural sustainability. This can lead to soil erosion, water pollution, and habitat loss for wildlife.

In view of the above, the state government should enact strict laws limiting the conversion of agricultural lands into non-agricultural lands.

05

Soil Degradation & Problem Soils

India is witnessing an alarming rise in soil degradation, threatening its agricultural productivity, food security, and environmental sustainability. Soil, a vital resource supporting the livelihoods of millions of farmers and maintaining ecosystem balance, is under siege from various forms of degradation (Indian Express 19 October 2024).

According to recent estimates, nearly 115 to 120 million hectares (Mha) roughly 33% of the country's total geographic area are affected by soil degradation, including water erosion, wind erosion, salinity, and vegetation loss.

Out of 360 million hectares of total geographical area, 115 to 120 million hectares are degraded. This data was harmonised from different sources, including ISRO's Satellite Application Centre (SAC), National Bureau of Soil Survey and Indian Institute of Soil Science.

The parameters to categorise soil degradation are chemical and physical. For instance, in the case of chemical degradation, soil would have become acidic. Even if farmers apply loads of urea, the soil will give no produce. The trials show in some locations, the soil quality came down by 10 times.

The latest Desertification and Land Degradation Atlas of India published by the SAC, which formed the basis for the assessment, reveals that water erosion is the most significant contributor, affecting 11.01% of India's land. Other major processes include vegetation degradation (9.15%) and wind erosion (5.46%). These processes, compounded by deforestation, poor agricultural practices, and climate change, are particularly prevalent in semi-arid and dry sub-humid regions of the country.

The atlas also highlights the growing impact of desertification, with 83.69 Mha of dryland classified as undergoing this process, which has seen a cumulative increase of over 1 million hectares since 2003-05.

In addition to natural processes, human-induced activities, such as mining, overgrazing, and industrial pollution have further exacerbated the problem. States like Rajasthan, Maharashtra, Gujarat, and Telangana are among the worst affected, with significant portions of their land showing severe degradation. Rajasthan alone, for example, has over 21 million hectares classified as degraded, largely due to wind erosion in its arid and semi-arid zones.

Soil degradation has far-reaching consequences on India's agricultural sector, which contributes significantly to the national economy and provides employment to a large percentage of the population. The loss of topsoil and nutrients due to erosion has reduced the land's ability to sustain crops, leading to lower yields and increased vulnerability to extreme weather events.

Ms Sunita Narain, Director General of Centre for Science and Environment (CSE) stated that "Depletion in soil quality means depletion of carbon content and increased need for fertilisers. This adds to Greenhouse Gases emissions. The way ahead is to increase soil carbon through increased use of biomass. There can be many options to do this - from natural farming to increased use of nitrogen fixing crops and increased use of organic manure. This is a win-win as it will add fertility, reduce subsidies for fertilisers and emissions."

Problem Soils

Soils which set a limit to crop production due to mineral stress, drought, acidity, sodicity, waterlogging, etc. could be considered as problem soils. The problem soils are categorized into Vertisols, acid sulfate soils, saline-sodic soils, peat soils and fine textured alluvial soils. About 100 million hectares of land physio-graphically and climatically suited to rice lie idle because of soil toxicities caused by salt, alkali, acid or organic matter, besides vast areas where deficiencies of zinc, phosphate and iron, or excesses of iron, aluminum and manganese limit rice yields. A general definition of problem soils could be visualized as those which have adverse conditions, inherent or man-made (created), posing severe limitations to successful crop production. Thus, the soil profiles having high ground water tables and less permeable argillic horizon, eroded soils, sandy soils of low fertility, coastal soils which are inundated frequently, and the laterites (Oxic soils) could be considered as problem soils. However, because of the importance and magnitude of severity, only the saline and sodic, acid, and acid sulfate soils are discussed here, as they constitute approximately 60 million hectares out of about 140 million hectares of net area under cultivation in India.

5.1. Saline and Sodic Soils:

The salt-affected soils of the country are classified into four broad groups based on the nature of soil problem and their geographical distribution. Sodic soils of the Indo-Gangetic plains alone account for roughly one-third of the 7 million hectares of the salt affected soils in India. The salient physico-chemical characteristics of sodic soils in the Indo-Gangetic plains are: (a) excess soluble salts with preponderance of sodium carbonate and bicarbonate, and high soil pH (up to 10.5) in 1 :2 soil water suspension; (b) high exchangeable sodium percentage (80 - 90); (c) heavy texture in the subsurface soil; (d) usually calcareous nature with a zone of accumulation of calcium carbonate (sometimes with a calcic horizon); (e) highly dispersed and extremely impermeable to water and air; and (f) dominance of illite clay mineral. The other important characteristics these soils have in relation to crop production are - high boron content. A fluorine content of 32 ppm in wheat straw which resulted in significant reduction in grain yield was associated with 22 ppm of water-soluble fluorine in soil.

Types of salt-affected soils in India:

Sr. No.	Type of soils	States in which they occur	Approx. area (m.ha.)
1	Coastal salt-affected soils		
	a) Coastal salt-affected soils of arid region	Gujarat	0.714
	b) Deltaic coastal salt-affected soils of the humid region	West Bengal, Orissa, Andhra Pradesh and Tamil Nadu	1.394
	c) Acid salt-affected soils	Kerala	0.016
2	Salt-affected soils of the medium and deep black soil regions	Karnataka, Madhya Pradesh, Andhra Pradesh and Maharashtra	1.420
3	Salt-affected soils of the arid and semi-arid regions	Gujarat, Rajasthan, Punjab, Haryana and Uttar Pradesh	1.000
4	Sodic soils of the Indo-Gangetic plains	Haryana, Punjab, Uttar Pradesh, Bihar, Rajasthan and Madhya Pradesh	2.500
	Total		7.044

Crop growth on these soils is adversely affected owing to the effect of excess exchangeable sodium directly, and more importantly through its effect on the physical-chemical properties of the soil. The management of these soils should basically meet two objectives - (a) replacement of excess Na on the soil exchange complex by Ca, and (b) leaching of the exchanged Na out of the root zone. The most commonly used soil amendment for the purpose in India is gypsum ($CaSo_4$, $2H_2O$) although sulfuric acid or acid forming substances such as aluminum sulfate and pyrite have been used. The studies show that pyrite is an inferior amendment compared to gypsum, its relative ineffectiveness being due to lack of oxidation once incorporated into a sodic soil with high pH. The scientists at the Central Soil Salinity Research Institute, Karnal (India) have evolved a management technology for the improvement of saline-sodic soils in the Indo-Gangetic plains, which essentially consists of: mixing of gypsum in shallower depths (10-15 cm soil), growing of crops in a rice based cropping system, and application of balanced dose of NPK and zinc. Management of these soils centres around cropping with rice owing to the fact that because of the peculiar situation under which it is grown it is tolerant to exchangeable Na. It has been found that rice can not only tolerate high ESP (up to 55 but at 80 the yield decline is about 50%), but it also results in high cumulative removal of soil exchangeable Na by mobilizing native insoluble calcium carbonate.

The effect of gypsum and cropping system on the improvement of saline-sodic soils under field conditions and observed that rice-sugar cane system had the best reclamation effect followed by rice-berseem and rice-rice sequence. Gypsum application had little effect on the yield of a three-crop sequence of rice-wheat-rice as compared to that of NPK in saline-sodic soil. The ameliorative role of zinc in the growth of maize under saline-sodic conditions has been found to be associated with the enhanced absorption of Zn, Ca, and K and the widening of Ca/Na and K/Na ratios. It has also been observed that tolerance to sodicity is related to lower Na/K ratio in the tillering phase of wheat. Any variety which can take up K in the face of competition from excess Na is more tolerant.

Saline-sodic soils contain low amounts of exchangeable Fe, Mn, Zn and Cu but available Mo content is high. The available Zn is lower in calcareous sodic soils than in non-calcareous soils. The effect of excess fluorine on the reduction in crop yield is associated with higher Na and lower K, Ca and P contents in the plant. Addition of high levels of P reverses the situation to a great extent. The saline-sodic soils have peculiar physical and chemical properties which influence adversely the water and solute movement and are responsible for deficiencies or toxicities of nutrient elements. Therefore, efficient management of such soils for successful crop production does require an efficient and economic use of fertilizers, besides leaching and application of amendment such as gypsum, pyrite, organic matter, green manuring, rice husk, etc. Management of saline soils involves reclamation measures for leaching of soluble salts and drainage and once the excess salts have been removed from the surface soil layers, growing of crops simultaneously with leaching. Rice is again an effective crop, as it grows satisfactorily under flooding, and green manuring with berseem (Trifolium alexandrinum) after rice hastens the process of salt leaching. Research findings indicate that there is a definite varietal difference amongst maize and wheat cultivars in their susceptibility / tolerance to salinity. It has been further observed that application of Fe and Zn mitigates to a large extent the adverse effects of salinity on yield and nutrient uptake by crops.

5.2. Acid Soils:

About 49 million hectares are considered acidic of which 26 million hectares have pH below 5.6 and 23 million hectares pH between 5.6 and 6.5. These soils include red, laterite, mixed red and yellow, brown forest, foot hill soils, peat soils and varieties of acid sulfate soils. Acid soils have been mainly formed as a result of drastic weathering under humid climate and heavy precipitation. Laterization, podzolization, intense leaching and accumulation of undecomposed organic matter under marshy conditions are the contributory processes for acid soil development. However, there is considerable heterogeneity in the morphological, physical and chemical characteristics which may be attributed to various soil forming factors in the development of these soils in the various regions of the country. Acid soils have generally kaolinite, hydrous mica and illitic type of clay minerals. The acid laterite and lateritic soils which have kaolinitic clay minerals have low cation exchange capacity, varying from 3 to 10 meq/100 g soil, while some of the red and alluvial soils may have slightly more CEC because of the presence of illite. On the other hand, the organic matter rich acid sulfate soils (kari and pokkali) have CEC as high as 40 - 55 meq/100 g of soil. Since the acid sulfate soils form a distinct class by themselves, these are discussed separately. Illite is the dominant clay mineral in tarai (foothill) soils and chlorite is next in order of abundance. The dominant clay minerals in the acid alluvial soils are illite, smectite and kaolinite. Exchangeable aluminum is the main contributing factor in acid laterite and alluvial soils (Alfisols and Inceptisols, Entisols) while exchangeable hydrogen is the main cause of soil acidity in tarai and brown forest soils (Mollisol and Spodosol). Acid soils are generally deficient in calcium and magnesium, the degree of base saturation being usually 20 - 25% in most of them. Exchangeable magnesium has been reported to be higher than exchangeable calcium in the acidic red soils of Bihar and alluvial soils of Assam. The soils are poor in organic matter and total nitrogen except in the forest areas (tarai soil of Himachal Pradesh and in the acid soils of Assam). These soils are generally low in phosphorus, having high phosphorus fixing capacity. In the acid soils of Assam, organic phosphorus contributes about three-fourths of the total phosphorus while aluminum and iron bound phosphorus constitutes the main phosphorus fractions in the acidic red and laterite soils. Usually, potassium is not deficient except in the acid laterite and red soils. Acid soils belonging to these groups have made good store of potassium, but the availability depends on the mechanism of release in relation to potash bearing minerals and presence of clay minerals of hydrous mica type. Acid soils are well supplied with Fe, Mn, Zn and Cu but have low content of Mo and B. The management problems of acid soils for successful crop production are related to: (a) toxicity of Al, (b) availability of P, (c) supply of Ca and Mg, and (d) deficiency of Mo. Application of lime is the main approach in the management of acid soils, and supplementary application of organic matter has been found to be necessary for the improvement of acid laterite soils.

Proper selection of crops and crop varieties which are tolerant to excess Al has been another useful approach in the management of acid soils for crop production. In this approach a crop which is highly responsive to liming and/or tolerant to Al is included as the first crop in the rotation in order to realize maximum benefit from liming and also from the standpoint of economics of liming. Classification of the upland crops according to their responsiveness to liming: (a) high response - pigeon pea, soybean, cotton; (b) medium response - gram, lentil, peas, groundnut, sorghum, maize; and (c) low response - small millets, rice, mustard and potato.

5.3. Acid Sulfate Soils:

Acid sulfate (also included are the saline acid and saline waterlogged soils) soils constitute an important group of problem soils in India. Although they are limited in extent, these soils comprise an area of over 108,000 hectares in the coastal areas of the western parts of Kerala, i.e. 12% of the area under rice cultivation in this state, and over 280,000 hectares in the southern parts of West Bengal. These soils are both saline and acidic, occurring in areas which remain submerged under water for the major part of the year and are situated at a depth of 1 to 1.5 meter below the sea level. In addition to the peculiar physical, chemical and biological characteristics common to waterlogged soils, the permanently waterlogged lands in Kerala present other typical features of their own, such as acid saline soils, acid sulfate soils, peat marshes, alternate inundation with saline and fresh water, and situation below the sea level endangering drainage.

The physical, chemical and mineralogical characteristics of some typical acid sulfate soils of Kerala have heavy texture (clay loam), low bulk density (I .24 - 1 .40 g/ cm3), strong acidity (pH 3.2 -3.8) and high organic matter (2.3 - 7.0%). They have low contents of K, Ca and Mg, medium contents of P and Fe but high contents of Al, Mn, Cu, Zn, sulfate S, and total S (which is mainly in organic form). Kaolinite is the dominant clay mineral but is associated with fairly large amounts of smectite and small amounts of halloysite. Rice is the single most important crop grown on these soils and the major soil limitations for crop production are the toxicity of Al and Fe and deficiency of P and Ca. Besides leaching and adequate drainage, application of suitable amendment such as lime which can inactivate Al and Fe is the main management solution to these problems. Liming and application of phosphate are necessary for crop production. Flushing of the soil followed by application of lime at half the amount required to raise the soil pH to 6.5 in combination with nitrate or MnO2 increased the pH and markedly decreased the salt content and concentration of Fe and Al on submergence and thereby resulted in good rice crop.

Ongoing efforts

The government, under its commitment to the United Nations Convention to Combat Desertification, has set an ambitious target of achieving land degradation neutrality by 2030. This includes the restoration of 26 million hectares of degraded land.

06

Soil Reclamation

Reclamation and Management of Salt Affected Soils

Soil salinity is one of the main environmental problems affecting extensive areas of land in both developed and developing countries. Salinity is common in the region of arid and semi-arid regions where rainfall is too low to maintain a regular percolation of rainwater through the soil and irrigation is practiced without a natural or artificial drainage system. Such irrigation practices without drainage management trigger the accumulation of salts in the root zone, affecting several soil properties and crop productivity negatively. Globally, more than 900 million hectares (M ha) of land, accounting for nearly 6% of the world's total land area and approximately 20% of the total agricultural land is affected by salinity. Salinity is the product of complex interaction of many variables which lessen the current and/or potential capability of soil to produce goods and services. Presently, the total degraded land due to salinity and sodicity is estimated to be 6.74 M ha in India (NRSA and Associates, 1996) of which 2.22 M ha is present in Gujarat State and about 0.12 M ha area is affected by salinity in black soil region of Gujarat. While some of the problems are widespread and operate over long term the others are mainly localized and more intensive in their impacts. Soil salinity problems are further compounded where the ground water is highly saline and such areas by and large remain barren for want of economically feasible technological interventions and thereby affecting the livelihood of the farmers because of low productivity of the existing farming practices. The adverse effects of salinity have put the food and nutritional security at stake besides creating environmental pollution and affecting soil health and income of the farmers.

Soil salinity

Concentration of soluble salts in the surface or near-surface soil horizon is a major problem with severe worldwide economic and social consequences. In terms of agricultural consequences, excessive salt in soil accelerates land degradation processes resulting in increased impact on crop yields and agricultural production and ultimately leads to lower the farmers' income. Accumulation of soluble salts at the surface or near-surface of soil horizon is called salinization (Szabolcs, 1974). As a consequence, chlorides and sulphates of sodium, calcium and magnesium increase in their concentration resulting in increased electrical conductivity

(EC). Further, presence of salt crystals, salt crusts and salic horizons result in presence of loose and quite porous granular structure in the top soil. The top soils become puffy in the presence of large amounts of sodium sulphate and appear moist when soils have calcium chloride and magnesium chloride. Natural or primary salinity, primarily results from the accumulation of salts over long period of time, in the soil or groundwater, which is generally caused by two natural processes.

- The first is the weathering of parent materials containing soluble salts which break down rocks and release soluble salts of various types, mainly chlorides of sodium, calcium and magnesium, and to a lesser extent, sulphates and carbonates. Sodium chloride is the predominant soluble salt.
- The deposition of oceanic salt carried by wind and rain forms the second cause. 'Cyclic salts' are ocean salts carried inland by wind and deposited by rainfall, and are mainly sodium chloride.

Table 1. Extent (ha) of salt affected soils in different states of India

State	Saline	Sodic	Total
Andhra Pradesh	77598	196609	274207
Andaman & Nicobar Islands	77000	0	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	183399	232556
Karnataka	1893	148136	150029
Kerala	20000	0	20000
Madhya Pradesh	0	139720	139720
Maharashtra	184089	422670	606759
Orissa	147138	0	147138
Punjab	0	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	1346971	1368960
West Bengal	441272	0	441272
Total	**2956809**	**3770659**	**6727468**

Secondary or human-induced salinity

Salinity occurs through natural or human-induced processes that result in the accumulation of dissolved salts in the soil water to an extent that inhibits plant growth. Secondary salinisation results from human activities (anthropogenic) that change the hydrologic balance of the soil between water applied (irrigation or rainfall) and water used by crops (transpiration).

Sources and causes of ccumulation of salts

The main causes of salt accumulation include:

- Capillary rise from subsoil salt beds or from shallow brackish ground water;
- Indiscriminate use of irrigation waters of different qualities
- Weathering of rocks and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials
- Ingress of sea water along the coast
- Salt-laden sand blown by sea winds
- Lack of natural leaching due to topographical situation, especially in arid and semi-arid conditions.

Characteristics of salt affected soils

In general, saline and alkali (sodic) soils are the two major groups of salt affected soils that can be distinguished on the basis of physico-chemical and biological properties and their geographical and geochemical distribution. Saline and alkali soils are defined and diagnosed on the basis of EC and SAR determination made on soil samples and the information thus generated contributes substantially to the scientific agriculture based on USDA classification. In India, salt affected soils are mainly confined to the arid and semiarid and sub humid (dry) regions and also in the coastal areas. The salt deposits are of sodium carbonate, sulphate and chloride with some calcium and magnesium. As there are large black soil (Vertisol) areas in the country, the limit of ESP for defining sodic soil can be appropriately lowered based on the study conducted. It is inferred that at salinity of < 2 dS m-1, the Vertisol can be grouped as sodic if the ESP is > 6 and >10 in clayey and silty clayey soils, respectively. Similarly, at salinity of < 4 dS m-1, the Vertisol can be grouped as sodic if the ESP is > 13 and >21 in clayey and silty clayey soils, respectively.

Saline soils

These soils have Electrical Conductivity (EC) of the saturation extract more than 4 dS m-1, the Exchangeable Sodium Percentage (ESP) less than 15 and the pH is less than 8.5. With adequate drainage, the excessive salts present in these soils may be removed by leaching thus bringing them to normalcy. Saline soils are often recognized by the presence of white crusts of salts on the surface. The important soluble salts comprise cations viz., sodium, calcium and magnesium with low amounts of potassium and anions viz., chloride, sulphate and sometimes nitrate. Owing to the presence of excess salts and the absence of significant amounts of exchangeable sodium, saline soils generally are flocculated and as a consequence the permeability is equal to or higher than that of similar non-saline soils.

Saline-alkali soil

These soils will have EC of the saturation extract more than 4 dS m-1, the ESP greater than 15 and the pH is seldom higher than 8.5. These soils form as a result of combined process of salinisation and alkalisation. As long as excess soluble salts are present, these soils exhibit the properties of saline soils. Leaching of excess soluble salts downward, the properties of these soils will become like that of non-saline alkali soils. On leaching of excess soluble salts, the soil may become strongly alkaline (pH > 8.5), the particles disperse and the soil becomes unfavourable for the movement of water and for tillage.

Non-saline alkali soil

Alkali soils which are known as Sodic or Solonetz have their ESP greater than 15, the EC less than 4 dS m-1 and the pH ranges between 8.5 and 10. The exchangeable sodium content influences significantly the physical and chemical properties of these soils. As the ESP tends to increase, the soil tends to become more dispersed. Sometimes distinction is made between alkali and sodic soils especially in Vertisols, where the term 'sodic' is preferred as pH of these soils increases slowly with increase in ESP.

Reclamation and management of salt affected soils

Technological knowledge generated till date has helped in taming the problem in large tracts of land in different countries to restore their full potential. However, new challenges are set to be faced either due to changing climate or land use anomalies, leading to exponential increase in the area under salinity. With new challenges cropping up, soil salinity related stresses can be more pronounced and more damaging to crop production in coming years. It is well established that plant growth can be restricted or entirely prevented by increased levels of salinity and alkalinity in the soil. The productivity of these soils can be restored by management and reclamation using different technologies available with the ICAR-Central Soil Salinity Research Institute. The processes of accumulation of salts and build-up of ESP have to be reversed. To achieve this, provision of adequate drainage, replacement of Na+ ions from the exchange complexes and leaching out of soluble salts below root zone has to be ensured. For reclamation, different methods like physical, chemical, hydrotechnical and biological are to be adopted so that yield level of the crops grown on these soils can be enhanced and in turn income of the farmers. Physical methods include deep ploughing, sub-soiling, sanding, profile inversion, scrapping etc. Hydro-technical methods include leaching of salts, provision of drainage, use of leaching curves etc. Under chemical methods, application of gypsum is the prominent one. Other chemical techniques include application of calcium chloride, calcite, phospho-gypsum and iron pyrites etc. Biological methods include green manuring, addition of FYM and other organic manures, incorporation of crop residues, press mud, municipal solid waste, microbial consortium, bio-saline agriculture, use of salt tolerant varieties etc.

Strategies for enhancing farm productivity and farmers' income:

For increasing farmers' income, the rate of growth in farm income has to be sharply accelerated and therefore strong measures will be needed to harness all possible sources of growth in farmers' income and these sources are improvement in productivity, resource use efficiency, lowering of the cost of production, increase in cropping intensity, crop diversification with high value crops, use of salt tolerant varieties, use of proper technology, etc. ICAR-CSSRI has developed various technologies for reclamation and management of salt affected soils and with the use of these technologies for the purpose, the hitherto unproductive or low productive salt affected land can be put under optimum productivity which will lead to more production and income.

6.1. Gypsum technology for reclamation of sodic soils:

Using this technology till date, about 1.94 Mha sodic land has been reclaimed and the reclaimed area contributes 14-15 million tonnes of food grains to the National pool. The cost of intervention and output per unit area is about Rs 42500 per hectare. Farmers obtained 4 tonnes/hectare rice and 2 tonnes/hectare wheat yield from reclaimed alkali land right from the first year of the reclamation, which increased to 5 and 3 tonnes/hectare during 3rd year onwards, respectively with 135 man-days of employment generated per hectare per year. Its net present worth (NPW) estimated to be Rs 52,000/ha. This technology improved soil health, increased resource use efficiency, raised farm income, reduced poverty, minimised inequity, reduce flood hazards and waterlogging and improve quality of overall environment.

6.2. Sub-surface drainage technology:

Subsurface drainage is an effective technology for amelioration of waterlogged saline irrigated lands in India. The technology has been widely adopted and replicated in Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka and almost about 66,084 ha waterlogged saline soils have been reclaimed. Due to notable increase in crop yields, the technology results in 3-fold increase in farmers' income. The technology also generates around 128 man-days additional employment per ha per annum and also enhanced the crop intensity by

40-50%, significant enhancement in crop yields (up to 45% in paddy, 111% in wheat, 215% in cotton and 138% in sugarcane in different parts of the country, and farm income by 200-300% leading to benefit cost ratio of 1.5.

6.3. Cultivation of Salvadora persica on highly saline land:

This species was found to grow well on saline black soils having salinity up to 55 dS m-1 and found to yield well. Based on the studies conducted, the National Bank for Agriculture and Rural Development (NABARD), Mumbai in association with the RRS, Bharuch has developed a bankable model scheme for cultivation of Salvadora persica on salt affected black soils through the project sponsored by NABARD. Regreening of highly saline black soils that cannot be put under arable farming and reduction in salinity by 4th year onwards that enable to take up intercropping with less tolerant crops/ forages. Planting of Salvadora persica would fetch about Rs. 7000/- per hectare. Apart from this, the species provide a dwelling place for birds and enhances the environmental greening.

6.4. Cultivation of dill (Anethum graveolens):

Non-conventional crop like dill can be grown using residual moisture resulting in 2.6 q/ha seed yield with net returns of Rs. 8000/-. This crop forms an ideal option for the state in general and the region in particular, which by and large faces water scarcity problems (Rao et al., 2000). Under saline water irrigation, crop would yield net returns of Rs. 16500/- ha-1 with Rs. 6000/- per hectare as cost of cultivation.

The Benefit Cost Ratio (BCR) works out to be 2.75. This crop thus would help farmers of the region to go for the second crop in the rabi season on lands, which hitherto remain fallow due to water and salinity constraints. Thus, dill crop can be taken up using residual moisture and/or with saline ground water. The green can be used as leafy vegetable, an additional source of income.

6.5. Farmers based ground water recharge:

The ICAR-Central Soil Salinity Research Institute, Karnal along with its Regional Research Station at Bharuch, Gujarat has designed artificial groundwater recharge structures for better harnessing rainwater in Bharuch and Narmada districts mainly for cultivation purposes. The CSSRI, RRS, Bharuch has installed 15 artificial rainwater recharge wells at farmers' fields in Bharuch and Narmada districts of Gujarat through the financial assistance from the Ministry of Water Resources, Government of India. The Prolonged availability and improvement in groundwater quality in recharge well of Gujarat increased farmer's income by Rs 30,000 to Rs 75,000 per ha in banana and papaya crops (Success Story-ICAR website, 2013).

6.6. Integrated farming system model for salt affected black soils:

The farming system model comprised of a rain water harvesting structure, fruit species like papaya and vegetables on dykes, other fruit crops like banana, jamun, aonla, seed spices, woody biomass species like Eucalyptus and Pongamia and a compost pit has been developed with a aim to get farmers a staggered income throughout the year. Water productivity of banana, papaya, dill, coriander, brinjal, bottle gourd and tomato has been worked out along with benefit: cost ratios. Papaya followed by banana amongst different fruit species; dill followed by ajwain and coriander amongst spices and bottle gourd followed by tomato and brinjal amongst vegetables showed higher B:C ratios. The BC ratios of vegetables and spices were more than that of the fruit species. The productive components like fruits, vegetables and spices could provide a net income of about Rs. 52258/- ha-1. In view of low water requirement, spices, vegetables and papaya are better suited for water scarce regions like Bara tract of Gujarat with saline black soils.

6.7. Cotton-pulse intercropping proved to be beneficial on moderately saline black soils:

Farmers who take cotton as rainfed mono crop in the Bara tract in Amod, Vagra and Jambusar talukas of Bharuch district of Gujarat and other parts of the state do face crop losses due to salinity and due to other climatic vagaries. Under such situations, intercropping with pulses provides some remuneration to the farmer in the event of failure of cotton crop. The farmers of the region have been adopting the cotton intercropped with pulse technology for maximising the production and income also.

6.8. Cultivation of forage grasses on saline black soils:

Gujarat state has one of the largest dairy industries in the country. As the fodder produced on arable lands and grasslands is not sufficient to meet the demands of the cattle population, cultivation of forage grasses, Dichanthium annulatum and Leptochloa fusca in a ridge-furrow planting system with 50 cm high ridge and 1 m between midpoints of two successive ridges was found ideal in saline black soils having salinity up to 8-10 dS m-1. For maximizing forage production on saline black soils, Dichanthium on ridges and Leptochloa in furrows form ideal proposition. Cultivation of salt tolerant grasses like Dichanthium annulatum and Leptochloa fusca on moderate saline soils result in 1.9 t/ha and 3.2 t/ha, respectively.

6.9. Cultivation of desi cotton on saline Vertisols:

Desi cottons are known for their short staple characteristics, deep root system, resistance to diseases and pests and drought. The ICAR- CSSRI, RRS, Bharuch has been working on improvement in salt tolerance of herbaceum and arboreum cotton and has screened and identified salt tolerant germplasm of cotton. Studies conducted by the station has revealed that desi cotton line (G Cot 23) as salt tolerant and high yielding even at 11.2 dS m-1 salinity and identified as salt tolerant desi cotton variety. Field trials were also taken up on farmers' fields with G. Cot 23 on saline Vertisols in four villages namely Rajpur, Mingalpur, Shela and Kamatalav in Dhandhuka taluka of Ahmedabad district indicated seed cotton yields in the range of 1.7-1.8 t/ha and the salinity ranged from 9.4 to 10.2 dS m-1 (Success Story- ICAR website, 2015).

6.10. Salt tolerant cultivars in field crops:

Salt Tolerant Cultivars (STCs) capable of growing in un-reclaimed or partially reclaimed soils represent a sustainable approach to obtain high productivity in saline soils and increase in income of farmers. This strategy assumes several greater importances in sodic areas still uncovered by the gypsum-based package and other technologies. Again, they are an attractive option for the poor farmers lacking material resources to use the costly chemicals. STCs developed in different crops have been adopted in many parts of Punjab, Haryana, Uttar Pradesh and other states (ICAR-CSSRI, 2015). Many promising lines such as CSR 46 in rice, KRL 283. KRL 345, KRL 347 and KRL 351 in wheat have been identified and are being evaluated for release. Several potential genetic stocks have also been developed for the use as parents in future selection and hybridization programs.

Salt affected soils either due to excess soluble salts or due to high exchangeable sodium content have become non-productive, so to restore its productivity, it is highly essential to reclaim and manage these soils using different specific technologies. To achieve this restoration, there would be a need for the involvement of relevant stakeholders such as farmers, public institutions (research and extension institutions, other line department of government, KVK, NGO) for expansion, adoption and awareness about available technologies which not only help in restoring the productivity but also enhancing the productivity and directly or indirectly increase farmers' income.

07

Land Development based schemes implemented by NABARD

NABARD has been in the forefront in implementation of schemes for soil and water conservation with people's participation. Rainfed areas, which account for 51% of the cultivated area, play a significant role in food production, contributing 40-45% of the total food production. To address the issues in rainfed farming, NABARD entered into watershed development space in the year 1992 through KfW assisted Indo-German Watershed Development Programme (IGWDP) in Maharashtra, wherein participatory approach of watershed development was adopted on a large scale for the first time. The watershed development programmes were subsequently implemented in Gujarat, Rajasthan and Andhra Pradesh.

Based on the success in implementation of the participatory watershed development under IGWDP, Watershed Development Fund (WDF) was set up at NABARD in 1999-2000 with an initial corpus of Rs 200 crore contributed equally by GoI and NABARD.

7.1. Watershed Development Fund:

Cumulatively, 2942 projects have been successfully completed/closed against the sanctioned 3,747 watershed development and related projects, covering an area of 27.09 lakh ha. As on 31 January 2025, 805 watershed development and related projects are under various stages of implementation across 28 states.

Watershed Development and Related Projects

7.1.1. Integrated watershed development with climate proofing

Integrated watershed development programmes are implemented in two phases – (i) Capacity Building Phase (CBP) and (ii) Full Implementation Phase (FIP) in participatory mode, with the active involvement of Village

Watershed Committees (VWCs) and Project Facilitating Agency (PFA). The projects are being implemented in 20 states, namely Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, Uttarakhand and West Bengal. As on 31 January 2025, 1,214 WDF projects have been sanctioned with financial outlay of Rs.1083.91 crore, against which an amount of Rs.763.47 crore has been disbursed.

7.1.2. Agroecology-JIVA

JIVA, an agro-ecological transformation programme has been launched in the year 2022 to pioneer and scale up agro ecology as a strategic and transformational approach in watershed and tribal development projects, leveraging the pre-existing natural and social capital. The key aspect of such transition is affecting 'behavioural change' through farmer led extension. As first of its kind programme, 24 pilot projects, including watershed and tribal areas, covering five agroecological zones in vulnerable rainfed areas, across 11 states have been sanctioned. JIVA adopts natural farming as its cardinal principle, balancing ecology and economy in the rural ecosystem following a natural progression (farmer-farm-landscape). Designed in tune with FAO framework on agroecology, natural farming practices under JIVA promote diversified climate resilient crop systems (crops-livestock-trees), rejuvenation of biological processes, natural methods of pest and nutrient management and efficient management of rainfall and soil moisture. While placing soil at the heart of the system JIVA will enable local communities to protect and improve their environment and wellbeing by creating positive impacts through working in harmony with nature. Based on the success of pilot projects, they are expected to graduate to next phase i.e. upscaling and consolidation phase. Further, scaling up across Natural Resource Management projects is expected in the coming years, thus giving Agroecological orientation. As on 31 January 2025, 24 JIVA projects are ongoing under watershed and tribal development programmes.

7.1.3. Climate-proofing in completed watershed projects (WDF-CP)

To reduce vulnerability of watershed community to the impact of climate change on production, productivity and livelihood of the farmers, NABARD is implementing climate change adaptation initiatives in its watershed projects under WDF in 11 states (Bihar, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, Tamil Nadu, Telangana and Uttarakhand). These projects are planned and designed based on the climate change vulnerability assessment in various sectors of agri & allied activities by the watershed communities. Based on the vulnerability of the sectors and the community to climate change impact, the project interventions are identified by the watershed communities and implemented with financial support from NABARD under WDF. Core interventions under the initiative include additional soil and water conservation measures in the hot spot areas, soil fertility and productivity enhancement, promoting sustainable farming practices, risk mitigation and knowledge management, etc. As on 31 January 2025, 207 climate proofing projects have been sanctioned across 11 states.

7.1.4. Spring-shed Development Programme in NE and hilly regions

Due to adverse impact of climate change in recent years, the springs, which are lifeline of the North Eastern Region (NER), are getting dried up affecting agriculture and livelihood of rural community. In order to revive and rejuvenate these springs and minimize the adverse impact of climate change on water availability both for human consumption and irrigation, especially during off-season, NABARD has launched an innovative and integrated spring-shed-based participatory watershed development programme in the NER, including Sikkim with financial support under WDF since January 2017. These projects are extended to 16 states (Arunachal Pradesh, Assam, Chhattisgarh, Himachal Pradesh, Jammu & Kashmir, Karnataka, Kerala, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Odisha, Sikkim, Tripura and Uttarakhand). As on 31 January 2025, 157 spring-shed development projects have been sanctioned.

7.1.5. Soil and water conservation promotional measures and other farming practices in the dryland/ watershed areas on non- watershed basis

WDF corpus used towards capacity building, awareness creation through campaign mode, etc., as part of developmental and promotional interventions under NRM sector along with implementation of location specific activities relating to soil and water conservation, technology transfer-demonstration of climate resilient and climate smart agriculture, promotion of organic farming, vermi-composting, apiculture, mushroom cultivation, sericulture, etc. in rural areas. The activities can be implemented on project /programme mode as well as non- project mode in the rainfed/dryland areas/ completed watershed projects under central/state/NABARD assisted programmes. As on 31 January 2025, 34 projects have been sanctioned.

7.1.6. Pilot projects on reclamation of Alkaline soils through rainwater management with watershed/ landscape approach in Punjab & Haryana

Indiscriminate use of agri-inputs especially water and fertilizer, during Post- Green Revolution has resulted in severe land degradation leading to formation of alkaline soils in Punjab, Haryana and Western Uttar Pradesh. In order to demonstrate long-term sustainability of alkaline soil through participatory approach, pilot projects on reclamation of alkaline soil through rainwater management with watershed/ landscape approach are being implemented in Punjab and Haryana with technical support from Central Soil Salinity Research Institute (CSSRI), Karnal. It covers an area of 2000 ha for reclamation of alkaline soils. Four pilot projects for Reclamation of Alkaline soils in Punjab and Haryana were grounded in the districts of Patiala and Sangrur in Punjab; and Kaithal and Karnal in Haryana. As on 31 January 2025, 4 pilot projects have been sanctioned.

7.1.7. Soil Restoration and Rehabilitation of Degraded Soils for Food Security (Climate Proofing Soil Project) through KfW, Germany

NABARD, in collaboration with KfW, is implementing 'Integration of Watershed Development for Rehabilitation of Degraded Soils and Climate Change Adaption' project since 2017. The project was approved for support from the German Government (BMZ) under its initiative "One World- No Hunger" (SEWOH) for rehabilitation and regeneration of degraded soils, especially in areas with communities vulnerable to climate change. The project envisages strengthening the adaptive capacity of the communities in watersheds and enhancing their resilience to climate change through investments in conservation of natural resources, mainly soil.

The project is co-financed by KfW, NABARD and contribution of beneficiaries for investments at watershed level (in cash/in kind). The total grant provided by KfW under the project for three phases is € 19.5 million (Rs 143.75 crore). The grant extended by KfW is routed through NABARD to village watershed committees and implementing agencies for implementation on ground. The project is implemented in three phases covering 226 watersheds in 10 states, of which 123 projects under Phase I are completed. SEWOH I was implemented in Andhra Pradesh, Chhattisgarh, Karnataka, Odisha & Telangana, SEWOH II was implemented in Kerala and Jharkhand and SEWOH III in Bihar, Maharashtra and Tamil Nadu.

7.1.8. Web-based monitoring of watershed projects

NABARD had signed a MoU with National Remote Sensing Centre (NRSC), Hyderabad for the monitoring of watershed projects by leveraging geospatial technologies. Under this initiative, a web portal and mobile app have been developed for uploading the data by Project Facilitating Agencies (PFAs). The portal is facilitating NABARD in real time tracking of physical and financial progress and impact evaluation (change detection) of watershed projects ('pre' and 'post' stages) through analysis of satellite images, generation of MIS reports on real time basis and mapping as well as geo-tagging of assets created in the project areas through mobile app. As on 31 January 2025, a total of 1173 projects were digitised with 1,95,890 assets geotagged and 718 impact evaluation studies were conducted.

7.2. Development through credit:

NABARD is also promoting various activities of Land Development by formation of model schemes and unit for important activities. This model schemes and the unit cost will help bankers in developing banking plan and financing in a big way. The unit cost which are indicated in the following table is just indicative and bankers can modify the same considering the local cost of materials and labour cost. The state-wise unit cost of various activities are available in NABARD website (www.nabard.org)

Indicative Unit Cost of Land Development Activities:

S. No.	Activity / Investment	Specifications	Unit	Unit Cost (Rs)
1	On-Farm Development (OFD) Works		Ha	66,000
2	Land levelling			
i.	Av. Slope 0.5 to 1.5%		Ha	44,000
ii.	Av. Slope 1.6 to 3.0%		Ha	86,000
3	Farm pond			
i	Farm pond	20 m x 20 m	No.	97,000
ii	Farm pond	30 m x 30 m	No.	2,18,000
iii	Farm pond	40 m x 40 m	No.	3,94,000
4	Compost Unit from Agro-waste	100 tpa capacity	1 unit	19,00,000
5	Bio-fertiliser / Bio-pesticide units		1 unit	1,60,00,000
6	Mini Vermicompost unit	10' x 6' x 2.5'	1 unit	30,000
7	Commercial Vermicomposting	150 tpa capacity	1 unit	7,50,000
8	Commercial Vermicomposting	200 tpa capacity	1 unit	11,84,000
9	NADEP compost	10 tpa	1 unit	27,000
10	Barbed wire fencing (rock poles)	100 m	m	57,000
11	Barbed wire fencing (cement poles)	100 m	m	63,000
12	Reclamation of Salt effected soil	5-8 t of Gypsum and Daincha crop	Ha	43,600
13	Tank silt application (Transport & application)	0.02 ham	ha	36,000
14	Watershed Development	Unit cost	Ha	22,000

08

Natural Farming / Organic Farming

Natural Farming is a chemical-free farming system rooted in Indian tradition enriched with modern understanding of ecology, resource recycling and on-farm resource optimization. It is considered as agroecology based diversified farming system which integrates crops, trees and livestock with functional biodiversity. It is largely based on on-farm biomass recycling with major stress on biomass mulching, use of on-farm cow dung-urine formulations; maintaining soil aeration and exclusion of all synthetic chemical inputs. Natural farming is expected to reduce dependency on purchased inputs. It is considered as a cost- effective farming practice with scope for increasing employment and rural development.

Many states are already fallowing natural farming and have developed successful models. State of Andhra Pradesh, Karnataka, Himachal Pradesh, Gujarat, Uttar Pradesh and Kerala are among the leading states. Currently, the acceptance and adoption of natural farming systems are at early stages and gradually gaining acceptance among the farming community.

Natural farming Practices

Natural farming aims at restoring soil health, maintenance of diversity, ensure animal welfare, stress on efficient use of natural/local resources and promote ecological fairness. Natural farming is an ecological farming approach where farming system works with the natural biodiversity, encouraging the soil's biological activity and managing the complexity of living organisms both plant and animal to thrive along with food production system. Important practices, essential for adoption of natural farming includes:

- No external inputs,
- Local seeds (use of local varieties)
- On-farm produced microbial

formulation for seed treatment (such as bijamrita)

- On-farm made microbial inoculants (Jivamrita) for soil enrichment
- Cover crops and mulching with green and dry organic matter for nutrient recycling and for creating a suitable micro-climate for maximum beneficial microbial activity in soil.
- Mixed cropping
- Managing diversity on farm through integration of trees
- Management of pests through diversity and local on-farm made botanical concoctions (such as neemastra, agniastra, neem ark, dashparni ark etc)
- Integration of livestock, especially of native breed for cow dung and cow urine as essential inputs for several practices and
- Water and moisture conservation.

Aims and objectives of Natural Farming:

- Preserve natural flora and fauna
- Restore soil health and fertility and soil's biological life
- Maintain diversity in crop production
- Efficient utilization of land and natural resources (light, air, water)
- Promote natural beneficial insects, animals and microbes in soil for nutrient recycling and biological control of pests and diseases
- Promotion of local breeds for livestock integration
- Use of natural / local resource-based inputs
- Reduce input cost of agricultural production
- Improve economics of farmers

Principles of Natural Farming:

Adoption of diversified cropping system-based agriculture

Recycling of naturally available nutrients in fields

Recycling of on-farm generated biomass

Use of locally developed and refined practices based on plant, animal and microbial source as raw materials

Innovative practices continuously evolve on the field of farmers based on the cropping pattern, local climatic conditions, altitude, soil quality, severity and variability of insects and pests etc.

Scope of Natural Farming

There are many working models of natural farming all over the world, the zero budget natural farming (ZBNF) is the most popular model in India. Natural Farming improves soil fertility, environmental health as well as helps in the reduction of greenhouse gas emissions and also promises the enhancement of farmer's income. In broad terms, Natural Farming can be considered as a prominent strategy to save the planet Earth for future generations. It has the potential to manage the various farmland practices and hence sequester the atmospheric carbon in the soils and plants, to make it available for plants.

Importance of Natural Farming

Several studies have reported the effectiveness of natural farming in terms of increase in production, sustainability, saving of water use, improvement in soil health and farmland ecosystem. It is considered as a cost- effective farming practices with scope for raising employment and rural development. Natural Farming offers a solution to various problems, such as food insecurity, farmers' distress, and health problems arising due to pesticide and fertilizer residue in food and water, global warming, climate change and natural calamities. It also has the potential to generate employment, thereby stemming the migration of rural youth. Natural Farming, as the name suggests, is the art, practice and, increasingly, the science of working with nature to achieve much more with less.

Benefits of Natural Farming

Improve Yield Farmers practicing Natural Farming reported similar yields to those following conventional farming. In several cases, higher yields per harvest were also reported.

Ensures Better Health: As Natural Farming does not use any synthetic chemicals, health risks and hazards are eliminated. The food has higher nutrition density and therefore offers better health benefits.

Environment Conservation: Natural Farming ensures better soil biology, improved agro-biodiversity and a more judicious usage of water with much smaller carbon and nitrogen footprints.

Increased Farmers' Income: Natural Farming aims to make farming viable and aspirational by increasing net incomes of farmers on account of cost reduction, reduced risks, similar yields, incomes from intercropping.

Employment Generation: Natural farming generates employment on account of natural farming input enterprises, value addition, marketing in local areas, etc. The surplus from natural farming is invested in the village itself.

Reduced Water Consumption:

By working with diverse crops that help each other and cover the soil to prevent unnecessary water loss through evaporation, Natural Farming optimizes the amount of 'crop per drop'.

Minimized Cost of Production:

Natural Farming aims to drastically cut down production costs by encouraging farmers to prepare essential biological inputs using on-farm, natural and homegrown resources.

Current Scenario of Natural Farming in India

There are several states practicing Natural Farming. Prominent among them are Andhra Pradesh, Chhattisgarh, Kerala, Gujarat, Himachal Pradesh, Jharkhand, Odisha, Madhya Pradesh, Rajasthan, Uttar Pradesh and Tamil Nadu. Till now 6.5 lakh ha. area is covered under natural farming in India. Different State governments are promoting natural farming through various schemes.

Andhra Pradesh

The Andhra Pradesh Community-Managed Natural Farming (APCNF): This programme is being implemented by Rythu Sadhikara Samstha (RySS), a not-for-profit company established by the Department of Agriculture, Government of Andhra Pradesh. RySS's mandate is to plan and implement programmes for the empowerment and all-round welfare of farmers.

Gujarat

In Budget 2020–21, special financial assistance was announced for promoting Natural Farming practices under the Gujarat Atma Nirbhar package. Further, on 17 September 2020, two schemes were launched viz. Sat Pagala Khedut Kalyaan and Pagala for Natural Farming by the Government of Gujarat. Under Atma Nirbhar package, Rs 900 monthly subsidy for the maintenance cost of one cow to a farming family practising Natural Farming. Under the 2nd scheme, provision of Rs 1248 subsidy to farmers for purchase of a Natural Farming kit to prepare Jeevamrit has been made.

Himachal Pradesh

Himachal Pradesh practices Natural Farming under the Prakritik Kheti Khushhal Kisan (PK3) Yojana. The scheme aims to reduce the cost of cultivation and enhance farmers' income. The scheme was announced by the Chief Minister in the Budget speech of 2018–19. The scheme seeks to promote the production of food grains, vegetables, and fruits without the use of synthetic chemicals/ pesticides and fertilizers. The scheme went beyond its target of covering 500 farmers to 2669 in 2018– 19. By 2019–20, 54,914 farmers were practicing Natural Farming on 2,451 hectares of land. The scheme has now targeted to bring more farmers under its ambit and cover 20,000 hectares.

Rajasthan

Honourable Chief Minister of Rajasthan during the budget speech of FY2019-20 declared support to natural farming to reduce input costs with a view to empower farmers through remunerative agriculture – Kheti Mein Jaan Toh Sashakt Kisan. The scheme in the form of a pilot project was initiated in three districts of the State viz. Tonk, Sirohi and Banswada. Under the scheme, 18,313 farmers were trained in a two-day long workshop conducted by master-trainers of the Department. 10,658 farmers were provided with drums, buckets, jugs and sprayers at a subsidy of up to 50% of their costs but limited to Rs.600 per farmer for preparing the organic inputs.

NITI Aayog is among the foremost promoters of natural farming Multi-location studies are imperative for scientific validation, its long-term impact and viability of the model promoting it country-wide. The Indian Council of Agricultural Research is also studying the Natural Farming methods practiced by basmati and wheat farmers in Modipuram (Uttar Pradesh), Ludhiana (Punjab), Pantnagar (Uttarakhand) and Kurukshetra (Haryana), evaluating the impact on productivity, economics and soil health including soil organic carbon and soil fertility. Recently Andhra Pradesh Government Launch Indo German Global Academy for Agro ecology Research and learning (IGGAARL) at Pulivendula on 7th July 2022. As per the study, India which holds almost 20 % of the world population has consumption of only 1 % organic produce of the total organic produce. Whereas India itself is the country with the largest farmlands in the world. It suggests that there is a lot of hindrances being faced by organic food products whether obtained organically or naturally in the Indian market. A proper market infrastructure is yet to establish for selling of the produce and awareness among the farmers is required for proper implementation of all the schemes that are promoting the Natural Farming in India.

09

Impact of Climate Change on Soils

Soil systems are fundamental to sustainable development due to their multifunctional role in providing services including biomass production (food, feed, fibre, and fuel); habitats for living organisms and gene pools (biodiversity); cleaning of water and air; mitigation of greenhouse gas emissions; contributions to carbon (C) sequestration; buffering of precipitation extremes; and provisions to cultural, recreational, and human health assets. The effects of climate change are associated with increases in temperature (T) and extreme weather events such as heavy rainfall, droughts, frosts, storms, and rising sea levels in coastal areas. These effects may also increase the threats to soil such as soil erosion, soil compaction, reduced soil fertility, and lowered agricultural productivity, which ultimately deteriorate food security and environmental sustainability. These climate-related risks raise major concerns regarding the future role of soils as a sustainable resource for food production.

Climate change can affect soil functions directly and indirectly. The direct effects include soil process changes in organic carbon transformations and nutrient cycling through altered moisture and T regimes in the soil or increased soil erosion rates due to an increased frequency of high-intensity rainfall events. Climate change and soil management can change the ability of soils to perform soil functions, which, for the sake of simplicity, the study calls changes in soil functions.

The indirect effects of climate change on soil functions include those that are induced by climate change adaptation options. Agricultural management can mitigate climate change effects, for example, through increased Soil Organic Carbon (SOC) sequestration. Farmers may implement adaptations as a result of multiple, intertwined driving forces, including market price changes, new technologies, and improved knowledge in combination with climate change. Regarding European agriculture, several scenario studies have investigated agricultural adaptation options in response to climate change, including the introduction of irrigation regimes in drought-prone areas, crop rotation changes, increased fertilization rates on cropland, amended soil tillage practices, and cultivation of melting permafrost soils.

Although ample knowledge is available for the direct effects (although the interactions are not completely understood), evidence of the indirect effects of agricultural adaptation options on soil functions is more scattered and difficult to derive experimentally because it depends on an uncertain future climate and corresponding adaptation. However, the anticipation of development pathway impacts is a precondition for decision-making.

Although farm management concerns the local field level, the multiple soil functions need to be maintained and improved at higher spatial aggregates to achieve the Sustainable Development Goals (SDGs) formulated by the United Nations agenda 2030.

Climate change will affect soils, leading to changes in soil erosion, organic carbon, nutrients and alkalinity. Decreasing soil carbon due to climate change also has implications for accounting of carbon emissions from the land, which is an important avenue for NSW to meet its Net Zero Emissions by 2070 target.

Climate change can affect soil functions both directly and indirectly. Direct effects include temperature, precipitation, and moisture regime changes. Indirect effects include those that are induced by adaptations such as irrigation, crop rotation changes, and tillage practices.

Temperature and rainfall are two main climatic factors responsible for soil formation. Rainfall contributes in breaking the rocks by applying pressure. Temperature fluctuations between hot and cold also form cracks in the rocks. Climate indirectly affects soil formation through its influence on organisms as well. High temperatures and rainfall increase the degree of weathering and therefore the extent of soil development. Increase of rainfall increase organic matter content, decrease pH, increase leaching of basic ions, movement of clay etc.

Conversely, climate change can also influence land cover, resulting in a loss of forest cover from climate-related increases in disturbances, the expansion of woody vegetation into grasslands, and the loss of beaches due to coastal erosion amplified by rises in sea level.

Climate change can affect agriculture in a variety of ways. Beyond a certain range of temperatures, warming tends to reduce yields because crops speed through their development, producing less grain in the process. And higher temperatures also interfere with the ability of plants to get and use moisture.

Soil temperature directly affects plant growth. Most soil organisms function best at an optimum soil temperature. Soil temperature impacts the rate of nitrification. It also influences soil moisture content, aeration and availability of plant nutrients.

India has the world's highest social cost of carbon. A report by the London-based global think tank Overseas Development Institute found that India may lose anywhere around 3-10% of its GDP annually by 2100 and its poverty rate may rise by 3.5% in 2040 due to climate change.

10 Conclusion

Soils are important for sustaining the life of flora and fauna. Soils though seen differently by the different users, they are the supporting system for the growth and sustainability. Soil characteristics like structure, texture, pH, soil porosity, bulk density etc will determine the nature of the soil. The soil fertility depends on the parent material from which the soil has formed due to weathering and other processes over the years.

It is important factor to maintain the health of the soils in its natural form. The use of chemicals has largely deteriorated the soil quality leading to salinity and sodicity and abandoning the large tracts of otherwise fertile soils. All the productive soils are fertile; however, all the fertile soils are not productive because of limitations such as soil salinity soil acidity etc. Therefore, reclamation of the problem soils is an important aspect in soil management. Besides the reclamation using soil amendments like gypsum, pyrites etc, soil amelioration by growing crops like Daincha, Sunhemp etc. are also suggested.

Further, to protect the soil in its natural form cultivation practices like natural farming are suggested which improve the soil fertility, increases organic matter content of the soil due to increased microbial activity. Natural farming practices are gaining importance in the country supported by Govt. schemes like promotion of vermicompost, biopesticides, biofertilizers, etc. through Paramparagat Krishi Vikas Yojana (PKVY).

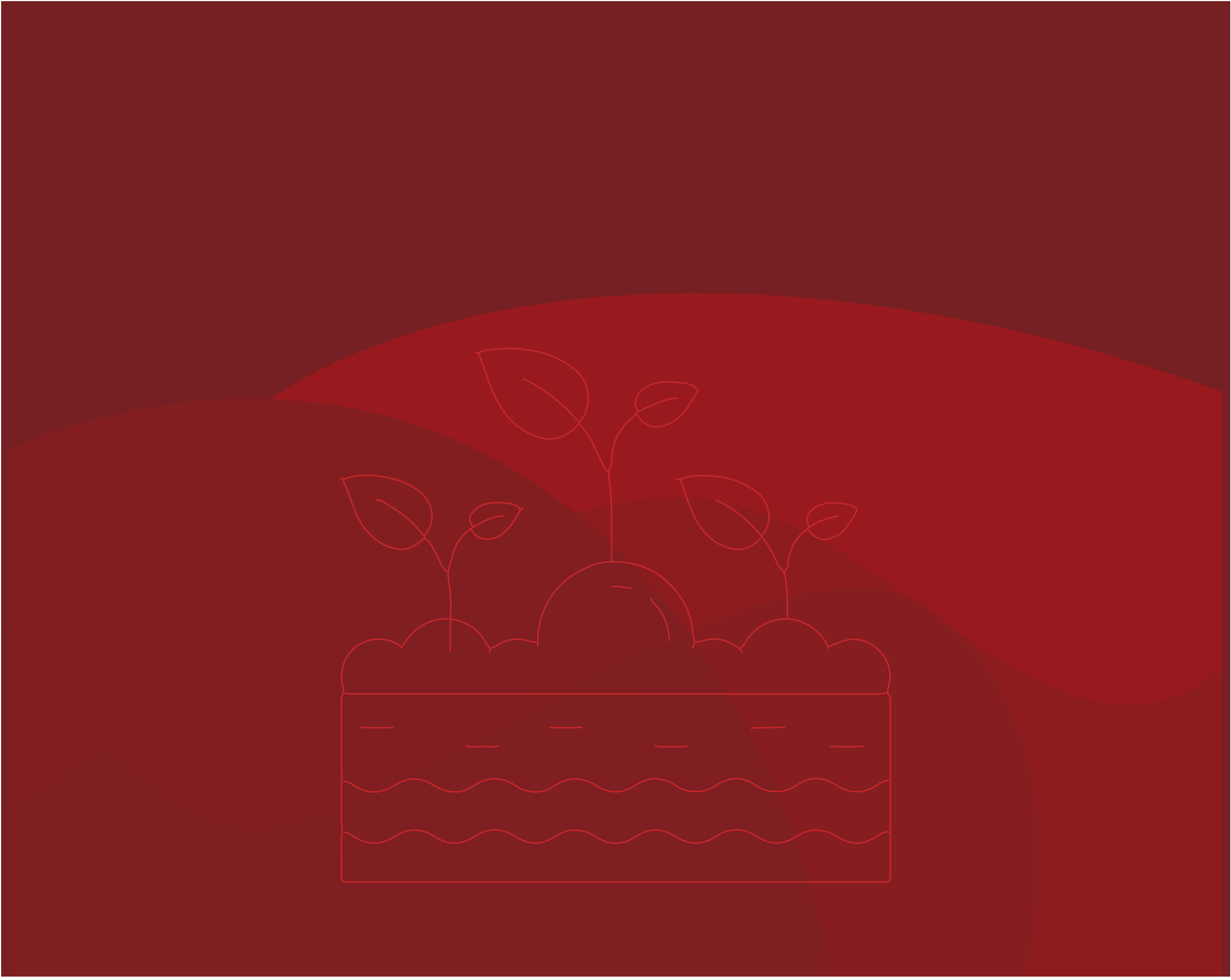
NABARD had initiated various soil and water conservation programme on pilot basis to protect the soil and also increase crop productivity in dryland agriculture systems. Watershed development programmes implemented by NABARD in States like Maharashtra, Gujarat, Rajasthan, Andhra Pradesh etc. were highly successful and paved the way for replication. Subsequent programmes like soil water programmes with KfW assistance, JIVA programme etc. are also aimed at promoting conservation agriculture.

Climate Change is taking its toll on agriculture productivity due to its impact on increased soil temperature which increase water evaporation, reduces microbial activity leading to reduced organic matter content in the soil.

Climate proof agricultural practices are gaining importance to ameliorate the impact of climate changes in crop productivity.

Notes

Notes



National Sectoral Paper

Land Development

NABARD

Farm Sector Development Department
National Bank for Agriculture and Rural Development
Mumbai