Soil Taxonomy Categories

(10 marks question in ARS Mains 2017)

a) Higher Categories

1. **Order** – The **highest category** in the system *(SRF 2015)*
2. **Suborder** – Comparable to great soil groups of the genetic system
3. **Great Group** – A basic category, based on diagnostic subsurface horizons

b) Lower Categories

4. **Subgroup** – A new category designed to **define the central concept of Great Groups**
5. **Family** – A practical category for making predictions for land use plans
6. **Series** – The **lowest category** and the most specific category

S. No	Category	Differentiating Characteristics and Description
1	Order (12)	These are based largely on ***morphology***, as produced by soil-forming processes, and indicated by ***presence or absence of major diagnostic horizons***
2	Suborder (68)	These emphasize *genetic homogeneity*, *wetness*, climatic environment, parent material, and vegetational effects. The differentiate used vary, but ***most tend to emphasize wetness and moisture regime***
3	Great Group (300+ approx)	The ***major emphasis is on the diagnostic horizons*** (except in Entisols which have no such horizons) and ***presence or absence of diagnostic layers, base status, soil temperature and moisture regime (If not taken in suborder level)***
4	Subgroup (2000+)	Define central concept of great group
5	Family	***Texture***, mineralogical class (dominant of solum), soil temperature class and ***pH*** are used to differentiate families ***(IARI Ph.D 2017 and ARS 2015)***

Newly Proposed Soil order = Andisol and Gelisol

6	Series (200+ in India and12,000 in USA)	The series is a ***collection of soil individuals***, essentially uniform in differentiating characteristics (like colour, texture, structure, consistence, pH and EC) and in a arrangement of horizons.

[NOTE: Regular bit in IARI Ph.D, NET, SRF and ARS exam]

World : Entisol

Soil Orders

In Soil Taxonomy, there are 12 soil orders, including newly-proposed Andisol and Gelisol. **"A VAGAMI HOUSE"** phrase suggested facilitate naming of all the orders.

1. **Entisols** – These are ***recently developed*** mineral soil with ***no diagnostic*** horizon. The main feature of Entisols is a slight degree of soil formation, because of either limiting time or exceedingly unfavourable conditions.
   (ARS &NET 2015)

2. **Inceptisols** – These soils, representing ***early stage in soil formation.*** They may have some accumulation of clay in a subsurface horizon, but it is not sufficient enough to qualify argillic horizon, which is diagnostic for Alfisols and Ultisols. Inceptisols may have one or more diagnostic horizons (cambic, umbric or mollic) and do not have an argillic horizon.
   [NOTE: Inceptisol is dominant order in India]

3. **Vertisols** – These are uniform, thick (atleast 50 cm) tropical black and other dark colour, cracking clay mineral soils that have **high content (>30 %) of clay.** These soils swell on wetting and shrink on drying. The swell shrink process induces the development of wide, deep cracks associated with ***gilgai microrelief*** or intersecting ***slickensides***. **Smectite type (Montmorillonite) minerals dominant** in Vertisols and these soils are occur in peninsular India.
   Black colour - Mn, Ti (Titanium)
   (ARS Mains 2017)

4. **Mollisols** – These are soils of grassland vegetation under sub humid to humid environment. They have dark colour, well developed, **base rich (>50 %),** well structured (granular and crumby) surface horizon that is rich in organic matter (Mollic epipedon). In India these soils are dominantly observed in the ***'Tarai'***

region of Uttar Pradesh and Uttarakhand and occasionally to commonly in the Himalayas (kulu region) of Himachal Pradesh.

[**NOTE:** Mollisols of Russia country are called ***Chernozems***]

5. **Aridisols** – These soils are occur in arid climates and soils dry for most part of the year and we can observe salt accumulation at surface or subsurface (salic/ gypsic or calcic) horizon.

6. **Alfisols** – These are ***base rich soils (> 35 %)*** with clay enriched (Argillic) horizon and having evidence of clay illuviation. These soils ***more strongly weathered*** **than Inceptisols but less than Ultisols.**

7. **Spodosols** – These are mineral soils with **accumulation of sesquioxides and humus in the subsurface horizons.** The diagnostic feature of these soils is an illuvial horizon, enriched with free sesquioxides (Bs) and humus (Bh) underlying a bleached wood ash-colour eluvial E-horizon. Formed in cool, humid climate with siliceous parent material.

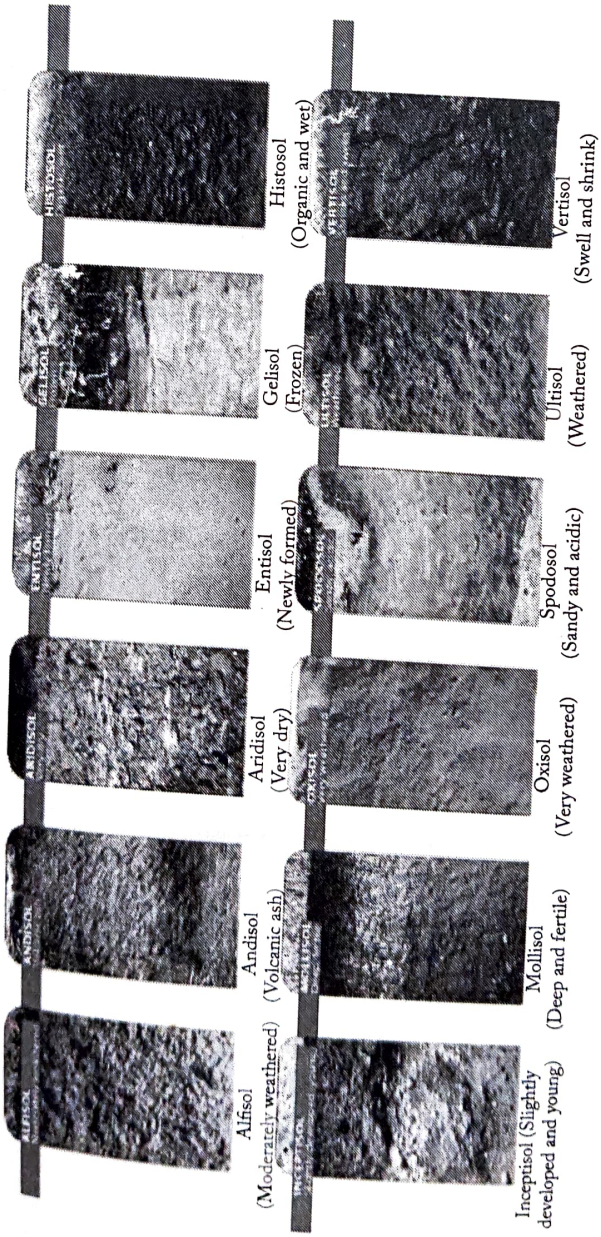
8. **Ultisols** – These soils are more comparable with Alfisols, except for having ***low (< 35 %) base saturation*** on the exchange complex, which is due to advance stage of weathering. These soils are characterized by a clay enriched subsurface argillic or kandic horizon. ***(ARS & NET 2017) & (ARS Mains 2017)***

9. **Oxisols** – These are ***strongly and deeply-weathered*** **(Highly weathered soils in the world)** mineral soils of the humid tropics with brick red colour and that are **poor in fertility.** These are characterized by ***uniform profile*** having negligible amounts of weatherable minerals and are dominated by the kaolinitic and sesquioxide–rich horizon (Oxic horizon. These soils are also called ***"chemically degraded"*** soils. ***(ARS & NET 2017)***

10. **Histosols** – These are ***organic matter rich*** (>20 %) soils with peaty horizon under permanent water saturated environment. In Histosols we can observe more organic matter addition than decomposition. They are soils that are commonly called ***bogs, moors*** or peats and mucks.

11. **Andisols** – These are the soils ***developed on volcanic ash.*** **Andisols were first reported in Japan and were named as volcanic ash material.** They are typically dark colour, with low bulk density (< 0.9 Mg/m^3) due to high content of Allophane minerals soils that do not have an albic horizon, but must have andic properties.

12. **Gelisols** – The order Gelisol is the **most recently introduced one.** These soils are show **evidence of cryoturbation,** i.e. frost churning or mixing. These soils are **not reported in India** but may occur in snow-covered Himalayas. ***(ARS Mains 2017)***



Soil Orders

Soils of India

India is situated between 8^0 and 37^0 N latitudes and 69^0 and 97^0 E longitudes. India has geographical area of 329 mha. Physiographically India divided into three broad regions namely, **Peninsula, Extra Peninsula and the Indo-Gangetic Plain** separating these two regions. Govindrajan (1965) divided the soils of India into 24 major soil groups. **Raychoudari and Govindarajan** (1971) revised the soil map of India into corresponding soil groups in the United States comprehensive system of soil classification.

[NOTE: *The first soil map of India was developed in 1932 by* ***Scholaskaya****, a Russian scientist]*

Azonal soil (without horizon)

1. **Alluvial Soils** – These soils covers ***largest area in the country*** and occupied ***113 M ha*** in the Indo-Gangetic plain, Brahmaputra valley and Coastal area. Alluvial soils are ***rich in plant nutrients*** (fairly sufficient in P and K) excepting ***low in nitrogen and organic carbon contents***. Soils are usually neutral to alkaline in reaction but it may be acidic in reaction in high rainfall zones like in Assam (Annual rainfall > 2000 mm). The most recent ***young alluvial*** soils are called ***"Khadar"*** and ***old alluvial*** soils are called ***"Bhangar". Illite is the dominant type of clay mineral in alluvial soils*** and these are classified as ***Entisols, Inceptisols***, Alfisols and Aridisols as per Taxonomy.

[NOTE: *Alluvial soils are dominant soils in India and most fertile soils too]*

2. **Black Soils (Black Cotton Soils or Self Mulching Soils)** – These are very dark, cracking, clay dominated soils. Black soils are locally called as ***"regur"*** (Central India), ***"karail"*** (U.P) and ***"bhal"*** (Gujrat). Black soils are developed from weathered alluvium of Deccan **Basalt or basic parent material** under arid, semi arid and sub-humid conditions. These soils are occupying in about 55 M ha and occur in Maharashtra (Dominant state), Madhya Pradesh and Gujarat etc. ***Swell shrink*** phenomena, deep wide cracks and ***slickensides*** are main features of black soils. Generally these soils are having high **clay varying from 30 - 80 %,** high CEC and base rich, calcareous and pH varies from 7.5 to 9.5. **Black colour of soil due to clay humus complexes and presence of titaniferrous magnetite mineral.** These soils are classified as Vertisols. Montmorillonite mineral is dominant type of clay mineral in black soils or Vertisols and these soils are ***do not exhibit any***

eluviation and illuviation process because of churning process.

3. **Red Soils** – Red soils are occupying about 85.7 M ha in the states of Tamil Nadu, Karnataka etc. These are well drained soils found in semi arid to warm humid tropical climates. These soils are generally **developed from granite** and metamorphic rocks like gneisses and schists. **The colour of red soil due to ferric oxides on soil particles rather than high Fe content- red when oxide is anhydrous (FeO- haematite) and yellow when hydrated (FeO-OH – limonite).** The pH of red soils is slightly acidic to slightly alkaline, low CEC and base saturation (lower than black and alluvial but more than laterite and lateritic soils). **Kaolinite is dominant type of clay mineral** in red soils and these soils are classified as Alfisols.

[NOTE: *Limonite is responsible for yellow colour and Haematite is responsible for red colour]*

S. No	Soil Type	Dominant Mineral
1	Red soil, Alfisols, Laterite and Lateritic soils	Kaolinite
2	Black soil or Vertisols	Montmorillonite
3	Alluvial soil	Illite

[NOTE: ***frequent bit in all exams]***

4. **Laterite and Lateritic Soils** – These soils are **formed by laterization** (alkali hydrolysis) process which means accumulation of sesquioxides and removal of silica. ***Buchanan*** (1807) a British geographer first coined the word laterite (Brick red) for highly ferruginous, vesicular deposits found in Malabar hills of Kerala. These soils are formed in tropical and subtropical climate with alternate wet and dry season. These soils are red in colour, high clay content, **deeply weathered and very deep.** Generally laterite soils having low CEC (due to kaolinite mineral presence) and low base saturation (20-40 %). Deficient in almost all nutrients ***(Multi-nutrient deficient soils)*** but can be managed well. **True laterite soils equivalent to Oxisol** in Soil Taxonomy but Oxisol are not found in India in spite of all the favourable conditions for its formation. Generally laterite soils have vesicular structure. Kaolinite is the dominant clay mineral of these soils and is formed due to ***neosynthesis***.

Laterite = require alternate wet and dry condition
base saturation 20-40%
Lateritic = x require
base saturation >40%.

[NOTE: *The lateritic soils do not require alternate wet and dry conditions and the ground water level may not be very near the surface. These soils having high base saturation (>40%) and kaolinite is the dominant clay mineral]*

5. **Salt-Affected Soils** – Salt –affected soils occur in arid and semi-arid climate (< 850 mm rainfall) and ***occupy about 6.74 Mha.***
(IARI Ph.D 2017) & (ARS NET 2017)

Soil characteristics	Saline soil	Alkali or Sodic soil	Saline-alkali soil
pH	<8.5	>8.5	<8.5
ECe	>4	<4	>4
ESP	<15	>15	>15
SAR	<13	>13	>13

6. **Desert Soils** – These are the soils of arid climate and occupy about 26.3 M ha in India. These soils are generally **low in nutrients, very less profile development** and water retention capacity and classified as Aridisols.
Ex: Western part of Rajasthan

7. **Forest and Hill Soils** – These soils are developed under forest canopy and generally these soils are found in Himachal Pradesh, Jammu and Kashmir, Uttarakhand etc. **"Brown forest soils"** under sub-humid to humid climate are neutral to slightly acidic, rich in organic carbon, moderate CEC (15-25 cmol $(p)^+ kg^{-1}$ and > 60 % base saturated and classified as Mollisols, Inceptisols and Entisols.

8. **Peat and Marshy Soils** – High organic matter with presence of pyrites (FeS_2) and generally developed under humid climate and occur in localized pockets of Kerala. These soils are generally submerged (reduced) but sulphuric acid is formed when oxidized and soil becomes extremely acidic (pH < 4). These soils are called acid sulphate soils or cat clays, **saline peat soils of Kerala are called "kari" soils (salts + organic matter).** Marshy soils are found in tidal swamps in West Bengal (Sunderbans).

Historical Developments in Soil Classification

Early Systems of Classification –

a. **Economic Classification** – Grouping of soils **based on taxation.**

b. **Physical Classification** – Grouping of soils **based on soil texture** (Ex: sandy soils, loamy soils)

c. **Chemical Classification** – Grouping of soils **based on their chemical composition** (Ex: Calcareous soils and acid soils)

d. **Geological Classification** – Residual or sedentary soils which are developed in situ from the underlying rocks and 'transported soils" developed from sediments like alluvium and colluvium.

e. **Physiographic Classification – Based on characteristics of landscapes** (Ex: levee, basin, terrace, mountain, valley, upland and lowland)

Modern System of Classification – The first classification of soil, as proposed by Dokuchaev (1900), divides soils into three categories - Normal, Transitional and Abnormal. These categories were later termed as Zonal, Intrazonal and Azonal soils, respectively.

1. **Zonal Soils** – ***Fully developed soil profiles***, which are in ***equilibrium with*** the *environmental conditions such as* ***climate and vegetation*** (Ex: Lateritic, Sierozem, Chestnut, Podzol and Red soils)

2. **Azonal Soils** – The soils, where ***time has been a limiting factor*** to develop horizons are termed as Azonal soils (Ex: Regosols, Alluvial soils and Lithosols)

3. **Intrazonal Soils** – If soil characteristics are ***modified by local conditions*** like ***topography, specific parent material*** etc such soils are termed as Intrazonal soils [Ex: Halomorphic (Saline and alkali soils), Hydromorphic and Calcimorphic]

[**NOTE 1:** Zonality concept was developed by Dokuchaev]

[**NOTE 2:** *frequent bit in all exams, especially examples for Zonal, Azonal and Intrazonal soils are very important]*

[**NOTE 3:** Father of Soil Taxonomy - Dokuchaev

Marbut's Morphogenetic System

At the highest category level, zonal soils were divided into 2 classes

- **Pedalfers** – *Accumulation of* ***Fe and Al*** *(Humid climate)*
- **Pedocals** – *Accumulation of* ***Calcium*** *Carbonate (Arid climate)*

✓ Some Important Points about Soil Classification

1. A new category, soil ***family was introduced*** between Great Soil Group and Soil Series by ***Baldwin and Associates.***

2. The USDA soil classification system was developed through several approximations from 1951 onwards and the ***7th approximation was published in 1960*** and through a series of 4 supplements from 1965 to 68 and was finally published as ***Soil Taxonomy in 1975***

3. The ***nomenclature of soil taxonomy*** is coined, largely from ***Greek and Latin*** roots that fit in any modern European language without translation.

4. ***Soil Taxonomy was adopted in India in 1969*** to classify the soils of India and since then, it has been introduced in the course curriculum of Agricultural Universities for teaching soil science.

Epipedons

The diagnostic surface horizons are called as ***epipedons***

Greek *Epi – Over, upon*

Pedon – soil

The epipedons are uppermost soil horizons and include the upper part of the soil darkened by organic matter. They are not synonymous with A-horizon. **Nine epipedons,** viz. Folistic, histic, melanic, mollic, anthropic, umbric, ochric, plaggen, and grassarenic but mollic, ochric and umbric epipedons are important in India.

1. ***Folistic Epipedon*** – **Never saturated with water** for more than 30 days in normal years, bulk density less than 0.1 Mg/m^3, organic carbon content 8 to 16% depending on clay content and most folistic epipedons comprise organic soil materials that remain saturated for 1 month.

2. ***Histic Epipedon*** - **>20-30 % organic matter** depending on clay content and remains saturated with water for 30 days or more during some season of the year, unless artificially drained. It is thinner than 30 cm if drained, or 45 cm if not drained.

   [NOTE: *The difference between folistic and histic epipedons, especially in terms of saturation with water]*

3. ***Melanic Epipedon*** - A thick black colour horizon at or near, but with in 30 cm of the soil surface and **having andic properties.** It contains 6% or more organic carbon as weighted average, and 4 % organic carbon in all layers. The deep black colour is due to the accumulation of organic matter resulting from root residues, supplied by gramminace-eous vegetation result in colour value and chroma of two or less.

4. ***Mollic Epipedon*** - A thick, dark colour, **soft mineral horizon** with **high (>50 %)**

base saturation and strong structure. It contains **1 % or more organic matter** and soil structure cannot be massive and hard, very hard or extremely hard when dry. This epipedon is not naturally dry in all parts for more than 9 months in a year, value < 5 and chroma < 3 and n value < 0.7.

[**NOTE:** *In each and every exam mollic epipedon bit compulsory regarding base saturation percentage*]

5. ***Anthropic Epipedon*** - A surface horizon, like the mollic, but **formed due to under continued system of farming or cultivation** that involves large addition of organic matter (compost). **It contains 1500 mg or more citric acid soluble P_2O_5 per kg soil.**

6. ***Umbric Epipedon*** – A surface horizon like mollic, but is **low (<50 %) in base saturation (dominantly saturated with H^+) with high C: N ratio.**

[**NOTE:** Remember mollic and umbric epipedon having same characteristics except in base saturation]

[*Mollic Epipedon - > 50 % base saturation*
Umbric Epipedon - <50 % base saturation] ***(ARS & NET 2015)***

7. ***Ochric Epipedon*** – A surface horizon that is **light in colour.** It contains less than 1 % organic matter and do not qualify for any other horizon.

7. Anthropic Epipedon

8. ***Plaggen Epipedon*** – A thick (> 50 cm) man-made surface horizon **produced by a long and continued manuring** with sod. It can be easily identified by artefacts, such as bits of brick, pottery, etc. It also shows spade marks. ***(ARS Mains 2017)***

[**NOTE:** Remember Anthropic and Plaggen both are manmade epipedons but anthropic formed due to continued farming or cultivation and plaggen epipedon formed due to continued manuring]

9. ***Grossarenic Epipedon*** – **A sandy horizon,** 100 cm or more thick over an argillic horizon.

Endopedons

The diagnostic subsurface horizons are called as endopedons. The characteristics of ***19 endopedons*** described below.

1. ***Argillic Horizon*** – **A silicate-clay-enriched B horizon with clay skins or clay films** formed by Illuviation of clay. The fine clay is carried downward by percolating water and is deposited as clay skins or cutans on ped faces and on the walls of pores. ***(ARS & NET 2017)***

2. ***Natric Horizon*** – A high **sodium-clay-enriched** horizon with columnar and prismatic structure.

3. ***Agric Horizon*** – An illuvial horizon of clay, silt and humus **formed directly under the plough layer due to long and continued cultivation** and it has thickness of 10 cm or more and 5 percent or more (by volume) wormholes. ***(ARS & NET 2014)***

4. ***Spodic Horizon*** – **A humus and /or sesquioxides** enriched subsurface horizon with or without iron.

5. ***Sombric Horizon*** – A free – draining horizon and formed due to **illuviation of humus** and not of aluminium or Na.

[NOTE: **Spodic horizon** – Both humus and sesquioxides enriched
Sombric – Only humus
Plinthite – Humus poor and sesquioxides rich]

6. ***Cambic Horizon*** – A colour or ***structural B- horizon*** formed **due to alteration** by the physical movement or chemical weathering. The horizon is extremely

variable in mineralogy because of its youthfulness, occurs under widely differing environment and may develop in the presence or absence of fluctuating ground water.

7. ***Kandic Horizon*** – A subsurface horizon of ***low activity clays*** with or without clay-skins. It has CEC, 16 c mol (p^+) kg^{-1} soil at pH 7 and effective CEC (ECEC) of < 12 c mol (p^+) kg^{-1} soil. **It does not show stratification.**

[**NOTE:** Altered or structural B-horizon – **Cambic**
Low activity of clay – **Kandic horizon**]

8. ***Oxic Horizon*** – A horizon enriched with Fe- and Al –oxides **with dominance of 1:1 type clay minerals (kaolinite)** and from where silica has leached. The increase in clay content gradual than Kandic horizon.

9. ***Sulphuric Horizon*** – A horizon that has **pH < 3.5,** is toxic to plant roots and has **yellow mottles of jarosite** ($KFe^{+3}_3 (OH)_6 (SO_4)_2$)

10. ***Salic Horizon*** – A horizon with **secondary accumulation of water soluble salts** ($NaCl, Na_2SO_4$) at some depth in soil profile. Salt percentage 60 or more. The salt content in terms of EC (electrical conductivity in a saturated paste should be 30 dS/m or more) ***(ARS & NET 2017)***

11. ***Albic Horizon*** – A **bleached E-horizon** of podzols and planosols

12. ***Glossic Horizon*** – A horizon which shows albic horizon characteristics gradually intruding into an argillic, kandic or a natric horizon and it is **partially altered or degraded argillic, kandic or natric horizon.**
(ARS& NET 2014) argillic, natric, kandic

13. ***Calcic Horizon*** - A horizon with secondary Ca- and /or Mg carbonate enriched materials.

14. ***Gypsic Horizon*** – Calcium and /or magnesium sulphate-enriched horizon

15. ***Petrocalcic Horizon*** – An indurated calcic horizon that has hardness of 3 or more (Moh's scale).

16. ***Petrogypsic Horizon*** – A strongly cemented gypsic horizon whose dry fragments do not slake in water.

17. ***Placic Horizon*** – **Slowly permeable**, dark reddish brown to black colour Fe or Mn pan that lies with 50 cm of the surface.

Important Terms

1. ***Cryoturbation (Frost Churning)*** – **It is the mixing of soil matrix with in a pedon** that results in irregular or broken horizons, accumulation of organic matter over the permafrost table, silt capping on rock fragments and oriented rock fragments.

2. ***Durinodes*** – These are weakly-cemented to indurated nodules, cemented by SiO_2

3. ***Duripan*** – It is a subsurface horizon at least ***half cemented by SiO_2***. The air-dry peds do not slake in water or HCl, but are destroyed by hot KOH after acid washing.
(ARS & NET 2015)

4. ***Fragipan*** – It is a **subsoil layer (s) of high bulk density.** It is ***brittle when moist,*** and very hard when dry. It does not soften on wetting, but can be broken by the hands. The air dry fragments slake in water.
[NOTE: *In each and every exam Duripan and Fragipan bit compulsory]*

5. ***Permafrost*** – It is a layer where soil **temperature is always < 0 °C.**

6. ***Plinthite*** – (Greek, *plinthose - brick*) – It is a ***humus poor, sesquioxides rich horizon.*** This horizon usually mottled with yellowish, greyish or white materials.

7. ***Tonguing*** – It is used when ***albic horizon material penetrates into an underlying argillic or natric*** horizon

8. ***Lithic Contact*** – A boundary between soil and continuous coherent, underlying material that has ***hardness of > 3 on Moh's scale*** and through which ***roots cannot penetrate.*** ***(ARS & NET 2015) & (ARS Mains 2015)***

9. ***Paralithic Contact*** – A boundary between soil and continuous non-coherent, underlying material that has ***hardness < 3 on Moh's scale***. The ***roots can penetrate,*** at irregular and infrequent intervals to 10 cm or more.
(ARS Mains 2015)

10. ***Petroferric Contact*** – A boundary between soil and an indurated layer of iron cemented material.

11. ***n value*** – It is used to predict ***degree of subsidence*** which is **(A-0.2 R) /(L + 3H)**

A = % of water in the field condition

R = (silt + sand) %

L = clay %

H = organic matter %

12. ***Slickensides*** – *Polished and grooved surfaces* developed by one soil mass sliding over another and common in *swelling clays soils.*

13. **COLE *(Coefficient of linear Extensibility)*** – Ratio of difference between moist length (L_m) at 33 kPa (moisture at field capacity) and dry length (L_d) to its dry length that is

$$\frac{L_m - L_d}{L_d} \times 100$$

Soil Moisture Regimes

Soil moisture regime refers to the presence or absence of water in a soil at different times of a year.

The broad soil moisture regimes, *viz.* aquic, udic, ustic, xeric, aridic, torric. The Soil Moisture Regime Map of India shows that **India is dominantly represented by "ustic" soil moisture regime covering almost three – fourth (72 %) followed by aridic (16 %) and udic (12 %).**

Ustic 72%. Xeric
aridic 16%. torric
udic 12%. aquic

Temperature Regimes

Soil temperature regimes play an important role in classifying soils at the ***Family and Suborder levels.*** There are ***seven*** soil temperature regimes, *viz. pargelic, cryic, frigid, mesic, thermic, hyperthermic and megathermic.*

Temperature Regimes

S. No	Temperature Regime	Features
1	Pargelic <0°c	The mean annual soil temperature is less than 0 °C
2	Cryic 0°-8°c	The mean annual soil temperature is more than 0 °C but less than 8 °C
3	Frigid <8°c >5°c	Mean annual soil temperature is less than 8 °C and the difference between mean winter and summer soil temperature is more than 5 °C
4	Mesic 8-15 >5°c	Mean annual soil temperature is from 8 °C to less than 15 °C and the difference between mean winter and summer soil temperature is more than 5 °C
5	Thermic 15-22 >5°c	Mean annual temperature is 15 °C or more, but less than 22 °C and the difference between mean winter and summer soil temperature is more than 5 °C
6	Hyperthermic 22	The mean annual soil temperature is 22 °C or more
7	Megathermic 28	The mean annual soil temperature is 28 °C

[NOTE: If the mean summer temperature for July and August and the mean winter temperature for December, January and February differ by less than 5 °C a prefix "Iso" is used, viz. Isofrigid, Isomesic, Isothermic, Isohyperthermic] ***(ARS & NET 2015)***

⇒ pH terms – Sorenson (1909)

1 Sep. 2021
7:10 am –

4 SOIL FERTILITY

⇒ pH is Physical phenomena given by = Marshall

Soil Fertility: The ability of soil to supply plant nutrients and water in adequate amounts and in suitable proportions is called soil fertility.

Soil Acidity – Soil acidification means an addition of acidity to the soil. Acidification occurs naturally but faulty agricultural practices also enhance this process. Soil ***pH is a measure of the soil solution's acidity or alkalinity.*** By definition, "***pH is the negative logarithm of the hydrogen ion activity of the soil solution***". Acid soils are less productive because of some soil-related constraints. These are toxicity of Al, deficiency of some plant nutrients, such as P, Ca, Mg, B, Mo and poor biological activity. It is possible to ameliorate soil acidity by application of lime at the time of sowing of crops. Another option to manage soil acidity is to grow crops, which are relatively tolerant and grow well under acidic environments.

Acid soil toxicity = Al

Soil pH –

Concept – The term pH first coined and used by ***Danish scientist, Sorenson in 1909.*** Soil pH measures the ***H^+ ion activity (Activity = Concentration x Activity coefficient)*** and is expressed in logarithmic terms. The practical significance of this is that, ***each***

1 unit pH change = 10 fold change Acidity or basicity

unit change in pH means a "ten-fold"(10 fold) change in the amount of acidity or basicity. It is given by expression

$$pH = \log 1/ [H^+] = -\log [H^+]$$

Where, H^+ ion concentration is expressed in ***moles per litre*** ($M\ L^{-1}$)

Water (H_2O) is both a weak acid and a weak base. The product of H^+ and OH^- concentration, is the dissociation constant of water (K_w) and is given by expression

$$K_w = [H^+]\ [OH^-] = [10^{-7}]\ [10^{-7}] = 10^{-14}$$

[**NOTE:** Thus ***pH scale*** for aquatic environment ***ranges from 0 to 14***, with 7 being neutral. Solutions with pH < 7.0 are acidic, and those with > 7.0 are basic or alkaline]

Soil pH determination – The pH of soil is ***measured by a pH meter.*** A pH meter is basically a high impedance amplifier, which accurately measures the minute electrode voltages and displays the results directly. A glass electrode in contact with H^+ ions of the solution acquires an electric potential, which depends on the concentration of H^+ ions. This is measured potentiometrically against a ***reference electrode, which is usually a Calomel electrode.*** The potential difference between glass and Calomel electrode is expressed as pH.

The electrode consists of ***mercury in contact with a solution of KCl saturated with mercurous chloride ($HgCl_2$).*** It maintains a constant potential at a given temperature. In commercial models, a paste of Hg and $HgCl_2$ is contained in an inner tube connected to KCl in an outer jacket. A lead-wire is connected to the $HgCl_2$ paste through a column of mercury. The outer tube ends in a fine capillary to provide a ***salt bridge*** through the test solution to the glass electrode. pH meter with combined electrode is available in digital type instrument.

[**NOTE 1:** pH slope will be **59 mV/unit** pH at 25 ^{0}C]

[**NOTE 2:** For measuring pH, the pH ***meter is calibrated by standard buffer solutions*** of pH ***4.0, 7.0 and 9.2,*** and generally pH measured in soil-water suspension (1:2.5 soil-water suspension ratio).

[**NOTE 3:** A solution with an H^+ ion activity of 0.001 M will have a pH of 3.0 and one with an H^+ ion activity of 0.0001 M having pH 4 and so on] ***(SRF 2015)***

[**NOTE 4:** If pH is 6.0 the H^+ ion concentration of OH^- ions will be $10^{-14}/10^{-6} = 10^{-8}$ M per litre]

[**NOTE 5:** At neutrality, the H^+ ion concentration is 0.0000001 M or 10^{-7} M per litre of solution]

[**NOTE 6:** The H^+ ion concentration has a ***ten-fold*** change between each whole pH number. Thus a soil of pH 5 has 100 times (10^2) more H^+ ions in soil solution than a soil solution with a pH of 7.0]

The relationship between H^+ ion concentration [H^+] and pH

Note:

$OH^- = \frac{10^{-14}}{pH}$

S.No	[H^+]	pH
1	1×10^{-0}	0
2	1×10^{-1}	1
3	1×10^{-2}	2
4	1×10^{-3}	3
5	1×10^{-4}	4
6	1×10^{-5}	5
7	1×10^{-6}	6
8	1×10^{-7}	7 (Neutral)
9	1×10^{-8}	8
10	1×10^{-9}	9
11	1×10^{-10}	10
12	1×10^{-11}	11
13	1×10^{-12}	12
14	1×10^{-13}	13
15	1×10^{-14}	14

Ranges in Soil Reaction – For mineral soils the extreme range in soil reaction or pH extends from 3.5 to 10.5. Some-times in peat soils, soil reaction or pH may be low to 3.0 or less and some alkali soils the reaction or pH may high as 11.0.

Degree of soil acidity and the pH range

S.No	Soil acidity	pH range
1	Extremely acidic	< 4.5
2	Very strongly acidic	4.5 – 5.0
3	Strongly acidic	5.1 – 5.5
4	Moderately acidic	5.6 – 6.0
5	Slightly acidic	6.1 – 6.5
6	Neutral	6.6 – 7.3

Sources of Soil Acidity

The important sources of soil acidity are ***exchangeable H^+ and Al^{+3}, Fe and Al oxides, soil organic matter and clay minerals.*** Some of the factors which are sources of acidity in soil described below

1. High Rainfall - Generally acid soils are common in regions where rainfall or precipitation is high enough to leach appreciable amounts of exchangeable bases from the surface soils and relatively insoluble compounds of Al and Fe remains in soil.

2. Parent Material – Some soils have developed from parent materials which are acid, such as ***granite*** and that may contribute to some extent soil acidity.

3. Acid Forming Fertilizers – The use of Ammonium sulphate $(NH_4)_2SO_4$ and Ammonium nitrate (NH_4NO_3) increases soil acidity.

4. Humus and Other Organic Acids – Humus materials in soils occur as a result of microbiological decomposition of organic matter and contain different functional groups like ***carboxylic (-COOH), phenolic (-OH)*** etc, which are capable

of attracting and dissociating hydrogen (H^+) ions. During decomposition of organic matter humus, organic acids and different acid salts may also be produced and also concentration of CO_2 increased. ***The increased concentration of CO_2, hydrolysis of acid salts and various organic acids combinedly increased the total acidity of soil.***

5. Carbondioxide (CO_2) – Soil containing high concentration of CO_2, the pH value of such soil will be low *i.e.* the soil become acidic. Root activity and metabolism may also serve as sources of CO_2 which ultimately helps the soil to become acidic.

Kinds of Acidity

There are 3 major forms of soil acidity namely, active acidity, exchangeable acidity and reserve acidity. If we add all three forms, it constitutes the total acidity of a soil. A less common form, but sometimes ***very important is the potential acidity,*** which can arise upon the oxidation of sulphur compounds in certain acid sulphate soils.

1. Active Acidity - The acidity which is develops ***due to hydrogen (H^+) and aluminium (Al^{+3}) ions concentration of the soil solution***. The ***magnitude*** of this acidity is ***limited.*** This ***pool is very small,*** compare to the exchangeable and residual pools. Active acidity is extremely important, because it determines the solubility of many substances and provides the soil solution environment to which plant roots and microbes are exposed. ***(ARS Mains 2017) & (ARS Mains 2015)***

2. Exchangeable Acidity or "Salt-Replaceable" Acidity - The acidity which is develops ***due to hydrogen (H^+) and aluminium (Al^{+3}) ions on the soil colloids.*** Magnitude of this acidity is very high. Exchangeable acidity very high in soils with moderate to strong acidity, and is difficult to neutralize. At a given pH, exchangeable acidity is generally highest for smectite (Montmorillonite), intermediate for vermiculite and lowest for kaolinite. ***(ARS Mains 2017) & (ARS Mains 2015)***

Montmorillonite > Vermiculite > Kaolinite

3. Residual Acidity – This acidity generally associated with H^+ and Al^{+3} ions (including Al-hydoxy ions *viz.* $Al(OH)^{2+}$ and $Al(OH)_2^+$ that are ***bound in non-exchangeable forms by clay and organic matter in the soil***). As pH increases, the bound hydrogen dissociates

and the bound aluminium ions are released and precipitate as amorphous $Al(OH)_3$. These changes free up the negative cation exchange sites and increase the CEC.

[**NOTE**: *The residual acidity is commonly far greater than the active or exchangeable acidity. It may be 1000 times greater than the active acidity in a sandy soil and 50,000 or even 1, 00,000 times greater in a clayey soil high in organic matter*]

Thus, Total acidity = Active acidity + Salt – replaceable (exchange) acidity + Residual acidity.

[~~NOTE~~: **pH measures active acidity of the soil**] ***(SRF 2015)***

Lime Potential – ***Schofield and Taylor in 1955*** proposed the use of ***0.01 M $CaCl_2$/ KCl*** solutions for obtaining stable readings in pH measurement. These scientists suggested that instead of using single ion activity (H^+) measurement, it is better to use ion activity ratios (H^+/Ca^{+2}) for the determination of soil acidity and base saturation. If the soil exchange complex is saturated with both H^+ and Ca^{+2} ions, then at equilibrium as per Schofield's ratio law. ***$pH^{-1/2}$ pCa is termed as lime potential***. It characterizes the composition of the exchange complex with respect to its saturation by H^+ and Ca^{+2} ions.

[**NOTE**: *Hydrogen ions contribute soil acidity directly and Al ions do so indirectly through hydrolysis*]

[**NOTE**: *As a result of soil reduction, the nutrient elements like Mn^{+4} and Fe^{+3} reduced to Mn^{+2} and Fe^{+2} respectively and increases their concentration to a very high and toxicity of those elements develops. Due to such toxic effects (Both Fe and Mn), a* ***physiological disease of rice found in submerged soils*** *which popularly is known as* ***"Browning disease"***]

Liming of Acid Soils – A liming material is defined a material, ***whose Ca and Mg compounds are capable of neutralizing soil acidity***. Application of lime to neutralize exchangeable Al^{+3} helps in raising the pH of acid soils for improved availability of plant nutrients, reduced toxicity of aluminium and iron etc.

Limestone = Calcite & Dolomite

Reaction of Lime in Soil – Lime, when applied to acidic soils, either in the form of oxide, hydroxide or carbonate, reacts with carbon dioxide and water to form bicarbonates.

$$CaO + H_2O + 2CO_2 \rightarrow Ca(HCO_3)_2$$

$$Ca(OH)_2 + 2CO_2 \rightarrow Ca(HCO_3)_2$$

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$$

These liming materials, on reaction with soil colloids, replace H^+ and Al^{+3} ions from the colloidal phase to the soil solution.

Lime requirement – The ***amount of liming material that must be added to raise the pH to some prescribed value.*** This value is usually in the range of ***pH 6.0 to 7.0,*** since this is an easily attainable value within the optimum range of most crop plants. ***(IARI Ph.D 2013-14)***

Principles of Liming Reactions – Lime reaction in soils depends upon the nature and the fineness of the liming materials. Lime is usually applied to soils in the form of ground limestone. Limestones can be classified as calcite($CaCO_3$), dolomite ($CaCO_3.MgCO_3$) or a mixture of the two. Both of these limestone are sparingly soluble in pure water but do become soluble in water containing carbondioxide. The greater the partial pressure of carbon dioxide in the system, more soluble the limestone becomes. Dolomite is somewhat less soluble than calcite.

Crops like ***pigeon pea, soybean and cotton*** are ***highly responsive*** to lime application, while ***chickpea, pea, groundnut, maize and sorghum*** are ***medium in response*** and small ***millets, rice, potato*** etc. have ***low response.*** Crops like tea and coffee favour acidic soil environment for growth.

Determination of Lime Requirement – Common methods to estimate lime requirement, are based on the change in pH of a buffered solution added to a soil. ***When a buffer solution (pH usually >/or = 7.3)*** is added to an acid soil, the buffer pH is depressed in proportion to the original soil pH and its buffering capacity. A large drop in buffer pH would indicate a low pH soil with large reserve acidity, and a high

Lime requirement = Shoemaker

lime requirement. From filed and laboratory calibration of the decrease in buffer pH, the amount of lime required to increase the soil pH to the desired level (LR) can be determined. The buffer solutions used are generally a mixture of two or more buffers. Common methods for the determination of lime requirement of soils are ***Shoemaker, McLean and Pratt (SMP) buffer method, Mehlich buffer method, Woodruff, Adams and Evans method***, etc. The ***SMP buffer method is widely used for soils with high exchangeable Al and high LR***. In this method, 5 ml of distilled water and 10 ml of extractant buffer (1.8 g nitrophenol, 2.5 mL triethanolamine, 3 g potassium chromate, 2 g calcium acetate and 53.2 g calcium chloride dehydrate, are dissolved in one litre of water and ***pH adjusted to 7.5 with dilute NaOH solution***) are added to 5 g of soil. It is then stirred continuously for 10 minutes or intermittently for 20 minutes and the pH of the suspension is determined by a pH meter. In ***Mehlich method $BaCl_2$-TEA buffer solution of pH 8.0*** is shaken with the soil and the amount of acidity reacting with the buffer is determined by titrating a fresh sample of buffer with acid down to the measured pH of the soil + buffer.

Liming Materials - Common lime sources are calcite and dolomite. But, both these have industrial uses, and thus are costly. Industrial wastes e.g. basic slag from steel industry, paper mill sludges from paper mills, carbonated ***pressmud from sugar industry*** are reported to be effective as amendments. Basic slag (calcium silicate) generated by steel plants contains 24 -50 % CaO, 2 to 10 % MgO and 1 to 2 % P_2O_5. Pressmud has a pH of 6.5-6.9 ad 16-18 % organic carbon. Though the neutralizing value of pressmud is low (22-24 %), but its high organic carbon content help in amelioration of soil acidity.

Neutralizing Value and Effectiveness – The calcium carbonate equivalent (CCE) is defined as the acid neutralizing capacity of a liming material expressed as a weight percentage of $CaCO_3$. Liming materials with atleast 50 % of the particles small enough to pass through a 60-mesh screen (smaller than 0.25 mm in diameter) are satisfactory for most liming purposes.

Pressmud (Sugar industry) - pH 6.5 - 6.9, 16-18% OC
Neutralizing value 22-24%

Basic slag (Calcium silicate) - CaO 24-50%
MgO

S.No	Liming materials	Neutralizing value of CCE (%)
1	Calcium oxide (CaO)	179 *(SRF 2015 & ARS NET 2017)*
2	Calcium hydroxide ($Ca(OH)_2$)	136
3	Dolomite ($CaCO_3.MgCO_3$)	108.7
4	Calcite ($CaCO_3$)	100
5	Basic slag ($CaSiO_3$)	86

[NOTE: *Blast furnace slag and Electric furnace slag also used as liming materials*]

Burned lime or "quick lime" (CaO) – It is normally produced by heating limestone and dolomite.

$$CaCO_3 + Heat \rightarrow CaO + CO_2 \uparrow$$

$$Ca\ Mg\ (CO_3)_2 + Heat \rightarrow CaO + MgO + 2\ CO_2 \uparrow$$

"Slaked lime" ($Ca(OH)_2$) – It can be produced by adding of water to burned lime.

$$CaO + H_2O \rightarrow Ca\ (OH)_2$$

S.No	High lime requirement crops	Medium lime requirement crops	Low lime requirement crops	Very low lime requirement crops
1	Alfalfa	Black berry	Oats	Coffee
2	Barley	Cabbage	Potato	Napier grass
3	Spinach	Corn	Pea nut	Pine apple
4	Cotton	Sorghum	Rasp berry	Tea
5	Pea	Lettuce	Rice	Stylosanthes
6	Soybean	Peanut	Rye	-
7	Sugar beet	Sweet potato	Straw berry	-
8	Sunflower	Wheat	Water melon	-

S.No	Crop	Optimum soil reaction (pH)
1	Rice	4.0 – 6.0
2	Maize	6.0 – 7.5
3	Sorghum	4.0 – 6.5
4	Barley	6.0 – 7.5
5	Soybean	5.5 – 7.0
6	Potato	5.0 – 5.5 *(ARS & NET 2015)*
7	Tea	4.0 – 6.0

Rice Tea - 4-6
Sorghum - 4-6.5
Potato 5-5.5
Soybean 5.5-7.5
Maize, barley 6-7.5

Neutralizing Value (N. V.) or Calcium Carbonate Equivalent (CCE) -

$$\text{CCE of a liming material} = \frac{\text{Molecular weight of } CaCO_3}{\text{Molecular weight of a liming material}} \times 100$$

Problem – Calculate the calcium carbonate equivalent (CCE) of dolomite.

Molecular weight of $CaCO_3$ = 100

Molecular weight of dolomite = 184/2 = 92

So, CCE of dolomite = 100/92 x 100 = 108.7

Effective Calcium Carbonate (ECC) or Neutralizing Index (NI) -

Percent ECC or N.I = CCE x fineness factor

Liming Factor - The factor by which actual amount of lime can be calculated from the estimated theoretical amount of lime. This ***factor is varies from 1 to 3,*** depending on rate of limestone solution, plant uptake and leaching during the reaction period. A liming factor of ***1.5 to 2.0 is generally used.***

☆☆☆

Over liming – When large amounts of lime applied which leads to one or many of these following causes.

1. Deficiency of Fe, Cu and Zn will occur.
2. Phosphorus and potassium availability will be reduced.
3. Due to application of lime in excess, the incidence of diseases like **scab in root** crops will be increased.

[**NOTE:** *Club root disease of cole crops can be reduced with the application of lime*]

Acid Sulphate Soils – Soils with sufficient sulphides (FeS_2) to become strongly acidic when drained and aerated enough for cultivation are termed as acid sulphate soils or as the ***Dutch*** refers to those soils "***cat clays***". Generally ***acid sulphate soils formed due to oxidation of sulphides*** in soil. Below 4.0 pH, the bacteria "***Thiobacillus ferroxidans***" are the most active oxidizers and the activity builds up rapidly. These soils are generally more acidic (< 4.0 pH). Acid sulphate soils occur more or less in parts of ***Kerala*** (Kari soils), ***Tamil Nadu,*** and ***Indian Sunderbans*** (parts of ***West Bengal*** and mangrove areas of Andaman & Nicobar Islands). The acid sulphate soils in addition to having pH less than 4 under "***aerobic condition***" is associated with ***yellow mottles*** or ***coatings of Jarosite and deposition of ochre*** in the soil or in drainage waters. Sometimes, in poorly drained soils, Jarosite cannot be seen even under severely acid conditions. ***(IARI Ph. D 2017)***

$$2S + 3O_2 + 2H_2O \rightarrow H_2SO_4$$

$$H_2S + 2O_2 \rightarrow H_2SO_4$$

[**NOTE**: *Both are due to microbial oxidation*]

Potential Acid Sulphate Soils – Potential acid sulphate soils are ***not acid but will become acid if they are drained***. Typically, they are ***immature***, saline and give off a strong smell of hydrogen sulphide when disturbed.

[**NOTE:** In general, ***bacteria prefer near neutral to slightly alkaline*** reaction between pH 6.5 and 8.0, the activity being sharply curtailed when the pH drops below 5.5. ***Fungi grow in acidic reaction between pH 4.5 and 6.5*** and ***actinomycetes prefer slightly alkaline*** conditions]

[**NOTE:** *Jarosites can be occur in acid sulphate soils under aerobic conditions only*]

[**NOTE:** *Saline peat soils of Kerala are called Kari soils (Mixture of organic matter and salts)*]

[**NOTE:** *Hydrogen sulphide (H_2S) often formed in low land rice soils causing* ***"akiochi"*** *disease that prevents rice plant roots from absorbing nutrients*]
(ARS & NET 2015)

Buffering Capacity

The ***capacity of soil tolerance to changes in pH*** of a soil solution is called buffering capacity (or) the ability of the soil to re-supply an ion to the soil solution. The degree of ***buffering capacity is highest between pH 4.5 and 6.0*** and drops below pH 4.5 and above pH 6.0. Buffering capacity depends on following factors -

1. Clay content – Soils containing large amounts of 1:1 type of clays are generally less strongly buffered than soils in which the predominant clay minerals are of 2:1 type (Montmorillonite > Kaolinite).

2. CEC (Cation Exchange Capacity) – Buffering capacity increasing with increase in CEC.

3. Organic matter – Soils containing large amounts of organic matter and clay are said to be ***highly buffered*** and ***require large amounts of lime*** for affecting a certain change in pH than acid soils containing smaller amounts of clay and organic matter.

[**NOTE:** *Soils containing large amounts of calcium carbonate, organic acids and phosphates shows higher buffering capacity*]

Importance of Buffering Capacity

1. Buffering tends to ensure some **stability in soil pH**, preventing drastic fluctuation that might be harmful for plants, micro-organisms and aquatic ecosystems. This is

also likely to reduce the adverse impact of soil pollution, acid rain, or continuous use of acid-forming N-fertilizers.

2. Buffering influences the amount of amendments, such as lime (acid soils) or Sulphur/gypsum (in alkali soils) required to bring about a desired change in soil pH.

Soil Reaction on Nutrient Availability – Primary and secondary nutrients ***nitrogen, phosphorus, calcium and magnesium*** are as available as or ***more available at a pH of 5.5 and 6.5*** for organic and mineral soils than at any other pH. ***Molybdenum availability is significantly dependent on pH.*** In ***strongly acid soils it is quite unavailable.*** However, ***molybdenum, boron, and copper availabilities are also relatively high at a range of pH 5.5 to 6.5.*** The micro nutrients like Fe, Mn and Zn are less available at pH of 5.5 and 6.5 than at more acidic conditions.

Soil Salinity and Alkalinity

The extent of soil Salinization and/or sodication depends on the type and amount of salts, their relative abundance in the soil, degree of solubility and effect on soil pH. For example, **in 1 litre of pure water 710 g of Epsom salt ($MgSO_4 . 7H_2O$), followed by 357 g of table salt (NaCl) could be dissolved.** The solubility of calcite ($CaCO_3$) is very low (0.013g L^{-1}), which increases with increase in partial pressure of CO_2 and decrease in pH of the soil.

[**NOTE:** The solubility of gypsum increases in the presence of NaCl thus, in salt-affected soils, the amount of gypsum in solution could be potentially ***three times*** as much as in non-saline soil.]

Distribution of Salt-Affected Soils – ***Globally, more than 800 million hectares*** (Mha) of land are estimated to be salt-affected (FAO 2008). It has been estimated that about ***7 Mha of land in India*** are salt affected that is saline and alkali soils. The states of ***Gujarat (2.20 Mha)*** and ***Uttar Pradesh (1.37 Mha)*** in India have the largest area under salt-affected soils.

[**NOTE:** ***Mica (Illite) is the dominant clay mineral followed by kaolinite in the salt-affected soils of Indo-Gangetic Plains.*** *Salt affected black soils are rich in swelling and shrinkage minerals, i.e. Smectites. In addition to the dominance of montmorillonite, these soils also contain varying amounts of chlorite, illite and kaolinite minerals depending upon the type of geological formation and history of soil development*]

Sources of Soluble Salts

1. Primary minerals - During the process of chemical weathering, which involves hydrolysis, hydration, solution, oxidation, reduction and carbonation, various constituents like Ca^{+2}, Mg^{+2} and Na^{+} are gradually released and made soluble.

2. Arid and Semi-arid regions – Salt-affected soils are mostly formed in arid and semi-arid regions where low rainfall and high evaporation prevails. The low rainfall or precipitation in these regions is not sufficient to leach down salts to the deeper layers of soil. Coupled with it, high evaporation in these areas results in the accumulation of large amount of slats in the root zone. Accumulation of salts has been found to increase with increase in dryness of the area.

3. Basic fertilizers – Use of basic fertilizers like **sodium nitrate ($NaNO_3$), basic slag** may develop alkalinity.

4. Ocean or Sea water – Sea water enters into the land by inundation and deposited on the soil surface as salts.

5. Irrigation water – The application of irrigation water without proper management (*i.e.* lack of drainage and leaching facilitates) increases the water table and surface salt content.

6. Salts blown by wind – In arid regions near the sea, appreciable amount of salts are blown by wind year after year and get deposited on the surface of the soil. The salinity of Rajasthan are mostly developed through this source.

The major constituents of dissolved salts in soil are the cations, *viz.* sodium (Na^{+}),

calcium (Ca^{+2}) and magnesium (Mg^{+2}), and the anions *viz.* Chloride (Cl^{-}), sulphate (SO_4^{-2}), carbonate (CO_3^{-2}) and bicarbonate (HCO_3^{-}). ***The salinity can be expressed as electrical conductivity (EC)*** of the irrigation water (ECw), the soil water (ECss) or the saturated soil extract (ECe). ***Sodicity is measured in the soil by exchangeable sodium percentage (ESP) and in soil solution by sodium adsorption ratio (SAR).***

[NOTE: 4 dSm^{-1} equal to 0.4 Sm^{-1} and 4 mmhos cm^{-1}]

Classification of Salt-Affected Soils

Salt-affected soil	Soil pH	Electrical conductivity (ECe) (dSm^{-1})	Sodium adsorption ratio (SAR)	Exchangeable sodium percentage (ESP)	Electro neutrality ratio (ER)	Typical physical condition (soil structure)
Saline	<8.5	>4	<13	<15	<1.0	Flocculated
Sodic	>8.5	<4	>13	>15	>1.0	Dispersed
Saline-sodic	**<8.5**	>4	>13	>15	>1.0	Flocculated

[NOTE: Electro neutrality ratio = $[Na^{+}] / ([Cl^{-}] + [SO_4^{-2}])$

[**NOTE:** Total soluble salt content (%) in saline soils is > 0.1, < 0.1 in sodic soils and >0.1 in saline sodic soils and if the salt content is more than 0.1 % which is injurious to plant growth]

The total salt concentration in the soils can be easily determined and expressed as EC or EC_e, because electrical conductance is directly related to salt concentration in the soil solution. The electrical conductivity is expressed as millimohs/cm at 25 ^{0}C or deci-Siemens/metre at 25 ^{0}C. In SI units, the unit of electrical conductivity is Siemens, **1S (Siemen) = 1 mho, so that 1dS/m = 1 mmho/cm and 1000 µmhos/cm.** The EC values and other soluble slats relationships in the soil solutions are given below.

1. For soil solutions having EC ranging from 0.1 to 5 dS/m

a) Total dissolved solids (mg/L) = EC (dS/m) x 640

b) Sum of soluble cations or anions [mmol (+ or -) /L) = EC (dS/m) x 10]

2. For soil solutions having EC ranging from 3.0 to 30 dS/m

c) OP (bars) = EC (dS/m) x (-0.36)

[**NOTE:** Here OP means osmotic potential or the negative of osmotic pressure of solution which directly measures the effect of salinity on plant growth]

[**NOTE:** Mg^{+2} has 27 times greater Flocculating power relative to Na and Ca^{+2} has 43 times greater Flocculating power than Na.]

1. Saline Soils – These soils contain sufficient neutral soluble slats which adversely affect the growth of most crop plants. The soluble salts are chiefly ***sodium chloride*** and ***sodium sulphate***. But, saline soils also contain appreciable quantities of chlorides and sulphates of Ca^{+2} and Mg^{+2}. These soils are characterized by ***electrical conductivity*** of the saturated extract (ECe) ***more than 4 dSm^{-1}*** at 25 ^{0}C and ***exchangeable sodium percentage (ESP) less than 15*** and ***sodium adsorption ratio (SAR) less than 13***. The soil ***pH is less than 8.5***. Because of the presence of excess salts and low amounts of Na^+ ion on exchange sites, these soils are ***usually in a flocculated state*** and their ***permeability is considered to be equal to or higher than the normal soils.*** Most of these soils have ***salt efflorescence*** or ***white encrustation*** of soluble slats at the surface, In India these soils are known by different names such as "***Thur***" in Punjab, "***Reh***" in Uttar Pradesh and "***Luni***" in Rajasthan. The relative difficulty with which common cations can be replaced or removed from the exchange complex, leading to increased flocculation of the clay particles, is in the following order $Al^{+3} > Ca^{+2} > Mg^{+2} > K^+ > Na^+$. In the reverse order, these cations will cause dispersion of clay particles, which is a typical property of alkali soils.

[**NOTE:** Saline soils are also called "***White alkali soils***" and "***Solonchaks***". The concentration of potassium is generally low in saline soils. Excessive concentrations of boron, fluoride and nitrates also be present in these soils under arid conditions]

2. Sodic Soils – These soils contain sodium salts capable of causing ***alkaline hydrolysis***, ***mainly Na_2CO_3***. Such soils were termed as the "***alkali soils***". The sodic soils have ***ECe less than 4 dSm^{-1}*** at 25 ^{0}C, ***ESP more than 15*** and ***SAR more than 13***. Most of the sodium is in exchangeable form. Very small amounts of free salts are present in

soil solution. ***The soil pH is more than 8.5.*** As a result of irrigation, strongly alkaline conditions may develop in these soils and ***pH values reaching or exceeding 10 are common.*** When organic matter is dispersed and deposited on the surface, sodic soils appear brown-black and are sometimes known as "***black alkali soils***". These soils are also known as "***Kallar***" in Punjab, "***Usar***" in Uttar Pradesh and "***Kshar***" in Gujrat. ***(ARS & NET 2017)***

[**NOTE:** Alkali soils are also called "***sodic soils***" or "***black alkali soils***" or "***solonetz***" or "***solods***"]

3. Saline-Sodic Soils – These soils have high concentration of neutral salts and appreciable sodium on the exchangeable complex. The saline-sodic soils have ***ECe more than 4 dSm^{-1}*** at 25°C, ***ESP more than 15*** and ***SAR more than 13***. In these soils, both free salts and exchangeable Na^+ are present. Excess salts present in the soil keep the soil flocculated and the soil ***pH is normally less than 8.5***. Upon leaching, when free salt content decreases, these soils may behave like a sodic soil (pH > 8.5) because of the hydrolysis of exchangeable Na^+.

[**NOTE:** Based on Indian experience, saline and sodic soils are distinguished on the basis of preponderance of chlorides and sulphates over that of sodium. If $[Na^+] / ([Cl^-] + [SO_4^{-2}])$ ratio is less than 1 and pH of saturated soil paste (pHs) is less than 8.2, the soil is designated as saline and if $[Na^+] / ([Cl^-] + [SO_4^{-2}])$ ratio of is more than 1.0 and pHs is more than 8.2, soil is defined as the sodic]

Slick spots – If the sodic soils occur in small areas (in localized spots) are often called as "slick spots".

Solodisation – The process of ***break-down of H-clay under alkaline condition*** is known as solodisation.

Degraded Alkali Soils – If extensive leaching of a saline-sodic soil occurs in the absence of any source of calcium or magnesium, part of the **exchangeable sodium is gradually replaced by hydrogen.** Such soil may be slightly acidic in nature, yet it may contain enough sodium to give it an unstable structure. Such a soil designated as a degraded sodic soil, earlier known as degraded alkali soil.

S. No	Unit conversion	Factor
1	$mScm^{-1}$ to dSm^{-1}	x 1
2	mmho cm^{-1} to dSm^{-1}	x 1
3	mSm^{-1} to dSm^{-1}	x 0.01
4	μScm^{-1} to dSm^{-1}	x 0.001
5	µmho cm^{-1} to dSm^{-1}	x 0.001
6	meq L^{-1} to dSm^{-1}	x 0.10

$mS\,cm^{-1}$ 1
mmhos cm^{-1} 1
$meq\,L^{-1}$ .1
mSm^{-1} .01
μScm^{-1} .001
$\mu mho\,cm^{-1}$ .001

Exchangeable Sodium Percentage – The exchangeable sodium percentage (ESP) corresponds to the amount of adsorbed sodium, compared to the CEC and is expressed as

$$ESP = \frac{\text{Exch. Na}}{\text{CEC}} \times 100$$

ESP = Exchangeable Na/CEC x 100

Sodium Adsorption Ratio – It is derived from the concentrations of sodium, calcium and magnesium in the soil solution.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Carbonic acid H_2CO_3

Calcareous Soils – Zonal soils of arid regions usually contain ***sufficient amount of lime ($CaCO_3$)*** at some horizons of the soil profile. The ***pH of calcareous soils is usually above 7.0 and may be as high as 8.5***. This variation is due to ***partial pressure of CO_2 being high*** and ***formation of undissociated carbonic acid***, so that hydrolysis of $CaCO_3$ is reduced. The lowering of partial pressure of CO_2 on dilution of soil suspension raises the pH of calcareous soils. Soils high in lime are frequently productive for many ordinary field crops, including most forage crops, corn cotton, sugar beets, potatoes and tomatoes.

Reclamation and Management of Salt-affected Soils

1. Physical Reclamation – Physical reclamation methods include deep-ploughing, sub-soiling, profile inversion, sanding, flushing and scrapping.

a) Deep ploughing and Sub-soiling – These two methods mechanically **break the impermeable layer,** cemented sub-soil layer or hardpan in the soil profile at some depth to enhance the infiltration and transportation of salts dissolved in water to deeper soil layers.

b) Profile inversion – It can be employed in situations where **surface soil is relatively free of salts and Na but soil below is sodic, saline or saline-sodic.** In this method, good surface soil is retained while the salty sub-soil is inverted down the profile. It is, however a cumbersome procedure. Hence it is not followed by farmers.

c) Sanding (Marling) – Sometimes **sand is mixed in the salt-affected soil** to improve permeability and air water relations in the root zone.

d) Flushing – Flushing involves washing away the surface accumulated salts by flushing water over the surface. It is sometimes used to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from the soil is rather small, this method does not have much practical significance.

e) Scrapping – Removal of few centimetres of salt encrustation is called scrapping. It might temporarily improve crop growth, but the ultimate disposal of salts still poses a major problem. Also this method ***fails to give permanent solution under shallow water table*** conditions where salts can again rise and accumulate at the surface due to evapotranspiration.

Reclamation or Amelioration of Saline and Sodic Soils

1. Reclamation of Saline soils

Leaching: - The main objective in reclamation of these soils is **to leach the salts below the root zone** (hence, drainage system should be installed if necessary). Leaching requirement (LR) has been defined as that fraction of water that must be leached through the root zone to control soil salinity at a specified level. This is achieved by flooding and draining. To make it effective, bunds are raised around plots prepared and water is applied depending on their water requirement to leach salts.

$LR = \frac{EC_{iw}}{EC_{dw}} \times 100$

LR % (Leaching Requirement) = EC_{iw}/EC_{dw} x 100

Here, ECiw = EC of irrigation of water in inches

ECdw = EC of drainage water in inches

Problem – Calculate the leaching requirement (LR) of irrigation water having electrical conductivity of 5 dSm^{-1} and electrical conductivity of drainage water is 10 dsm^{-1}. *(ARS & NET 2015)*

LR (%) = EC_{iw}/EC_{dw} x 100

= 5/10 x 100

= 50 percent

2. Reclamation of Sodic or Alkali Soils – Reclamation of sodic soil requires removal of part or most of the exchangeable sodium, improvement of the soil physical structure and lowering of the soil pH. The exchangeable sodium is replaced by the more favourable calcium (Gypsum) ions according to the exchange reaction given in equation and the sodium thus exchanged is leached out of the root zone.

$$2\ Na\text{-}X + Ca^{+2}\ (solution) = Ca\text{-}X + 2\ Na^{+}\ (solution) \downarrow$$

Where, X is the exchange complex of the soil.

Chemical reactions of Gypsum and Calcium chloride for sodic soils

1. Gypsum –

$$CaSO_4 + 2NaX = CaX + Na_2SO_4\ (Leachable) \downarrow$$

2. Calcium chloride –

$$CaCl_2 + 2\ NaX = CaX + 2\ NaCl\ (Leachable) \downarrow$$

Application of Gypsum – Gypsum normally applied broadcast and then incorporated into the soil by disking or ploughing as it is more effective in the removal of exchangeable sodium than when applied on the soil surface. Mixing limited quantities

of gypsum in shallower depths is more beneficial than mixing it with deeper depths. Deeper mixing exposes gypsum to react with Na_2CO_3 of the soil resulting in lesser reduction in ESP throughout depth. In shallow mixing, soluble carbonates move down with the wetting front without reacting with applied gypsum.

Gypsum Requirement – The ***quantity of gypsum or any amendment necessary to reclaim sodic soil*** depends on the total quantity of sodium that must be replaced.

If it is desired to replace larger quantities of adsorbed sodium, the quantity of gypsum can be accordingly increased. Quantities of other amendments relative to gypsum given below -

S.No	Amendment	Relative quantity (tons)
1	Gypsum ($CaSO_4$ $2H_2O$)	1.00
2	Calcium chloride ($CaCl_2$. $2H_2O$)	0.85
3	Sulphuric acid (H_2SO_4)	0.57
4	Iron sulphate ($FeSO_4$. $7H_2O$)	1.62
5	Aluminium sulphate ($Al_2(SO_4)_3$. $18H_2O$)	1.29
6	Sulphur(S)	0.19 ***(ARS & NET 2015)***
7	Pyrite (FeS_2) – 30 % Sulphur	0.63
8	Pressmud (Lime sulphur, 9 % Ca and 24 % S)	0.77
9	Limestone ($CaCO_3$)	0.58

In many laboratories the quantity of gypsum required for reclaiming sodic soil is determined by the ***gypsum requirement (GR) method*** suggested by ***Schoonover (1952).*** The test is performed by mixing a small soil sample (5 g) with a relatively large volume of saturated gypsum solution and measuring the calcium lost from the solution after reaction with soil. Sodium salts in a sodic soil are so diluted by this treatment that nearly complete displacement of exchangeable sodium by calcium from the gypsum solution occurs. The decrease in calcium from the gypsum solution when expressed on the basis of tonnes of $CaSO_4$. $2H_2O$ per 30 cm of soil is taken as the GR of the soil.