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REVIEW ARTICLE

Soil Type as One of the Major Contributing Factors for Top Ten Agri-Producing States of India

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ABSTRACT

A heterogeneous mixture of small rock particles/debris and organic materials/humus is called soil. It is usually produced over the surface of the earth and helps in the sustenance of autotrophic life in plant. India is an agriculture based country in which West Bengal, Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Chhattisgarh, Odisha, Andhra Pradesh, Telangana, and Karnataka are considered as the top ten states for their higher agricultural productivity. For higher agricultural productivity, knowledge of soil type, composition, texture, fertility, etc. is highly essential. However, no review article is presently summarising whether the soil type contributes as one of the major factors for the above top ten ranked agri-producing states of India. Here we review and found that the soil type could be one of the major reasons why the above states topped the list in agricultural attributes to India. As per India classification, both urvara (fertile) and usara (sterile) soils are found in the country. Majority of Indian soils harboring the agriculture of the above states are alluvial soil (43%), red soil (18.5%), black/regur soil (15%) and the rest are arid/desert soil, laterite soil, saline soil, peaty/marshy soil, forest soil and sub-mountain soil that harbors the agriculture in India in general and in the above states in particular. Therefore, the soil type present in the above states is one of the most contributing factors for the higher agriculture productivity in India.

INTRODUCTION

Soil is a complex multiphase mixture of minerals, air, water, and organisms and their products of transformation and degradation. It is the fine earth that covers land surfaces that are formed as a result of weathering of rock materials or by the accumulation of mineral matter transported by water, wind, or ice. The process of soil formation involves interaction between the lithosphere, atmosphere, hydrosphere, and biosphere and is known as pedogenesis [1-5]. The formation of different types of soil also depends upon the climatic conditions and the nature of the underlying rocks, the rate of formation which depends on the rate of weathering of rocks in the upper layers and biomass degradation in lower layers [6]. The basic process of weathering is about breaking up rocks and minerals and destroying or modifying

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their physical or chemical characteristics by carrying away the finer fragments and soluble products. Being an integral process of the Rock Cycle [7], the weathering can occur from either Igneous, Metamorphic or Sedimentary rocks. The rock exposed at the surface has decayed and crumbled producing a layer of unconsolidated debris overlaying the un-weathered rock called the Regolith [8]. Weathering of this regolith occurs from the surface to its way down resulting in the formation of layers through earth differentiated by chemical, physical or biological characteristics [9].

This sequence of horizons describes the soil Profile. The surface layers of undistributed ecosystems accumulate the organic debris from the plant and animal remains which undergo various degrees of biochemical and physical breakdown. These organic surface layers of soil designate the O Horizons [10,11]. The intensely weathered and leached soil nearest to the surface is darkened due to organic matter accumulation. Such layers are dominated by mineral particles and are referred to as A Horizon. The A and O horizons, considered as the most biologically active part of the soil, are frequently exposed to drying and wetting cycles and to a varying range of temperatures subjected to considerable changes in it, resulting in high rates of activity in physical and chemical processes. In some soil, layers of un-accumulated organic residues are present, usually just below the A horizons, and are called E Horizons. Generally, layers that underlie 'A' and 'O' horizons comparatively contain less organic matter than layers nearer to the surface. Varying amounts of iron aluminum oxides, gypsum and silicate clays, or calcium carbonate are accumulated here, either by getting washed down from the above horizons or through weathering processes that may have led to their formation in the place. These underlying layers are referred to as B Horizons. B horizons are usually encountered below the 'A' horizons, where the balance from predominantly biological processes as in the 'A' horizons shifts to predominantly physical and chemical processes [12,13]. In humid regions, microorganisms and plant roots often extend below the B horizon, causing some biochemical weathering of the regolith forming the least weathered part of the soil profile known as C Horizons [11] (Figure 1 & 2).

Excluding the organic soil, most of the soil's solid framework consists of mineral particles of varying sizes. The soil particles size range in over four orders of magnitude, that is, from 2.0 mm to smaller than 0.0002 mm in diameter. Sand particles that are large enough measuring 2.0-0.05 mm can be easily seen by the naked eye. It feels gritty when rubbed between the fingers and does not adhere to one another [14]. The ones measuring between particle size 0.05-0.002 mm are too small and cannot be seen without a microscope, and this is called Silt. Clay particles are the smallest mineral particles <0.002 mm, which adhere together to form a sticky mass when wet and hard clods when dry. The smaller particles, that is, 60.001 mm of clay and similar-sized organic particles, have colloidal properties and can be seen

only with the aid of an electron microscope. The proportion of particles in these differing size ranges describes the soil texture, for example, sandy, loamy and clayey [15].

Soil is an important medium for plant growth and for support of animal activity which acts as a reservoir of water and nutrients, fulfilling the plant's needs for these requirements throughout their growth. And one of the important functions of soil is to absorb water and retain it where it can be used by the roots of the plants. A continuous stream of water is required by the plants for nutrient transport, cooling, turgor maintenance, and photosynthesis. The mixture of organic material and minerals provides the soil with its distinctive characteristics across the surface of the earth. The amount of water the soil holds is its water holding capacity which relies on structure, soil texture, organic matter content, and arrangement of soil pores in different layers (Figure 1 & 2). The presence of organic matter binds the soil and increases its water-retaining capacity due

Figure 1 Water holding capacity stages within the soil. Adapted after [18] under creative common attribution license.

Figure 2 Master horizons identified in a typical soil profile. Source [27].

to a high degree of micro-porosity [16]. The water-retaining function of the soil maintains the underground water storage which is also essential for plants survival.

The pedosphere of the globe displays a varying diversity of soil depending upon the geologic distribution of the lithosphere and the climatic conditions affecting them. India being a peninsular country has diverse geology where it is surrounded by the great mountain range Himalayas at the North and has plain grasslands surrounded by ocean from three sides [16]. Such varying geography leads to a varied soil distribution throughout the country. The Indian soil is divided into eight major groups by the All India Soil Survey Committee set up in 1963 by the Indian Council of Agricultural Research (ICAR). The eight types of soil groups found are namely 1) Alluvial Soils, 2) Black Soils, 3) Red Soils, 4) Laterite and Lateritic Soils, 5) Forest and Mountain Soils, 6) Arid and Desert Soils, 7) Saline and alkaline soils and 8) Peaty and Marshy soils [17,18].

The Alluvial soils are the sedimentary deposits of the rivers, distributed across the Indo-Gangetic plain and coastal areas of India. Covering about 45.6% of total soil cover, it is one of the most abundant and important soil groups of India. This nitrogen-deficient soil is composed of finer particles of rock material of mountain fans called Alluvium, which is carried in suspension with river water, and their later deposits in the river bed and banks are called Deltaic Alluvium [19]. In contrast, soil distributed along with coastal areas, known to be Coastal Alluvium, is deposited by sea waves carried and then transported from the origin. Alluvium throughout the great plains is further classified into newer soil Khadar and older soil Bhangar. Khadar is pale brown sandy clay and loams, whereas Bhangar is more clayey and darker colored with lime nodules in them. Occurring widely in the Indo-Gangetic plain starting from Punjab in the west to Assam in the east, it is also distributed over deltas of the Godavari, the Mahanadi, the Krishna, and the Cauvery.

The Black soils are derivative of Basalt rocks under semi-arid conditions, which are locally known as Regur soil. The soil is black in colour, comprising of iron and titaniferous magnetite, and is very retentive of moisture. Pedological studies report that these soils are formed in Triassic Period as a consequence of the solidification of lava spread during volcanic activities over areas in the Deccan Plateau. This highly argillaceous soil has a large clay factor consisting of iron oxide, alumina, lime, and magnesium carbonates [20]. Due to its high fertility and water holding capacity, it is used for producing several major crops such as cotton, jowar, wheat, castor, linseed, sunflower, etc. The soil is distributed over the Deccan trap region states of Madhya Pradesh, Maharashtra, Gujarat, Rajasthan, northern parts of Karnataka, and parts of Andhra Pradesh, Odisha, and Tamil Nadu [21].

Red soils are the result of weathering of granites, gneisses and crystalline rocks occupying 29.8% of the total soil cover of India. The soil occupying 4.30% of India's soil cover has a loam to clayey loam texture with a ferric oxide coating the particles giving it a characteristic red color. Used for a variety of crop cultivation such as Ragi, millets, Tobacco, Groundnuts and potato, red soil is rich in iron but slightly acidic in nature with a poor quantity of phosphorous and nitrogen. It extends extensively from parts of Madhya Pradesh, Tamil Nadu, southeast Maharashtra, Odisha, Kerala, Goa, Bihar, Uttar Pradesh, Nagaland Manipur, Tripura, Assam, Nagaland and Meghalaya [22].

Laterite is a soil formation found only in tropical countries with alternative wet and dry climatic conditions like India. The soil is rich in iron and aluminum because of heavy rainfall and high temperature depleting it completely from silica [23]. It is mainly widespread in the Western Ghats and Eastern Ghats, including the states of Karnataka, Kerala, Maharashtra, Madhya Pradesh, Odisha, Assam, and Tamil Nadu.

Desert soil is abundant in semi-arid and arid states of India that is, western Rajasthan, the Southern Haryana and South-West Punjab. These sandy to loamy textured soil are poor in nitrogen and humus but contains a rich amount of phosphates and nitrates containing soluble salts. Therefore, it is not suitable for many crops except for a few that are grown with the help of irrigation. It has a pale brown to yellowish-brown colour with moisture deficiency and a very high pH varying from 7.2-9.2, making it unsuitable for crops to grow [24].

Mountain soils that cover all along the slopes of mountains and hills are formed by the decomposition of organic matter of the forest. Climates, vegetation and topography, differ in the characteristics of these soils contributing towards the development of soil profile. They are clayey silt to loamy in texture, having a dark brown color, is rich in humus that makes them slightly acidic in nature [25]. Being one of the most fertile soil, they grow crops such as tea, coffee, tropical fruits and spices. In India, they expand from Jammu & Kashmir, Himachal Pradesh, Manipur to the Western Ghats in Karnataka, Kerala and Tamil Nadu.

Saline and alkaline soils are seen in Saline, arid and Semi-arid regions which are very infertile and uncultivable. Their texture ranges from sandy to loamy sand with a deficiency in nitrogen, calcium and water-bearing capacity. These acidic soils range from Rajasthan, Punjab, Uttar Pradesh, Haryana, Gujarat, to Maharashtra [26].

Peaty and Marshy soils occur in hot, humid conditions. They are formed because of waterlogging, as a result of which a huge amount of organic matter gets accumulated. Essentially, they are heavy and highly acidic with a large amount of soluble salts and organic content. These types of soil are mainly found in Odisha, the Sundarbans in

West Bengal, parts of Bihar, Uttar Pradesh and Kottayam, Alleppey districts of Kerala. They are dark, almost black in colour, with abundant organic matter. Fine in texture with a moderate accumulation of ferrous and aluminum sulphate resulting in pH below 3.5 or 4 thereby strongly acidic. This is due to the decomposition of organic matter under anaerobic conditions [16,27,28].

India is an agriculture-based country in which the top ten states that are recognized for their highest agri-productivity are West Bengal, Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Chhattisgarh, Odisha, Andhra Pradesh, Telangana and Karnataka. We hypothesize that the soil type contributes as one of the major factors for the above top ten ranked agri-producing states of India. It was found that the soil type could be one of the major reasons why the above states topped the list in agricultural attributes to India. India also ranks in a good position as per her Agri-products in the world (Table 1-3). Therefore, describing the soil status of the above states is of paramount importance at this time point. A detailed description including their soils in the top ten agriculturally productive states of India is lacking. The knowledge of soil is of paramount importance, and this review is purposed to provide scope to further research on the field of pedology in such Indian states and to establish the fact that the soil type is one of the most important factors for high agriculture productivity in Indian states in general and the top ten Agri-producing states in particular [29].

SOILS OF TOP TEN STATES OF INDIA AND THEIR USE

Soil of West Bengal

Position and soil of West Bengal: West Bengal is the most Agri-rich state and 7th largest city of modern India. West Bengal is found in the eastern terminal side of India, ranging from Himalayas in the north to Bay of Bengal in the south. It is situated between 85 degree 50 minute and 89 degree 50 minute east longitude and 21 degree 25 minute and 27 degree 13 minute north latitude [29]. The state comprises a total area of 88,752 square kilometers. Bangladesh lies on the native border. The total record of forest land in West Bengal is 11,879 square kilometers out of which 7054 square kilometers is reserved forest and 1053 square kilometers is un-classed forest. About 88, 75,200 hectares that comprise 2.7% of land cultivated in west Bengal feed about 8% of the world's population. Soil of west Bengal is broadly divided into four types that is mountain soil, alluvial soil, saline soil, and red soil, while the alluvial soil comprises most of the parts of soil.

Types and texture of soil of West Bengal:

- **Red soil:** These soils have occasional concentrations of lime and morrum and feldspar. These soils are mildly acidic with the iron concentration varying

from top to bottom, that is, the concentration is lower on top and gradually increases as we proceed towards the bottom. Paddy grown in this soil responds well when nitrogenous and phosphate manures are added. This kind of soil is mostly found in Bankura, Midnapore, and Malda [30].

- **Alluvial soil:** The name is derived from the alluvial deposits and is broadly classified based on their original location that is "Ganga alluvium" and "Vindhya alluvium". All the soils that are derived from Ganga alluvial regions are called Ganga alluvium and all the soils that are derived from the Vindhya alluvial region are known as vindhya alluvium soil. These soils have mostly neutral pH. These soils are mostly found in Birbhum, Bankura, and Brudwan [30].
- **Mountain soil:** The soil, produced by the mechanical and chemical breakdown of indigenous and metamorphic rocks, is black in colour and less fertile. This soil is best for the cultivation of orange, tea, and pear. This soil is slightly basic [30].
- **Saline soil:** The soil is mostly found in Sundarban and other coastal areas. As there is no organic matter, this soil is not useful for cultivation. The soil is bluish [30].

Crops harvested in the soil of West Bengal: In the Agri-lands of west Bengal, paddy is so vigorously cultivated that it is hard to discriminate between the lands in which paddy is cultivated and rice is cultivated. The major crops cultivated in the land of West Bengal are as follows.

Rice: The state has 5.8 million hectares area in which the rice is cultivated with the productivity of 2.6 tons/ hectare. The quantity of cultivation of rice is minimum because of unavailability of nutrients, drought drainage of nutrient rich soil due to flood. Shatabdi, Rash, and khitish are the major types of rice strains cultivated in the state of West Bengal [31,32].

- **Rapeseed-Mustard:** The area has production and productivity of 4.2 lakh hectares 3.8 lakh tons and 909 kg/ hectare respectively. The major decrease in productivity is due to the late harvesting of kharif paddy, inadequate supply of moisture at sowing time. The major types of strains cultivated are Pusa Bold, Pusa Mahak, Sej 2 [31,32].
- **Mango:** Mango is grown widely in 69,100 hectares with a productivity of 6.7 ton/ hectare. More interventions should be implemented to enhance productivity [31].
- **Tomato:** The area in which tomato is produced is 46,100 hectares with the productivity of 15 tons/ hectare. Scientists are working on the species

Table 1: Top agricultural producing states in India. Adapted from Gkduniya [17] under creative common license attribution.

Agri-Products	1 st Position	2 nd Position	3 rd Position
Rice	West Bengal	Uttar Pradesh	Punjab
Wheat	Uttar Pradesh	Madhya Pradesh	Punjab
Jowar	Maharashtra	Karnataka	Tamilnadu
Bajra	Rajasthan	Uttar Pradesh	Gujarat
Maize	Karnataka	Madhya Pradesh	Bihar
Ragi	Karnataka	Tamilnadu	Uttarakhand
Small Millets Kharif	Uttarakhand	Madhya Pradesh	Andhra Pradesh
Barley	Rajasthan	Uttar Pradesh	Madhya Pradesh
Coarse Cereals	Rajasthan	Karnataka	Madhya Pradesh
Tur	Madhya Pradesh	Maharashtra	Karnataka
Gram	Madhya Pradesh	Karnataka	Rajasthan
Urad	Madhya Pradesh	Andhra Pradesh	Tamilnadu
Moong	Rajasthan	Andhra Pradesh	Tamilnadu
Other Pulses	Madhya Pradesh	Uttar Pradesh	Rajasthan
Pulses	Madhya Pradesh	Rajasthan	Maharashtra
Groundnut	Gujarat	Rajasthan	Tamilnadu
Castorseed	Gujarat	Rajasthan	Andhra Pradesh
Sesamum	West Bengal	Madhya Pradesh	Uttar Pradesh
Nigerseed	Madhya Pradesh	Orissa	Chhattisgarh
Soyabean	Madhya Pradesh	Maharashtra	Rajasthan
Sunflower	Karnataka	Haryana	Andhra Pradesh
Sugarcane	Uttar Pradesh	Maharashtra	Karnataka
Cotton	Gujarat	Maharashtra	Telangana
Jute	West Bengal	Bihar	Assam
Tobacco	West Bengal	Bihar	Assam
Tea	Assam	West Bengal	Tamilnadu
Coffee	Karnataka	Kerala	Tamilnadu
Foodgrains	Uttar Pradesh	Madhya Pradesh	Punjab

Table 2: Agri-products in India and its comparison to other top Agri-producing countries.

Rank	Commodity	Value (US\$, 2016)	Unit price (US \$ / kilogram, 2009)	Average yield (tonnes per hectare, 2017)	Most productive country (tonnes per hectare, 2017)	
1	Rice	\$70.18 billion	0.27	3.85	9.82	Australia
2	Buffalo milk	\$43.09 billion	0.4	2.00	2.00	India
3	Cow milk	\$32.55 billion	0.31	1.2	10.3	Israel
4	Wheat	\$26.06 billion	0.15	2.8	8.9	Netherlands
5	Cotton (Lint + Seeds)	\$23.30 billion	1.43	1.6	4.6	Israel
6	Mangoes, guavas	\$14.52 billion	0.6	6.3	40.6	Cape Verde
7	Fresh Vegetables	\$11.87 billion	0.19	13.4	76.8	United States
8	Chicken meat	\$9.32 billion	0.64	10.6	20.2	Cyprus
9	Potatoes	\$8.23 billion	0.15	19.9	44.3	United States
10	Banana	\$8.13 billion	0.28	37.8	59.3	Indonesia
11	Sugar cane	\$7.44 billion	0.03	66	125	Peru
12	Maize	\$5.81 billion	0.42	1.1	5.5	Nicaragua
13	Oranges	\$5.62 billion				
14	Tomatoes	\$5.50 billion	0.37	19.3	55.9	China

15	Chick peas	\$5.40 billion	0.4	0.9	2.8	China
16	Okra	\$5.25 billion	0.35	7.6	23.9	Israel
17	Soybeans	\$5.13 billion	0.26	1.1	3.7	Turkey
18	Hen eggs	\$4.64 billion	2.7	0.1	0.42	Japan
19	Cauliflower and Broccoli	\$4.33 billion	2.69	0.138	0.424	Thailand
20	Onions	\$4.05 billion	0.21	16.6	67.3	Ireland

Table 3: Various agriculture products in 2019 source [28].

Item	Value (in tonnes)
Apples	2316000
Bananas	30460000
Beans, green	725998
Cashew nuts, with shell	743000
Castor oil seed	1196680
Cauliflowers and broccoli	9083000
Cherries	11107
Chick peas	9937990
Chillies and peppers, dry	1743000
Chillies and peppers, green	81837
Coconuts	14682000
Coffee, green	319500
Cucumbers and gherkins	199018
Garlic	2910000
Ginger	1788000
Grapes	3041000
Lemons and limes	3482000
Mangoes, mangosteens, guavas	25631000
Melons, other (inc.cantaloupes)	1266000
Mushrooms and truffles	182000
Oilseeds nes	42000
Onions, dry	22819000
Oranges	9509000
Papayas	6050000
Pears	300000
Pineapples	1711000
Potatoes	50190000
Rice, paddy	177645000
Soybeans	13267520
Sugar cane	405416180
Sweet potatoes	1156000
Tea	1390080
Tobacco, unmanufactured	804454
Tomatoes	19007000
Watermelons	2495000
Wheat	103596230

to increase productivity. The species of tomato cultivated widely are ARTH 3, BSS 20, and TSS01436 [31].

- Brinjal: The area under which the brinjal is cultivated is 1.48 lakh hectares with productivity of 18.2 tons/hectare. The species which are broadly cultivated are JBH1, ARBH 541, and NDB25 [31].
- Potato: The area under which potato is cultivated in 23 lakh hectares with productivity of 22.2 ton/hectare. It has the highest grossing record of productivity all over India, with a potential of up to 35-40 tons/hectare. Nowadays various scientifically approved interventions are applied to multiply the yield of rice to feed the growing population [32].

These crops are cultivated here as the soil is rich in many essential elements like Carbon, Nitrogen, Oxygen, Boron, Magnesium, Potassium, etc. Boron is one of the most important micronutrients that are needed for proper yield of such crops. Therefore, proper management of these elements is essential for the growth of these crops.

Soil of Uttar Pradesh: Uttar Pradesh, being the most populous and 4th largest state of modern India, is present at the northern-central part of the country that extends from 25° 31' N to 77° 84' E and is bordered by many other states as well as shares international border with Nepal on the north. It covers an area of 2, 40,928 km² which is 7.34% of total land of India from which 6.09% is covered with forest and 82.1% is cultivable land but in actual 68.56% is used for agriculture [33]. The most major type of soil found in Uttar Pradesh is alluvial soil, also called Alluvium and covers almost half of the land of the state, is deposited as silt by the Ganges and its confluence. Uttar Pradesh receives a large portion of the Indo-Gangetic plain by the virtue of which much of the area is covered by a cavernous blanket of alluvium, spread by the wave action of the slow-moving rivers of the Ganges system. Alluvium, extremely fertile soil abundant of humus, is generally a deep brown colored and loamy textured soil that can be clayey or sandy. Since it is loamy, the soil is also porous which provides well-drainage and some other conditions, favorable for agriculture. It is replenished by recurrent floods [34,35].

In both greater and lesser Himalayan areas occurring in UP, the soil varies from sandy to loamy texture with slight acidity and low Available Water Capacity (AWC). In the Himalayan regions, the terrain varies excessively and level

land is not available. In the southern districts, like Jhansi, Mirzapur, and Sonbhadra, the soil is mixed red to black, or sometimes red to yellow. Soils in this region are developed from Vindhyan rocks and exhibit hilly landscape and arid conditions. This is fine loamy soil with lots of stones and gravels; water is excessively drained, slightly alkaline, and low AWC [36].

Based on the geographical formation and pedogenic characters, the soil of Uttar Pradesh is divided into 6 well-defined and distinct soil groups: Vindhyan soils, Alluvial soils, Bhabar soils, Bundelkhand soils, Tarai soils, and Alluvial soils; each of which have been developed under the combined influence of a wide range of pedogenic (soil formation) factors. Availability of iron in these 6 kinds of soil are in the descending order of Aravali > Alluvial > Vindhyan > Bundelkhand > Tarai > Bhabar. Soils of Unnao, Hardoi, and Farukhabad are the ones with low iron status. Availability of Nitrogen in soils is of very low status in most of the districts of Uttar Pradesh, whereas 41 districts have low and 14 districts have medium Phosphorous status. In 29 districts, Potassium status is low but medium in 17 districts; availability of Potassium is high in only 4 districts. Sulphur content is very high in the recent alluvium soil, found in Gangetic planes and its uplands, central lowlands, Kanpur, and Yamuna uplands. Similarly, Zinc availability is low in districts like Basti, Jhansi, Ghazipur, Azamgarh, etc. but high in Varanasi, Deoria, Gorakhpur, etc. Soils of Meerut, Hamirpur, Bulandshahr, etc. are deficient in Zinc [37] (Figure 3).

The map beside interprets that a major part of the state's land, that is, approximately 65% area is alkaline, ranging from pH 7.5-9.5, whereas the area covered with acidic soil is very low (4.5-6.5 pH), which is about 10-12% of the total area. Similarly, about 20-25% of soil is neutral [38].

Locally, the new and old alluvial soils are called 'Bhangar' and 'Khadar' respectively. Different soils of southern Uttar Pradesh are called: 'Maad', 'Regur', 'Rakad', 'Monta', 'Red' and 'Padwa' [33].

A survey on soil moisture percentage of different districts of Uttar Pradesh using microwave and optical satellite data revealed that approximate 65% of the soil is in very dry state and about 20% is moderately dry. Therefore, the agriculture of the state is hugely dependent on irrigation. Except for the river tributary areas, the wetland area or soil with high moisture content is almost negligible [39].

The major crops cultivated in Uttar Pradesh are rice, maize, pigeon pea, moong bean, sorghum, etc. which are common in Kharif season, while major crops of Rabi season are wheat, lentil, Bengal gram, pea, etc. Rice-wheat cropping system is more preponderant, being cultivated in about 55 lakh hectares and 91 lakh hectares of land respectively. Sugarcane is the main cash crop of UP, making it the largest producer in the country. Along with sugarcane, cotton,

turmeric, potato, tobacco, etc. are also widely cultivated. The state is divided into total of 9 agro-climatic zones, each of which is most suitable for the cultivation of rice and wheat, making UP one of the top 3 producers of the crops in India. Rapeseed, chickpea are some other major crops of the state. The soils of the northern districts are suitable for wheat, maize, rice, and pulses. The Alluvial soils of the Gangetic planes provide favourable conditions for the cultivation of wheat, rice, sugarcane, gram, barley, maize, pea, sorghum, etc. Wheat, sorghum, bajra, gram, arhar are the major crops of the Vindhyan zone soils lying in the southern districts of Uttar Pradesh. Uttar Pradesh is India's one of the largest food grain producing states, yielding about 20% of the total food grain production of the country annually, which is about 50 million tonnes [33,40,41].

Soil of Punjab: The name of the state Punjab is made of two words Punj (Five) + Aab (Water) meaning land of five rivers. These five rivers are Sutlej, Beas, Ravi, Chenab, and Jhelum among which Only Sutlej, Ravi, and Beas flow in today's Punjab while other two rivers are now in the state of Punjab, situated in Pakistan [42,43]. Punjab is situated in northern India extending from 29.3°N to 32.3°N and from 73.5°E to 76.5°E covering a total area of 50362 square kilometers and having cultivation area of 19445 square miles. It is a vast monotonous plain with alluvial soil deposits [41].

Soils type in Punjab: Soils on the river terraces are considered to be alluvial soil as they have a well-developed profile. The alluvial soil ranges from coarse loam to fine loam. It may also have a fine silt texture. The alluvial soil deposit is broadly two types bhangar and khadar. Bhangar is the old alluvium deposit that forms higher terraces than flood plain. It is dark colored, has more clay, and consists of more kankar or lime nodules. Khadar is the new alluvium deposit that occupies a lower terrance than bhangar. It has sandy Clay, loams, less kankar that is less cancerous and carbonaceous. Khadar type is drier and more leached. This khadar is deposited every year during flood adding new layers and is thus responsible for making the soil more fertile [42-44]. The color of alluvial soil is light grey to ash grey. It is rich in potash but deficient in phosphorus [29] (Figure 4).

According to the 1970-US comprehensive system of soil classification, soil is of 5 orders, 9 suborders, 17 great groups, and more than 25 subgroups. At the family level, these soils can be differentiated by their soil reaction, texture, temperature, and percent carbonates.

- **Acidic zone:** Area bordering the Haryana and Rajasthan states comes under an acidic zone that has light-colored soils. This zone has been developed under Arid and Hot (E, A'), and Semi-arid (dry), and Hot (DI, Aa') climatic conditions and under scarce vegetation consisting of thorny forest and bushes as these soils remain dry for most of the time in a year. The soils are calcareous throughout and have

Figure 3 Soil and its pH reaction in Uttar Pradesh, India. Source [38].

calcareous nodules in the sub-surface horizons. The soils generally have pH ranging from 7.5 to 8.5, texture from sandy loam to silty loam. The sandy soils occurring in the area are however confined to localized pockets (dunes/bars).

- **Ustic zone:** Most of central Punjab comes under ustic zone that, has developed under Semi-arid (dry to sub-moist) and Less-hot (DI-a, A'2) climatic conditions and support tropical thorn and deciduous forests. They occur in a belt between the aridic soils in the southwest and ustic soil in the northeast. The soils with an argillic horizon are only observed in the northeast sectors of the state [41]. The soils that occur on the foothill belt of the Shivalik hills known as the kandi area (piedmont area) of Punjab, cover 5 districts in the northeast. The soils of kandi region are deep, imperfectly drained, coarse-loamy, and non-calcareous. The texture variation is from sandy loam through silty loam to loamy sand or sand, from surface to depth. This texture variation from depth indicates that the soil has been developed

from the stratified parent material. There is even no evidence of structural development associated with pedogenesis [45]. The soils are generally without dispersed lime and/or secondary carbonates and are generally leached to the lower part of layer of soil. The soils are sandy loam to clay loam with pH ranging from 7.5 to 8.5 and are saturated with bases. The major soil groups recognized in the area are 1) Ustochrepts (Typic Calcic, Alfic) i.e. Calcisols or Alluvial Soils, 2) Halaqueptstt (Calcic, Aeric) i.e. Solanchaks/Humic gley Soils, 3) Ustipsamments (Typic), and 4) Ustifluvents (Typic) i.e. Alluvial Soils.

- **Udic zone:** In the northeast fringe starting from the Sub-humid (dry) and Less-hot (CIA') foothills bordering Himachal Pradesh is where lies the udic zone. Here, the rainfall is over 1000 mm and the natural vegetation is mostly shrubs with thin deciduous forest. The soils are reddish-brown to olive-brown but do not have any accumulation of alkaline earth carbonates. The pH varies from 6.5 to 7.5 and texture ranges from sandy loam to clay

Figure 4 Soil of Punjab. Source [44] under CC BY-NC-SA.

loam. The major soil formations in the area are 1) Hapludalfs crypic and Mollic) i.e. Gray Brown Podsolc Soil, 2) Eutrochrepts (Typic, Dystric), i.e. Brown Forest Soils, 3) Udifluvents (Typic) i.e. Alluvial soils, and 4) Hapludolls (Typic) i.e. Brunizems.

At the family level, the soils of the aridic and ustic zones could be considered for loamy (coarse to fine), mixed, calcareous, hyper-thermic while those occurring in the udic zone could be considered for coarse to fine loamy, mixed, non-acid, thermic family classes [41].

Crops in Punjab: Punjab State has a nickname of “Food Basket of the Country” & “Granary of India” which is due to the fact that it contributes about 40% of rice and 50-70% of wheat since last two decades. Punjab produces surplus food grains and contributes around 60% of food grains. The Punjab state has highly intensive agricultural practices in terms of land, energy, capital, agriculture inputs, nutrients, and water etc. Although it occupies only 1.5% of the geographical area of the country, Punjab produces about 22% of wheat, 13% of cotton, and 10% of rice of the total production of these crops in the country during 2001-02. The largest producer of wheat and rice in the state is Firozpur District [46]. Punjab occupies third rank in farming due to its best irrigation system and plain land that are ideal for farming [47]. The food crops widely harvested in the soil of Punjab are rice, maize, sugarcane, fodder, cotton, and vegetables. The main cropping system of the kandi region (Shivalik foothills) is maize and wheat in addition to which green fodder, pulses, and fruit plants are also grown [45].

Soil of Haryana

Haryana is one such Indian state which holds 22nd position among other states in terms of area (17,070 sq. m) but has 4th rank in terms of agricultural productivity. Despite major arid regions and less diversity in types of soil, it has managed to be the 2nd largest contributor to the Indian food grain pool. Haryana is situated in between latitude 27°39' to

30°35' N and longitude 74°28' and 77°36' E. Terrestrial area resides 700–3600 ft above sea level and is flanked by Punjab on the northwest, Delhi and Uttar Pradesh on the east, and Rajasthan on the south and southwest [48].

The state has 4 topographic divisions. Bagar or Sandy plains to southwest, Alluvial plain or Yamuna Ghaggar plain, Shivalik towards northeast, and Aravalli range towards the south [48]. Sandy soil and Alluvial soils are two major types of soils found in Haryana.

Haryana receives around 29% of rainfall (average 354.5 mm). State of Haryana experiences extreme hot in summer and mild cold in winters. As per the vulnerability study by ICAR, Southern districts of Haryana experience high vulnerability to climate change, leaving the area with dry patches of arid to semiarid lands with no or less scope for rain and groundwater. Hence this demands a well-equipped irrigation facility to support agriculture and life [49].

Types and texture of soil: With relatively less diversity in types of soil, Haryana has two major soil types. It is a broad leveled plain surrounded by Ganges and Indus on either side, hence the major soil type is Alluvial soil. That is mostly confined to North and North-eastern districts. Coarse sand, silt, and clay get deposited regularly by small mountain streams and river of Indo- Gangetic plain on its bank and bed which leads to the formation of alluvium.

The south and southwest districts of Haryana such as Faridabad, Mahendragarh, Hisar, and Bhiwani are surrounded by the deserts of Rajasthan. So, they experience undulating sandy plains with mobile dunes and tals. The type of soil found here is Sandy desert soil.

Texture of soils:

- Alluvial soil: It is regarded as one of the most fertile soil which supports wide varieties of crops. Geologically Alluvial soils are of two kinds i.e. older and newer alluvium. It is named Bangar and Khaddar respectively. Old surface soil is of reddish-brown to grey-brown colour with sandy loam to loamy texture, old subsoil has more of a clayey texture. New soil is coarse on the river bank and has more of a finer texture on low marshy lands. Frequent drainage is restricted in major parts of the state; hence, soluble salt is accumulated in various regions and deficient in others. So, in certain places soil remain deficient in humus and nitrogen but abundant in Potash and lime. Deficiency is compensated by proper analysis of soil and manuring accordingly [50–53].
- Sandy soil: Sand blown from coastal belts serves to be the major component of the soil along with the calcium carbonate that gives it an alkaline nature and pH ranging from 7.8 to 9.2. Organic matter is found in the least quantity, with poor water holding capacity

this soil has low productivity in agricultural practices. Soil has high salt content but below the toxic level. It is rich in phosphates but very poor in amount of nitrogen and humus therefore is not suitable for majority of crops. It has a pale to yellowish-brown colour. It has a subangular blocky structure [50,51].

- Crops harvested in soils of state Haryana: Haryana has a major contribution in food grains in meeting the need of other states of India. Sandy soils of arid regions with poor rainfall, irrigation, and groundwater facility support relatively less cultivation is done. Although proper irrigation helps but productivity is not up to the mark. Alluvial soil that has sandy loamy and clayey texture has good water holding capacity and serves as a blessing for major cultivable crops. Northern regions of Haryana with alluvial soil have good quality groundwater, a network of irrigation, and a drainage facility hence is suitable for majority of agricultural cultivation (Figure 5 & 6).

Basmati rice that is famous worldwide for its aroma and long slender grains is produced in abundance here. Wheat, rice, maize, and bajra are major cereals produced in the state. Both Rabi and Kharif (double crops) are cultivated in majority of areas. Short periods in between these two crops i.e., mid-May and July are sometimes used for raising 3rd crops in regions with good irrigation facilities (Figure 5 & 6).

Sugarcane, groundnut, maize, and paddy, etc, are major and chilies, bajra, jowar, pulses, and vegetables are minor Kharif crops. Wheat, Barley, Gram, Mustard, and Pulses are major Rabi crops [51]. North-western region supports temperate fruits, vegetables and the south-western supports exotic veggies, tropical fruits, medicinal and herbal plants (Figure 5 & 6).

Soil of Madhya Pradesh

The soil decides the agriculture of any area or state [52,53]. The soils are formed as a result of the breakage of rocks and this is how the soil has its own classification. The state Madhya Pradesh, a part of Central India, is situated having the coordinates 22.9734° N, 78.6569° E and it has the following types of soil [54] (Figure 7).

Black soil: Black soil is also known as regur (humus) soil and black cotton soil. It covers maximum area (around 47%) of the state [54] and is rich in iron and lime. But it lacks nitrogen, phosphorus, and carbonic elements. It is formed due to the deposition and weathering of Deccan trap (Malwa plateau), Narmada-Sone valley, and Satpura-Maikal range. The soil is basic. It is mostly suitable for cotton and good for wheat and soybean. Black colour is due to the titaniferous magnetite compounds of iron, aluminum, and accumulated humus [54]. The water holding capacity or moisture retention capacity in this soil is the highest due to which the moisture persists for a long time and needs less irrigation. Hence, soil

erosion is very less in Black soil. Black soil is again classified into three types- (a) Normal Black soil (b) Layered Black soil (c) Dark Black soil. Areas of the state covered with Black soil are- Bhopal, Barwani, Betul, Chhindwara, Dhar, Damoh, Dewas, Vidisha, Shajapur, Jabalpur, Khandwa, Mandsaur, Narsingpur, Raigarh, Raisen, Sidhi, Shivpuri, Seoni, Sehore, Sagar, Guna, Indore, Ujjain, Jhabua, Ratlam [55].

Red-yellow soil: The colour of the soil is due to the presence of ferric oxide which gives the reddish colour and when ferric oxide undergoes hydrolysis, it turns into yellow colour [55]. Hence the name red-yellow soil is given. The soil is the result of the Gondwana rock group. Like the Black soil, it is also basic in nature and rich in lime, which makes it suitable for the cultivation of Rice. The fertility is very low and poor in nitrogen and humus. It covers 37% of the state, [56] mostly the eastern part that is Bundelkhand and Baghelkhand and the main districts include Mandla, Balaghat, Shahdol, Anoopur, Sidhi, Umaria, Singrauli, Katni, etc.

Alluvial soil: The alluvial soil is formed due to the eroded deposits brought out by the river Chambal and its auxiliary rivers [57]. Spread over the North-western part of the state, it is the most fertile soil of all and spreads over 3 million acres of the landmass of the state, that is, approximately 3% [58] of the total soil of the state. It is of 2 types- Khadar and Bangar [59]. It is neutral and most suitable for growing sugarcane. Areas of the state covered with alluvial soil are- Bhind, Morena, Sheopur, Gwalior, and Shivpuri districts.

- **Mixed soil:** It is the mixture of red, yellow, and black soils which is rich in calcium carbonate [54]. It is found in many districts of the state and is not fertile due to the lack of nitrogen and phosphorus [56]. Suitable for growing crops like corn, bajra, etc. that need less nitrogen. Areas of the state covered with mixed soil are- Sheopur, Morena, Bhind, Gwalior, Shivpuri. Apart from the above types, there are more types of soils as well which are as follows-
- **Laterite soil:** Like the alluvial soil, it is also found in the North-Western part of the state. The content of nitrogen, organic matter and phosphorous are less. It is mostly suitable for crops like Sugarcane, Cotton, Wheat, etc. It is a mixture of sand, silt and clay. Areas of the state covered with laterite soil are Shivpuri, Gwalior, Bhind, and Morena [54].
- **Loamy soil:** The soil is light compared to other soils and is usually found in the river belts and plains. Medium level fertility is usually seen. It contains clay and sand in approximately equal proportions [55].

Soil of Chhattisgarh

Chhattisgarh, the 10th largest state which is centrally located on Indian map, is geographically situated between

Figure 5 Crops of Haryana. Source [52] under creative common attribution license.

Figure 6 Agro-climatic zones of Haryana. Source [52] under creative common attribution license.

Figure 7 Different types of soils of Madhya Pradesh. Source [54].

17°46' N and 24°5' N latitude and 80°15' E and 84°20' E longitude. The general geographical vicinity is around 136 lakh hectare area, of which cultivable land place is 58.81 lakh hectare area and forestland region is 60.76 lakh hectare area with more than 2.07 crore populace. About eighty percent of the populace within the nation is engaged in agriculture and forththree percentage of the land is beneath cultivation. Paddy is the most important crop and the critical plains of Chhattisgarh are called rice bowl of significant India. Other most important plants are coarse grains, wheat, maize, groundnut, pulses [60,61].

Chhattisgarh state has been divided into three Agro-climatic zones via Chhattisgarh Plains, Baster Plateau, and Northern-Hills zone covering 51.0%, 28.0%, and 21.0% of the geographical area, respectively. The state of Chhattisgarh is located in the northern part of the country, which is nearer to the Bay of Bengal, due to which monsoon comes every year in June. The state is having a cropping intensity of about 135 %, which shows an increasing trend since creation of the state and due to increases in irrigation facilities. Chhattisgarh basin has mainly evolved from lower Vindhyan rocks made up of sandstones, limestone, shale, gneisses, and quartzite [62]. The soils of Chhattisgarh are presented in table 4.

Red yellow soil: Around 55% of the area is covered with this type of soil which is composed of acidic rocks like granite, gneiss, and schist. Those soils are encountered over extensive non-alluvial tracts of peninsular India. The red colour is mainly due to ferric oxide present in the soil while the iron oxide occurs as haematite or as hydrous ferric oxide. This type of soil covers most parts of the state, which

is found in some districts they are namely Raipur, Bilaspur, Durg, Korba, Mahasamund, Jashpur. This type of soil is having the capacity to grow crops such as rice, sorghum, millets, and pulses [63].

Red sandy soil: Sandy Soils have a better percentage of sand than clay, drain quickly, heat up quicker in spring, and are generally less difficult to work with and its red colour indicates the presence of iron and prevents iron deficiency in plants.

The red sandy soil is the second most common type of soil, which is seen covering about 30% area of Chhattisgarh. Red sandy soil is mostly found in the districts of Dantewada, Kanker, Dhamtari, and Durg. The soil crystals are fine and sandy. Red sandy soil is ideal for crops such as watermelons, peaches, and peanuts [63].

Red loam soil: Clay, sand, silt and organic matters are generally found in red loam soil. Loam soil is suited for growing almost all plant varieties. This soil is loose, fertile, easy to work with, and drains well [63]. The Northern Hill agroclimatic zone of Chhattisgarh state is enriched with clay loam soil (suitable for the production of rice) and sandy loam soil (suitable for cultivation of maize) [64]. This soil is found in Dantewada, Bastar, Sukma, Bijapur region of Chhattisgarh state. It looks like a brick as the maximum part of the soil is containing iron-rich rocks that are why this soil appears reddish. Its pH of about 6.6 makes it suitable for the cultivation of course grains and paddy [63].

Black soil: The other name of black soil is regur (from the Telgu phrase Reguda) and black cotton soil due to the

Table 4: Distribution of soil type that harbours crops in Chhattisgarh source [66].

Soil type	Source mother rock	Distribution %	District/region	Main crops
Red-yellow soil (or Matasi)	Gondwana	60-65	Surguja, Koriya, Jashpur, Raigarh, Korba, Bilaspur, Kawardha, Durg, Raipur, Dhamtari, & Mahasamund districts.	Paddy
Red-sandy soil	Archaean Granite	20-25	Bastar, Dantewara, Kanker, Durg, Rajnandgaon, & Dhamtari districts.	Kodo-Kutki, Jwar, Maize, Potato, Coarse grains, etc.
Red-domat soil	Archaean Granite	--	Dantewara and Konta tehsils.	Paddy
Laterite soil	Mixed	--	Bagicha, Samri, Sitapur, Ambikapur, Kawardha, Chhui-Khadan, Saja, Bemetara and Jagdalpur tehsils.	Pulses, Jwar, Kodo-Kutki, Oilseeds, Potato, Coarse grains, etc.
Black soil	Deccan Trap & Basalt	--	Mungeli, Pandariya, Raipur, Rajim, Mahasamund, Kurud and Kawardha tehsils	Paddy, Wheat, Cotton, Gram, Sugarcane and Rabi Crops.

fact cotton is the maximum critical crop grown in those soils. Magnesium, lime, calcium, potassium, aluminium, and iron are the main components of this type of soil. The management of most important nutrients (N, P, K) is very important for proper yield of crops [65]. In Chhattisgarh it is also known as kanhari soil. Districts of Kawardha, Dhamtari, Mahasamund, Mungeli, Balod are covered by this soil. There the black cotton soil belt is famous for wheat, gram, oilseed, pulses, cotton, soybeans, etc. [63,66].

Laterite soil: As Chhattisgarh is a hot and wet tropical area, laterite is also found here which consists of rock-type materials that are rich in iron and aluminium. The monsoon climate works as key factor in the origin of this laterite soil of Chhattisgarh. The water holding capacity of the soil is very low due to the presence of pebbles in this type of soil.

Being infertile, it has less importance in agricultural point of view, but it is still able to cultivate millets, kodo, mites, cereals, potatoes, oilseeds, rabi crops, etc. This laterite soil is prevalent over few regions in the districts of Chhattisgarh. They are as follows Surguja, Jashpur, Balrampur, Durg, Baster, and Bemetara [63,67].

Soil of Odisha

Odisha is a state that lies in the eastern part of India in the tropical belt. It covers 155,707 square kilometers of area and is the 8th largest state in terms of area. The climate of Odisha is characterized by high temperatures and medium rainfall. The average rainfall annually is about 1500 mm, mostly occurring in monsoons [67]. Three major seasons are experienced by the state: summer, winter, and rainy seasons. The state can be divided into 10 agro-climatic zones on basis of its weather, soil, topography etc [68]. The state of Odisha is included in the list of 10 largest farming states of India. Around 87.46 lakh hectares of land are utilized in farming and 60% of population are farmers.

Soil of Odisha is divided into 8 major groups based on the climatic condition, parent material, texture and water holding capacity. Soils are mostly fertile but some need proper management [69].

Types and texture of soils in Odisha: The types of soil and their distribution in Odisha are presented in figure 8.

- **Red soils:** They are named so because of the presence of excess amounts of iron oxides that gives red colour to them. It covers around 7.14 million hectares of land and is found in districts of Koraput, Malkangiri, Mayurbhanj etc. Red soils in some of these districts are heavier in texture and lighter in some other districts. They are acidic and have low water retention capacity. They are deficient in various macronutrients and micronutrients like Boron, Zinc, Magnesium, etc. [70].
- **Laterite soils:** The laterite soil occupies 0.70 million hectares of land in districts of Khordha, Puri, Nayagarh, Dhenkanal, Cuttack, Sambalpur, etc. The laterite mass has a compact vesicular structure and also in some districts, they have honeycomb-like structures. Laterite soils are rich in iron and aluminium oxides. The soil is acidic with a pH of 4.5 to 5.7. These types of soils have low fertility as they have low organic matter content and very less amount of Nitrogen and Phosphate. They are deficient in micronutrients like Boron, Zinc, etc. 45% of soil samples were found to be deficient in Boron [60,61,70,71].
- **Red and yellow soils:** These types of soils occur in rolling and undulating terrains. They occupy 5.5 million hectares of land. The soils have moderate depth and are coarse in texture. Soils of upland are lighter in texture than lowland soils. The upland soils are acidic and have low nitrogen and phosphorus concentrations.
- **Black soils:** Due to the presence of titaniferous magnetite and humins they are black [44,72]. It covers an area of 0.96 million hectares of land and is found in districts of Angul, Kalahandi, Malkangiri, Ganjam, etc. [68]. The soils are heavier in texture; the clay content is more and has a good water retention capacity. It is moderately alkaline.

Soils of Orissa

Figure 8 Soils of Odisha. Source [72].

- **Deltaic alluvial soils:** These kinds of soils are present in deltaic regions of rivers such as Mahanadi, Baitarani, Subarnarekha, etc. The soil has a mostly sandy and clayey texture. They have good water holding capacity and are fertile too. These soils are slightly acidic or neutral.
- **Coastal saline and alluvial soil:** The coastal saline soil covers 0.254 million hectares of land and generally occurs along the coastal belt of the state. Saline soils have a high concentration of sodium, magnesium, chloride, etc. These soils are mainly clayey and loamy in texture. They are saline in nature due to brackish tidal water deposits.
- **Mixed red and black soil:** These types of soils cover 0.16 million hectares of land and are found in districts of Sambalpur, Bargarh, Bolangir, etc. It is named so as black soils are found in patches within the red soil. They are generally light in texture and moderately fertile. They generally have neutral pH [73].
- **Brown forest soil:** The soil covers 0.17 million hectares of land and is mostly present in forest areas in districts of Kandhamal, Ganjam, Nayagarh, etc. They are brown coloured soil and are acidic. They are rich in organic matter and nitrogen. They are mostly fertile and suitable for horticultural crops.

Crops harvested in soils of Odisha: Red soils, due to their acidity nature and low water holding capacity, need proper

management. By treating the soil with lime and various essential elements, crops such as rice, millets, potatoes, and brinjals can be grown. Fruits like mango, guava, and papaya can also be grown. In laterite soils, groundnut crops and pulses are grown by treating the soil with lime and providing proper fertilizer. Crops such as rice, sesamum, millets, and fruits like mango, jackfruit, sapota can be grown successfully in this soil.

In red and yellow soils, crops like rice, millet, sugarcane, tomato can be grown in upland areas whereas various pulses and fruits like bananas, guava, and mangoes can be grown in low land areas. As the black soil is fertile and has good water retention capacity, crops such as rice, bajra, jowar, cotton, mustard, and maize can grow well in these soils [74].

The deltaic alluvial soils are suitable for growing rice, groundnut, mustard, and sesamum as these soils are fertile. Green gram and black gram can also grow in appropriate soil moisture. In coastal saline soils, rice can be grown successfully if there is proper rainfall. Rabi crops like mustard, tomato, spinach, and barley can grow well. Cotton can grow if salinity is maintained.

The red and black soils are moderately fertile. Crops such as rice, maize, and sugarcane can be grown properly by proper management and supplying them with proper fertilizers. Horticultural crops like jackfruit, mango, and guava are mainly grown well in brown forest soils. Ginger, turmeric, maize, and wheat can also be grown if moisture content of soil is maintained [74,75].

Soil of Andhra Pradesh

The soil types in Andhra Pradesh are presented in figure 9.

Position: Andhra Pradesh has longitudes 77° E and 84° 40' E and latitudes of 12° 41' N and 22° N. Area of the land 2,75,045 km² [75]. According to the counting of biggest state list in Indian subcontinent, Andhra Pradesh comes 4th in rank. North to it Odisha is present, the northwest has both Telangana and Chhattisgarh, south to it Karnataka and east is covered with the Bay of Bengal. Andhra Pradesh has a coastline of length 972 kilometre which is considered the 2nd longest coastline in India [76].

Types of soil in Andhra Pradesh: Andhra Pradesh is known for its cultivation of rice, covers lesser fertile coastal soil deposition to more fertile deltaic alluvium of Mahanadi, Krishna, Godavari and Kaveri. Approximately 60% and more of the population depend on farming for their livestock [77]. Main economic growth of Andhra Pradesh is possible due to the production of rice. It is estimated that Andhra Pradesh contributes about half of the food in India's publicly distributed food system, according to a journal Combat Law [78]. These are some important soil types found in Andhra Pradesh [74].

- **Red soil:** About 66% of land area of Andhra Pradesh

is covered with red soil [77]. This soil is formed due to the degradation of metamorphic rock. It lacks fertility due to the poor holding capacity of nitrogen, humus, and various plant nutrients. It has a very low moisture retention capacity with less content of lime and the formation of iron oxides is seen. All these conditions indicate that these soils are poor for agriculture [78]. Red soil is also categorized according to its occurrence in the land of Andhra Pradesh in six categories, they are red sandy soil covers 8%, red earth also sub categorized as loamy (30%), and clay (3%), and deep red loamy soil (3%). Some parts of Guntur, Nellore, Srikakulam, and majority of Telangana, red soil is seen [77].

- **Black soil:** After red soil, it is the second largest composition found in about 25% of land area speared with fine grained black soil. It has the compositions like granite and Dharwars due to various geographical compositions [77]. Typically, calcium amounts are predominantly found in black soils. Like United States has prairie soil, Andhra Pradesh has black soil having a high concentration of calcium carbonate and magnesium carbonate. It also has a little bit of organic matter due to which it looks dark in colour [78]. pH ranges from mid to high indicating a neutral to high alkalinity in black soil.

Figure 9 Soil of Andhra Pradesh. Source [74].

Apart from black soil, another form of black soil is also found known as black cotton soil. Black cotton soils are categorized into deep black soil, medium black soil, light black soil, and somewhere mixed types mean red and black mixture is also seen. In the plateau region, the black soil looks white, thin, and is fertile enough for cultivation. The deep black soils are found along the Pranitha, the Godavari, and The Krishna rivers in broad belt, ranging from 10 to 26 kilometers of either side of these rivers. In States like Adilabad, Rangareddy, and Nizamabad, light black soils are found. Rivers like Krishna and penner create a patch of mixed type that looks cracked in dried atmosphere [77].

- **Alluvial soil:** Alluvial is best known for its fertility. Majority of crops are cultivated on these alluvial soils. They cover a very less portion of total land area. It consists of sand, carries potash, optimal ratio of silt and phosphoric acid [78]. There are two types of alluvial soil found on Andhra Pradesh, one is deltaic and another is coastal alluvial soil. Deltaic alluvial soils are formed by silt brought down by the rivers. They are richer in plant nutrients as compared to the coastal alluvial soil. The coastal alluvial soil is made of up sand and sandy loam. Along the coastal belt of Visakhapatnam and Srikakulam districts, the valley of Vansadhara and Nagavali Rivers along with Pennar in Nellore district are covered with deltaic alluvial soil whereas small parts of Nellore, Guntur and Srikakulam districts have coastal alluvial soil [77].
- **Lateritic soils:** Lateritic soils are found near about 1% of the total land mass. Lateritic soils hold hydrated oxides of aluminium and iron seen during humid monsoon season [78]. This soil has a very low pH; hence we can call it acidic soil too. They are very low in plant nutrients and black or brown to some extent reddish too. Low organic matter and poor fertility are major drawbacks of agriculture in this land. It occurs in Visakhapatnam, Nellore, Godavari, Srikakulam districts of Andhra Pradesh [77].

Crops harvested in soil of Andhra Pradesh:

- **Fruits:** Banana, sweet orange, mangos are considered as main fruits that are produced in Andhra Pradesh. The majority, that is, approximately 86% of the total land area are rich in fruits and these contribute around 77% of the total fruits to India.
- **Vegetables:** In Andhra Pradesh majority of the vegetable crops that are cultivated and produced are found to be of a hybrid variety. These crops are with high yield and desired quality like pest resistance, high nutritious value. The major vegetables produced are tomato, onion, tapioca, brinjal, bhindis, etc. As monsoon strikes seasonal crops are also seen in

Andhra Pradesh. It provides more opportunities to increase economic support to local people as local varieties.

- **Spices:** This State is also top producer of spices. Spices including turmeric and chilies are produced at higher rate. Other than that, spices like garlic, ginger, coriander, and black pepper are also produced.
- **Palm oil:** Farmers are also subjected to the production of palm oils in these areas. Not only in Andhra Pradesh but also most southern states palm oil is cultivated. The more producing areas are Anantpur and Eluru. There are other 11 districts also producing palm oils these are Srikakulam, Vizianagaram, Visakhapatnam, east of Godavari, Krishna, Guntur, Prakasam, Nellore, and Khammam.
- **Sugarcane:** More sugarcane is produced in the tropical and sub-tropical regions. As India is a favorable country for its sugarcane, it is cultivated in many of those tropical states. Tropical regions are more suitable rather than sub-tropical regions due to climatic conditions that favour the production of sugarcane. Tropical belt states like Andhra Pradesh and Maharashtra extensively produce sugarcane. Apart from these, Tamilnadu and Gujarat also produce sugarcane. Approximately 35% of total 300 million tons of sugarcane in India is meant for the production of Gur, Kandasari, and chewing products. As Karnataka, Tamilnadu, Uttar Pradesh is the predominant states, Andhra Pradesh also produces it in large quantities [75]. Sugarcane production is most prominent in Vishakhapatnam districts of Andhra Pradesh. Management of essential nutrients like (N, P, K, Cu, Mg), etc can lead to enhanced sugarcane production [79].

Soil of Telangana

Telangana is situated in a landlocked region in the deccan plateau and is drained by 2 major rivers- Godavari and Krishna. It extends from latitude 15°50' to 19°45' N and longitude 77°16' to 87°43' [80]. The state is situated in such a place that it has a variety of soil. The soils found in Telangana are mostly black soil while it also has red soil, laterite soil, and alluvial soils [81-83].

Soils of Telangana: The black soil of this region is mostly volcanic in origin [81-83]. It may also be derived from basalt rock under semi-arid conditions. The black soil gets its colour due to presence of titaniferous magnetite or iron in small proportion along with black constitutes of parent rock or volcanic rock. Various shades of black colour are available in Telangana from shallow to medium black and also very deep black cotton soil. Black soil highly retains moisture thus swells on accumulation of moisture. Self-ploughing is the characteristic of black soil. Moisture

evaporates leaving behind broad and deep cracks as the soil shrinks. These cracks are responsible for the extraordinary fertility of the soil as oxygenation of soil is facilitated to sufficient depths. During rainy season it becomes very sticky thus working with soil becomes difficult. The soil is rich in iron, lime, calcium, potassium, aluminium, and magnesium but deficient in phosphorus, nitrogen, and organic matter [84]. Some regions also have red soil which may be red loamy soil called Chalaka or red loamy sand called Dubba [81]. The colour of the soil is red due to the presence of ferric oxide. The colour is red in upper layers and in lower layers it becomes more yellowish. Red soil is deficient in lime, nitrogen, humus, phosphate, manganese, and potash. Traces of laterite soil are found in certain regions due to high leaching of lime and silica. Laterite is derived from Latin word later meaning brick [81]. Although the soil is well-drained and porous, it becomes too soft when wet and too dry when dry. The colour of soil is red due to iron oxide and aluminium oxide rich content but is poor in nitrogen, potash, potassium, lime, humus, calcium, and magnesium content. Owing to the two rivers, there is also the presence of alluvial soil in the riverbeds. The state of Telangana is covered by igneous depositions such as pink and gray granites and basalt as well as metamorphic depositions like granite gneiss [85-87]. Different forms of red and black soils

that occur in Telangana region is generally associated with pedogenesis of parent material with different mineralogical composition, conditioned by the drainage and relief [82,83] (Figure 10).

According to the 1970-US comprehensive system of soil classification, soil is of 5 orders, 9 suborders, 17 great groups, and more than 25 subgroups. At the family level, these soils can be differentiated by their soil reaction, texture, temperature, and percent carbonates. The major soil orders mostly found on land of the state are Inceptisols, Vertisols, Entisols, Alfisols, and Mollisols [82,83]. Soil of Telangana can also be categorized into agro-climatic region, Agro-Ecological Region (AER), and agro-ecological sub-region, and thus based on agro-climatic zonation, Telangana can be broadly classified as the Northern Telangana Zone (NTZ) and the Southern Telangana Zone (STZ). North zone receives 810-1135 mm rainfall and is categorized climatically as being semiarid, moist tropical. Southern zone receives 560-970 mm rainfall and is thus climatically classified as semiarid, dry tropical [84].

Crops of Telangana: The state has taken up agriculture as its main goal to educate farmers on the latest technical farming and train farmers to boost agricultural production. In Telangana, 27 important crops during Kharif and Rabi

Figure 10 Soils of Telangana. Source [89] under CC BY 4.0.

seasons are grown that together cover an area of about 53.51 lakh hectares [85-87]. 114.84 lakh hectares of Telangana land is dedicated to farming rice, sugarcane, tobacco, and mango so people even refer it to as “seed bowl of the country”. Telangana is also named as “Rice Bowl of South India”, as rice is cultivated in 44 lakh acres [88] (Figure 11).

The crops grown in the state are cotton, tobacco, sugarcane, horse gram, jowar, bajra, maize, ragi, red gram, bengal gram, green gram, black gram, sesamum, Millers, castor and sunflower, according to vanakalam report of 10.6.2020. Soils in Aurangabad district were found to be suitable for growing most annual crops in shallow soil and perennials in the deeper soils. In Medak district, around 1.4% of total area was classified as highly suitable (S1) 41.66% area as moderately suitable (S2) and 50.82 % as unsuitable (N2) for rice. Highly suitable rice lands are mainly distributed in Zaheerabad and Sadasipet. In case of sugarcane, highly suitable (SI) lands are distributed in Siddipet, Dubbaka, Ramayampet, Gajwel, Narsapur, Medak, Andole Jonipet, Sangareddy, Shankarampet, Sadasipet, and to a limited extent in Narayankher and Zaheerabad [84]. Red soils of Telangana were considered marginally suitable to highly suitable for cultivation of maize, sorghum, red gram, green gram, and black gram. black soils were moderately suitable to highly suitable for cultivation of cotton, sorghum, soybean, green gram, black gram, red gram, sunflower, sesamum, maize, and pearl millet while the red laterite soils were considered to be marginally suitable to moderately suitable for cultivation of groundnut, green gram, black gram, red gram, horse gram and pearl millet [82]. Understanding the behavior, nutrient supplying capacities, fertilizer responses, management strategies to be adopted for crop production and potential capability of soils are important to know the quality characteristic features of different soil [83].

Soil of Karnataka

Karnataka is situated in the Southern-Western part of the Indian Peninsula. It covers an area of 191,791 km², making it the seventh-largest state of India. It is situated within 11.5°N and 18.5°N latitudes and 74°E and 78.5°E longitude. The state has coastal regions, plateaus, and mountain ranges. These varied types of soils are present owing to these different regions, which may give rise to different types of crops, enriching the agricultural productivity of the state [89-91].

Types of soils in Karnataka: The major variety of soil in Karnataka is the red soil that is further sub-classified into red loamy soil, red clayey soil, red gravelly loamy soil, and red gravelly clayey soil [92]. As evident from the classification, the texture varies as clayey, gravelly, and majorly loamy. It is predominant in eastern districts of Karnataka like Bangalore, Kolar, Mysore, Simona, Hassan, etc. These soils are rich in phosphorus, iron, alumina, but deficient in nitrogen [93,94] (Figure 12).

The 2nd variety of soil is laterite soil which is classified into lateritic gravelly soil and lateritic soil [63]. These soils have mostly a soft texture which later becomes coarse or hard [95]. They occur in the western areas of some districts like Uttara Kannada, Dakshina Kannada, Udupi, etc. The insoluble iron and aluminum are deposited in the surface layers while the soluble part, the compounds of lime and silicates, settle down at the bottom layers [92, 95].

The 3rd variety is black soil which can be of deep black soil, medium-deep black soil, and shallow black soil. Above classification is based on different depths of soil. These soils are dark, finely grained in texture, and have very high fertility, hence considered very important from agricultural point of view [96]. They are rich in calcium and

Figure 11 Crops of Telangana. Source [90].

magnesium carbonates with a fairly high amount of iron, lime, magnesium, and alumina but are deficient in potash, nitrogen, and organic matter [93]. This soil is mainly found in plateau regions such as districts of Belgaum, Bijapur, Gulbarga, etc [96].

The next variety is alluvial soil which is classified into non-saline soil, saline soil, and sodic type soil [93]. These soils have textures varying from sandy loam to clayey [95]. They are found in the coastal districts of Karnataka like Udupi, Dakshina Kannada, and Uttara Kannada. These are

Figure 12 Soils of Karnataka. Source [81].

also found in regions like the Northern side apart from the coastal region. They are rich in organic matter mainly because they are formed as a result of deposition of sediments rich in the organic matter in coasts, riverbeds, etc. [92].

Crops grown in Karnataka based on different soil types:

- a) **Red soil:** Since they have low water retention, as they are mostly loamy, there is a requirement for irrigation techniques. Main crops raised in this soil are wheat, tobacco, sugarcane, oilseeds, millets, jowar, ragi, and bajra, etc.
- b) **Laterite soil:** The fertility is low in these soils due to intensive leaching, hence proper manuring and irrigation is a must. Some of the commercial crops grown in these soils are cashew, coconut, pepper, cardamom, tea, coffee, etc.
- c) **Black soil:** It has good moisture retention ability and is also rich in nutrients. Cotton is a major crop grown; as a result, it is also referred to as Black cotton soil. Other important crops grown in this soil are sunflower, onion, chili, maize, etc.
- d) **Alluvial soil:** This soil does not have good water retention but is very rich in organic matter. Crops grown mainly in this type of soil are coconut, arecanut, banana, paddy, etc. Other crops also grow well in this type of soil as well.

Forest soil of Karnataka: Forest soil is another type of soil, which can be considered as a subdivision or a mixture of major varieties of soil in Karnataka. Although they do not cover a large area and are not used for agriculture (the soil is under forest cover) as other soil types, they still hold relevance. They are important, considering that the soil helps in sustaining the rich vegetation of forest which supports the fauna, for maintaining the whole ecosystem [96]. These soils are found mainly in the Western Ghats and to a small extent in the Eastern Ghats, bordering Tamil Nadu. There is a transition occurring within the Western Ghats in terms of landforms and eventually in the types of soil found there. The difference is evident as one moves from the coastal region towards the fringes of Deccan plateaus (Bourgeon, 2010). Mostly the soils varied from sandy loam to clayey type. However, soil cover was brown clayey soil, rich in organic matter and good water retention ability [97].

All in all, the soils of Karnataka play a huge role in its agriculture, economy, natural ecosystem, etc. Karnataka is an agriculturally important state for India, considering its contribution to the total agricultural product output. Due to a large variety of soil as described in the previous sections, a variety of crops also grow in this state. The main crops being rice, wheat, maize, barley, groundnut, sugarcane [98]. Cotton is also an important crop here. It is the seventh largest cotton-producing state of India with abundance of

black soil essential for cotton production [99]. It tops among the Indian states in coffee production [85–87]. Because of the presence of loamy texture, both red soils, as well as sandy soils, are ideal for raising coffee plantations [100]. The other important crops grown in the state are cashew, arecanut, coconut, which require the alluvial soil of coastal areas rich in organic sediment. There are other crops that include spices, aromatic herbs which are required both for domestic uses and international export due to the high quality they have. Again, just like coffee, they also require rich loamy soil, mostly the black loamy soil rich in humus [85–87]. Cardamom, and rubber are important plantation crops as along with some fruit plantations like orange and grapes for which Karnataka are quite famous [85–87]. Well-drained loamy and sandy soils are essential for fruit plantations [101]. These fruits are sold in the domestic market, both locally and all over India. Foreign countries also have a huge demand for these fruits for their good quality and taste, which in turn leads to flow of high Foreign exchange to the country.

Hence, as described, above soil has a huge role to play in the agricultural fertility and economic prosperity of the state of Karnataka. This in turn contributes to the overall profit and wellbeing of the whole country [102–119].

CONCLUSION

India is one of the largest agriculturally productive countries in the world. Out of 28 states of India, West Bengal, Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Chhattisgarh, Odisha, Andhra Pradesh, Telangana and Karnataka topped the rank in productivity in their agriculture sectors. The soil type present in the above states is one of the major contributing factors. Both urvara (fertile) and usara (sterile) soils are found in the above states. The major soils of the above states that harbour their several agri-products are alluvial soil, red soil, and black/regur soil. Other soil types are arid/desert soil, laterite soil, saline soil, peaty/marshy soil, forest soil, and sub-mountain soil that additionally supports agriculture in the top ten states of India.

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References

1. Singh RL. India: a Regional Geography. National Geographical Society of India. 1971. <https://bit.ly/3jRHZ7g>
2. Bosch C, In Rosenkranz D, Bachmann G, Einsele G, Harreß HM (eds.): Bodenschutz, Erich Schmidt Verlag, Berlin; 1988. p. 1480.
3. PMFIAS. Major Soil Types of India: Alluvial Soils & Black Soils. 2021. <https://bit.ly/3l6bKAG>

4. Supriya. India: Soil Types, Problems & Conservation. 2021. <https://bit.ly/3yQr09G>
5. TIB. Top 10 Farming States in India [Largest Agricultural Producing States of India]. 2021. <https://bit.ly/3EatIAj>
6. Green WH, Ampt GA. Studies on Soil Physics. The Journal of Agricultural Science, 1911;4:1-24. <https://bit.ly/3jRlmPc>
7. Eves RL, Davis LE. Is the Rock Cycle an Outdated Idea, or a Unifying Concept? Journal of Geological Education. 1988;36:108-110. doi: 10.5408/0022-1368-36.2.108
8. Khullar DR. India: A comprehensive geography. Kalyani Publishers: New Delhi; India. 1999. <https://bit.ly/3z13F4Z>
9. Bazilevskaya E, Lebedeva M, Pavich M, Rother G, Parkinson DY, Cole D, Brantley SL. Where fast weathering creates thin regolith and slow weathering creates thick regolith. Earth Surface Processes and Landforms. 2013;38:847-858. doi: 10.1002/esp.3369
10. Hussain M. Geography of India. McGraw-Hill Education, New Delhi, India. 2014.
11. Zhang Y, Hartemink AE. Digital mapping of a soil profile. European Journal of Soil Science. 2019;70:27-41. doi: 10.1111/ejss.12699
12. Ahmad, Raza M. General Geography of India. National Council of Educational Research and Training (NCERT). 1978.
13. Brady NC, Weil RR, Weil RR. The nature and properties of soils. Upper Saddle River, NJ: Prentice Hall. 2008;13:662-710. <https://bit.ly/3BYnX0T>
14. Kroetsch D, Wang C. Particle size distribution. Soil sampling and methods of analysis. 2008;2:713-725.
15. Schoonover JE, Crim JF. An Introduction to Soil Concepts and the Role of Soils in Watershed Management. Journal of Contemporary Water Research & Education. 2015;154:21-47.
16. Siddiqui SA, Fatima N. Indian soils: identification and classification. Earth Sci. India. 2017;10:1-14. <https://bit.ly/3l5pN9D>
17. GKDUNIYA. Top agricultural producing states in India. 2021. <https://bit.ly/3DZ4f7h>
18. Gibbs A. Lecture 7 b Soil Water – Part 2 Source: Dept of Agriculture Bulletin 462. 1960. <https://bit.ly/393TQbW>
19. Cubrinovski M, McCahon I. Foundations on deep alluvial soils. University of Canterbury, Christchurch. 2011;40.
20. Roy BB, Barde NK. Some characteristics of the black soils of India. Soil science. 1962;93:142-147. <https://bit.ly/3lhoG6U>
21. Mishra A, Dash BB, Das D. Black soils of Orissa and their Management. 2011. <https://bit.ly/3A603jx>
22. Baligar V, Fageria N, Eswaran H, Wilson M, He Z. Nature and properties of red soils of the world. The red soils of China. Springer. 2004. 7-27. <https://bit.ly/3E5PCPv>
23. Gowaikar AS, Datta NP. Influence of Moisture Regime on the Genesis of Laterite Soils in South India I. Morphology and Chemistry of the Soils. Indian Soc Soil Sci J. 1971;19:279-291. <https://bit.ly/3k2dtHl>
24. Gupta JP. Moisture and thermal regimes of the desert soils of Rajasthan, India, and their management for higher plant production. Hydrological sciences journal. 1986;31:347-359. doi: 10.1080/02626668609491053
25. Romeo R, Vita A, Manuelli S, Zanini E, Freppaz M, Stanchi SJF. Understanding Mountain Soils: A contribution from mountain areas to the International Year of Soils. 2015. <https://bit.ly/3liUylb>
26. Chaudhari SK, Singh R, Kundu DK. Rapid textural analysis for saline and alkaline soils with different physical and chemical properties. Soil Science Society of America Journal. 2008;72:431-441. doi: 10.2136/sssaj2006.0117N
27. USDA. Natural Resources Conservation Service Soils. 2021. <https://bit.ly/3hrY9CG>
28. FAOSTAT. Crops. 2021. <https://bit.ly/3E9OuKF>
29. GoI. Pocket Book of AGRICULTURAL STATISTICS. 2017. <https://bit.ly/3nrtRnx>
30. Clear IAS. Soils of India classification and characteristics 2003. 2021. <https://bit.ly/3tzUUxT>
31. Chakravarthi P, Chakravarthi S. Soils of West Bengal. State Agriculture Research Institute, Calcutta. 1957;40. <https://bit.ly/3Em9VZg>
32. ICAR. West Bengal –icar, state-specific interventions for higher agricultural growth. 2016. <https://bit.ly/3C5qTZJ>
33. ICAR. West Bengal. 2021. <https://bit.ly/3A25f8d>
34. U.P. Govt. Department of Land Development and Water Resources, 2009. IWMP in U. P. Perspective and Strategic Plan. 2021.
35. Mathur RB. Uttar Pradesh. Encyclopedia Britannica. 2020. <https://bit.ly/2XdYzKg>
36. Singh M. Soils of U. P. 2017. <https://qr.ae/pGs9sQ>
37. Drishti the Vision Foundation. Uttar Pradesh. 2018. <https://bit.ly/2XfU39I>
38. UPEN. Uttar Pradesh PCS Exam Notes . Uttar Pradesh: Soils. 2021. <https://bit.ly/3nqXwwZ>
39. Brand Bharat. BrandBharat.com. Uttar Pradesh Soil Map. 2021. <https://bit.ly/3tzU18q>
40. Thiyaku S. Soil Moisture Map for the State of Uttar Pradesh. 2017. <https://bit.ly/3tBKz4n>
41. (DACMTD) Department of Agriculture & Cooperation Mechanization and Technology Division, Ministry of Agriculture, Govt. of India. Agricultural Mechanization Guide for Uttar Pradesh. 2021. <https://bit.ly/392NRnS>
42. Sehgal JL. Classification and distribution of the soils of Punjab. 1974. <https://bit.ly/3nqN1ty>
43. Government of Punjab. 2021. <https://bit.ly/3tCQ8jl>
44. DSWC Punjab. 2021. <https://bit.ly/2YQobJs>
45. Sehgal JL. Classification and Distribution of the Soils of Punjab. Proceedings of the Indian National Science Academy. 2015;40(4B):404-419.
46. Vashisht BB, Maharjan B, Sharma S, Kaur S. Soil Quality and Its Potential Indicators under Different Land Use Systems in the Shivaliks of Indian Punjab. Sustainability. 2020;12:3490. doi: 10.3390/su12083490
47. Crop pattern in Haryana. 2021. <https://bit.ly/3k4Rgsl>
48. IB. Crops of Punjab. 2021. <https://bit.ly/3tBK2zp>
49. Climate Position. 2021. <https://bit.ly/38Zy1yu>
50. Mondal B. Concept and approaches in soil science study and soils of India. 2021.
51. Aggarwal PK, Roetter RP, Karla N, Keulen H, Hoanh CT, Laar HH. Land use analysis and planning for sustainable food security: with an illustration for the state of Haryana, India. Indian Agricultural Research Institute, New Delhi; International Rice Research Institute, Los Banos; Wageningen University & Research Center, Wageningen, ISBN: 971-22-0168-6. 2001. <https://bit.ly/3EdWDha>
52. Nimbrayan P, Athwal S, Bhatia J, Dalip K, Neeraj P. Profitability of rabi crops in Haryana. 2020;10:406-410.
53. GoH. Scaling-up Climate Resilient Agriculture Practices towards Climate Smart Villages in Haryana. Department of Agriculture, Government of Haryana. 2016. <https://bit.ly/3z0GpEo>
54. Iasexamportal.com. Soils of Madhya Pradesh. 2021. <https://bit.ly/3A69DD6>
55. Mpenvis.nic.in. Soils of Madhya Pradesh. 2021. <https://bit.ly/3z4opco>
56. Sitenxt.com. Soils of Madhya Pradesh. 2021. <https://bit.ly/2XdwL3W>
57. Dolr.gov.in. Soils of Madhya Pradesh. 2021. <https://bit.ly/3E7SP0J>
58. Crops harvested in Haryana. 2017. <https://bit.ly/391F2e1>
59. Madhyapradesh.pscnotes.com. Soils of Madhya Pradesh. 2021. <https://bit.ly/2XdbwPQ>
60. Krishi.icar.gov.in. Soils of Madhya Pradesh. 2021. <https://bit.ly/3k7D56m>
61. Singh RN, Singh S, Kumar B. Interaction effect of sulphur and boron on yield, nutrient uptake and quality of characters of soya-bean (Glycine max L. merill) grown in acidic upland soil. Journal of the Indian Society of Soil Science. 2006;54:516-518.
62. Singh S, Dey P, Kumar V, Singh Y, Latore A, Singh C, Kumar D, Kumar O, Yadav S, Varma S. Primary and Cationic Micronutrient Status of Soils in Few Districts of Eastern Uttar Pradesh. 2016;64:319-332. <https://bit.ly/3ntgcVv>
63. Chtenvis. What is Biodiversity. 2021. <https://bit.ly/3A2czAJ>
64. Karnataka. Karnataka.pscnotes.com. Karnataka soil. 2021. <https://bit.ly/2VBZJtX>
65. Sastri A, Naidu D, Choudhury S. Agro-topo Climatological studies for crop planning-A Case Study for the Northern Hills Agroclimatic Zones of Chhattisgarh state. Journal of Agrometerology. 2009;11(1):33-36.
66. Devdas D, Srivastava LK. To analyse major nutrients (N,P,K) in black soil of Chhattisgarh. 2013. <https://bit.ly/2XiFdIU>
67. Chtenvis. Soils in Chhattisgarh. 2021. <https://bit.ly/3hplIMg>
68. Huke RE, Das MN. "Odisha". Encyclopedia Britannica. 2020. <https://bit.ly/3k7rxQc>
69. Mishra A, Dash BB, Das D. Black soils of Orissa and their management. Orissa Rev. 2011;67:24-26.
70. Sarangi, Jena. Determination of critical limit of boron for rice, potato, groundnut in red and laterite soils of Odisha. 2016. <https://bit.ly/3C7k5Lm>
71. Prasad R, Ray SJ, Chandran P, Patil N, Bhattacharyya T. Characterization of soils along a toposequence in Chhattisgarh basin. 2013. doi: 10.13140/2.1.4816.0008.
72. Prasad R, Kumar D, Shivay YS, Rana DS. Boron in Indian agriculture—A review. Indian Journal of Agronomy. 2014;59(4):511-517. <https://bit.ly/392KxsU>
73. Bradford N. Strategy in agriculture sector for Orissa. 2016. <https://bit.ly/3A65nUk>
74. Ramana KV. Use of Geoinformatics for Agricultural Sector in the State of Andhra

- Pradesh. The Andhra Agric J. 2018;65(4): 754-759.
75. Srinivasan R, Reza SK, Nayak DC, Singh SK. Characterization and Classification of major vegetables grown in soils Odisha. 2015. <https://bit.ly/3nsMHL2>
 76. Viswanadham N. Food & Retail chain: case study of Andhra Pradesh and Punjab. 2006. <https://bit.ly/3C5ZRlc>
 77. Mol. Maps of India.com. Geography and History of Andhra Pradesh. 2021. <https://bit.ly/3hrSi01>
 78. Apenvis.nic.in. Environment Information System. 2021. <https://bit.ly/3tCEOn7>
 79. Sciencing.com. Different Soils of Andhra Pradesh. 2021. <https://bit.ly/3C8Mm4i>
 80. Sireesha A, Ramalakshmi S, Sreelatha T, Usharani T. Study on Soil Fertility Status in Sugarcane Growing Soils of Visakhapatnam District, Andhra Pradesh. Int J Curr Microbiol App Sci. 2021;10(03):285-289. doi: 10.20546/ijcmas.2021.1003.037
 81. Researchgate.net. Spatial Distribution of Soil Resources in the state of Andhra Pradesh. 2021. <https://bit.ly/3z8hpuO>
 82. Ramachandrapa BK, Thimmegowda MN. Soil Conservation, Crop Water Planning and its Use Efficiency in Rainfed Agriculture. Spec Publ Geol Soc India. 2016;5:29-35. doi: 10.17491/cgsi/2016/95946
 83. Narsaiah E, Raj GB, Prakash TR, Reddy DV, Patnaik MC. Land suitability evaluation for crops in Warangal district of Telangana under Raghunathapally division. Journal of Pharmacognosy and Phytochemistry. 2020;9(4):874-881. <https://bit.ly/3C43DeK>
 84. Narsaiah E, Ramprakash T, Chandinipatnaik M, Reddy DV, Bhupal RG. Characterization and classification of soils of Mahabubabad district in Telangana state. International Journal of Chemical Studies 2018;6(6):2828-2835. <https://bit.ly/3nG6C9t>
 85. Reddy SM. Soil site suitability for six major crops in Telangana region of Andhra Pradesh Journal of the Indian Society of Soil Science. 2004;52(3):220-225.
 86. Agrifarming. Agrifarming.in. Agricultural Farming In Karnataka, Cultivation of Crops. 2021a. <https://bit.ly/3EaE3GS>
 87. Agrifarming. Agrifarming.in. Spice Farming, Cultivation Practices. 2021b. <https://bit.ly/3k55DX0>
 88. Agrifarming.in. Agriculture farming in Telengana and schemes. 2021. <https://bit.ly/3A63zuk>
 89. Rao KC, Reddy SN. Department of Agriculture, Government of Telengana. 2021. <https://bit.ly/3EbPr57>
 90. Biswas H, Raizada A, Mandal D, Kumar S, Srinivas S, Mishra PK. Identification of areas vulnerable to soil erosion risk in India using GIS methods. Solid Earth. 2015;6:1247-1257. doi:10.5194/se-6-1247-2015
 91. Best smart learning aid. Study Material, Test Papers & Worksheets, Class IV: Science - Cultivation crops, Seeds, Pesticides.
 92. Mudde R. karnataka.com. Area of Karnataka. 2016. <https://bit.ly/3z8eK4i>
 93. Beeman K, Hegde R, Vasundhara R, Anil KS. Characterization and classification of soils of Bilalagodu micro watershed Chikmagalur district Karnataka. 2017. <https://bit.ly/3tJfPic>
 94. Bourgeon G. Explanatory booklet on the reconnaissance soil map of forest area- Karnataka and Goa. 2010. <https://bit.ly/3lmR8nV>
 95. Civilsdaily. Civilsdaily.com. Soils- Alluvial, Black, Red, and Laterite soils. 2017. <https://bit.ly/3k3cfw3>
 96. Patil S, Kokkuvayil AK. Characterization and Classification of Soils of West Coast of Southern Karnataka. 2014;408-413. <https://bit.ly/3zar7wS>
 97. Agropedia. Agropedia.iitk.ac.in. Soils of Karnataka. 2010. <https://bit.ly/3EaD61g>
 98. Madurkarnataka.com. Physiography of Karnataka. 2015. <https://bit.ly/3k3ynWX>
 99. Tractor junction. Top 10 Agricultural States in India – Largest Crop Producing States. 2020b. <https://bit.ly/3A8nngP>
 100. Tractor junction. Cotton Production in India-Process and Benefits of Cotton Farming. 2020a. <https://bit.ly/393u9sk>
 101. Fao. Fao.org. Coffee plant & site selection. 2021. <https://bit.ly/3E9Rirb>
 102. Springpot.com. What is the best soil for fruit trees? 2018. <https://bit.ly/3C2Acd5>
 103. Agricoop. Pocket book of agricultural statistics 2017. 2021 <https://bit.ly/3z3LdJ1>
 104. Agroclimatic Zones of Haryana. 2016. <https://bit.ly/3EcEtFN>
 105. Bharat BV, Maharjan B, Sharma S, Kaur S. Quality and Its Potential Indicators under Different Land Use Systems in the Shivaliks of Indian Punjab. 2020. <https://bit.ly/3EBAQXG>
 106. Chhattisgarh.pscnotes.com. Soil of Chhattisgarh. 2021. <https://bit.ly/3Ab08CH>
 107. Shamsudheen M, Dasog GS, Patil PL. Characterization and classification of some forest soils of North Karnataka. Agropedology. 2005;15(2):86-89. <https://bit.ly/3tDr0bT>
 108. Farming in Punjab. 2021. <https://bit.ly/3EaCusu>
 109. Halder D, Saha JK, Biswas A. Accumulation of essential and non-essential trace elements in rice grain: Possible health impacts on rice consumers in West Bengal, India. Sci Total Environ. 2020 Mar 1;706:135944. doi: 10.1016/j.scitotenv.2019.135944.
 110. Kalra. 2001. https://www.researchgate.net/figure/Soil-textural-classes-in-Haryana_fig1_40172117 Accessed on: 07.06.21
 111. National Informatics Centre. OdishaStatus of Agriculture in Odisha. 2008. <https://bit.ly/3C5swGP>
 112. National Informatics Centre. MP State Centre.Soil Science research in India.A Bibliography of IIS Scientists Research Contribution. 2008. <https://bit.ly/2YSdF4o>
 113. Pmfias.com. Major Soil Types of India: Red Soils, Lateritic Soils & Alkaline Soils. 2016. <https://bit.ly/3900Dlc>
 114. Pradhan A., T. Idol and P.K. Roul. 2016. Conservation Agriculture Practices in Rainfed Uplands of India Improve Maize-Based System Productivity and Profitability. Front Plant Sci. 15;7:1008. doi: 10.3389/fpls.2016.01008. PMID: 27471508; PMCID: PMC4945640.
 115. Raju S, Ayyar NP. Madhya Pradesh. Encyclopedia Britannica. 2020. <https://bit.ly/3C2PFd2>
 116. Sahu and Mishra. Soils of Orissa and its Management. 2005. <https://bit.ly/3zYxxAz>
 117. Sarkar D, Das BK, Datta R, Hazra A, Mandal G, Jayanta BS. Boron in soils and crops of West Bengal. 2012.
 118. Singh R, Chaudhari KS, Kundu KD, Sengar SS, Kumar A. Soils of Chhattisgarh: Characteristics and water Management Options. 2006. <https://bit.ly/3yTPQoX>
 119. Topographic division. 2021. <https://bit.ly/3tpDsfx>

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