List of publications

Sr. No.	Details of Research paper	NAAS rating (2018)
1	**V. Goyal**, A.K. Singh, A.K. Mishra and S.S. Parihar (2018) Integrated effect of water regimes and nitrogen levels on productivity of transplanted rice (*Oryza sativa*) and wheat (*Triticum aestivum*) under rice-wheat cropping system: Field and simulation study, *Indian Journal of Agricultural Sciences,* 88(1): 54-62.	6.22
5	**Bhardwaj, K.K.,** Dhillon, R.S., Sushil Kumari, Johar, V., Dalal, V. and Chavan, S.B. 2017. Effect of eucalyptus bund plantation on yield of 6agricultural crops and soil properties in semi-arid region of India. *I7nternational Journal of Current Microbiology and Applied Sciences* **6:** 2059-2065	5.38
2	Mohinder Singh, **V. Goyal**, B.S. Panwar and P.S. Sangwan (2017) Soil Test Crop Response based fertilizer recommendations under integrated plant nutrient supply for Bt. cotton in Inceptisols of Haryana, *Journal of the Indian Society of Soil Science,* 65 (1): 80-85.	5.23
8	Singh, M.K., **Bhardwaj, K.K.,** Beniwal, R.S. and Sushil Kumari 2017. Quantification of litter fall and decomposition rate in shelterbelt and neem block plantation. *Journal of Pharmacognosy and Phytochemistry* 6(6): 2491-2493	5.21
6	**Bhardwaj, K. K.,** Jhorar**,** B.S., Sangwan, P.S., Kumari, S. and Deepak Kumar 2017. Soil moisture dynamics under different tree species in arid region of Haryana. *Indian Journal of Ecology* **44:** 770-780.	4.96
7	**Bhardwaj, K. K.,** Dhillon, R. S. and Kumari, S. 2017. Effect of poplar bund plantation on soil properties and yield of agricultural crops in semi-arid region of India. *Indian Journal of Ecology* **44:** 793-797.	4.96
3	**V. Goyal** and Mohinder Singh (2018) Validation of soil test crop response based fertilizer recommendations for targeted yields of *Bt.* cotton in semi arid south western zone of Haryana, *Journal of Cotton Research and Development,* 32 (1) 68-76.	4.69
4	D.S. Dahiya, Sunita Sheoran, Dev Raj, R.S. Antil and **V. Goyal** (2017) Effect of conjunctive use of Bio gas slurry and chemical fertilizers on crop productivity and soil health under wheat - pearl millet cropping system, *Indian Journal of fertilizers,*13 (2): 58-65.	2.89
5.	Narender, Malik, R.S. and ShivaKumar, L. 2017. Kinetics release behavior of DTPA- extractable Mn in soils of different cropping systems and total manganese content associated with soil texture. *Indian Journal Agricultural Sciences,*87(5):603- 606	6.22

6.	Khan, Shahroon., Godara, R.K. and Malik, R.S. 2017. Influence of Nitrogen and FYM application on quality of Pear (Pyrus pyrifolia Nakai). Indain Journal of Ecology, 44: 266- 268	4.96
7.	Malik, R.S., Yadav, H.K., Narender., RajPaul and Sangwan, P.S. 2017. Background levels of zinc, iron, managanese and copper in soil series of Haryana and their relationship with soil properties. Indian journal of Agricultural Sciences, 87(8): 1094- 1098	6.22
8.	Singh, Vijayata., Yadav, R.K., Yadav, N.R., Yadav, Rajesh., Malik, R.S. and Singh, Jogendra. (2017) Identification of genomic Regions/genes for high iron and zinc content and cross transferability of SSR markers in mungbean (*Vigna radiata* L.). Legume Research, 40(6): 1004-1011	6.12
9.	Lamba, S., Phogat, V.K. and Kumar, N. (2017). Sustainable agriculture for sustaining mankind- A Review of International Literature. *Vegetos-An International Journal of Plant Research*. 30: 477-482.	4.0
10.	Babli, Kumar, P., Kumar, M., Hooda, V.S., Munjal, R. and Kumar, A. (2018). Effect of integrated nutrient management on growth parameters of pearl millet in pearl millet-wheat cropping system. *International Journal of Pure and Applied Biosciences.* Manuscript No. 6279 (Accepted for publication)	4.74
11.	Rathi, Parveen, Ramprakash, Kumar, Sanjay, Rathi, Naveen and Vikas. (2018). Mapping o variability in quality of groundwater in Rajaund block of Kaithal District (Haryana). *Journal of Pharmacognosy and Phytochemistry* **7** (1): 1056-1059.	5.21
12.	Rathi, Parveen, Ramprakash, Kumar, Sanjay, Satyavan and Rathi, Naveen. (2018). Characterization of groundwater quality in Siwan block of Kaithal district in Haryana. *International Journal of Chemical Studies 6* (1): 981-985.	5.31
13.	Singh, Vijaykant, Ramprakash, Rajpaul, Kumar, Sanjay, Singh, Kuldeep and Satyavan. (2018). Evaluation of groundwater quality for irrigation in Gulha block of Kaithal district in Haryana. *Journal of Soil Salinity and Water Quality 9* (2): 241-248.	4.94
14.	Kumar, Narender, Jhorar, R.K., Kumar, Sanjay, Yadav, Rajpaul, Ramprakash, and Singh, Amandeep. (2018). Effect of fertigation on nitrogen use efficiency and productivity of tomato utilizing saline water through drip irrigation. *Journal of Soil Salinity and Water Quality 9* (2): 205-212.	4.94
15.	Kumar, Sunil, Satyavan, Jakhar, D.S. and Sihag. (2018). Effect of integrated nutrient management practices on soil properties and nutrient availability to wheat (*Triticumaestivum* L.) under saline and non saline irrigation water. *International Journal of Chemical Studies 6* (2): 3701-3704.	5.31

16.	Sangwan, Meenakshi, Singh, Samunder and Satyavan. (2017). Effect of sequrntial application of imazepthapyr + imazamox and propaquizafop in clusterbean (*Cyamopsis tetragonoloba*) in to texturally different soils. *Indian Journal of Agronomy 61* (4): 519-522.	5.46
17.	Dhaka, A.K., Kumar, Satish, Pannu, R.K., Malik, Karmal, Singh, Bhagat and Ramprakash. (2017). Production potential, energy efficiency and economics of wheat *(Triticum aestivum* L.*)* succeeding fodder sorghum intercropped in seed crop of dhaincha *(Sesbania aculeate*). *Indian Journal of Agricultural Sciences* 87 (2): 225-33.	6.22
18.	Singh, Mohinder, Yadav, D.B., Punia, S.S., Singh. Rajbir, Kumar, Naveen, Ramprakash and Dabur, K.R. (2017). Influence of different basmati cultivars and nitrogen scheduling on nutrient content, uptake and nitrogen use efficiency. *Journal of Soil Salinity and Water Quality* 9 (1): 84-93.	4.94
19.	Dinesh, Bhat, M. A., Grewal, K. S., Sheoran, H. S. (2017). Mineralogy of soils of major geomorphic units of north- eastern Haryana, India. *Journal of Applied and Natural Science,* 9(2): 924-934.	4.84
20.	Bhat, M. A., Grewal, M. S, Dinesh, Singh, I. and Grewal, K.S. (2017): Geoinformatics for Quantifying Salt Affected Soils in Gohana, Haryana Using Soil Techniques*. International Journal of Current Microbiology and Applied Sciences*, 6(9): 835-858.	5.38
21.	Grewal, K. S., Kumar, S., Bhat, M. A. and Dinesh (2017). Comparison of chemical extractants for determination of available potassium. *International Journal of Chemical Studies*, 5(6):417-423.	5.31
22.	Bhat, M. A., Wani, S. A., Singh, V. K., Sahoo, J., Tomar, D., and Sanswal, R. (2018). An Overview of the Assessment of Groundwater Quality for Irrigation. *Journal of Agricultural Science and Food Research*. 9: 1-9.	Impact factor: 2
	Sharma, M.K.; Mundra, M.C.; Siyag, R.S. and Poonia, S.R. 1993. Effect of farm yard manure on Ca-Zn and Ca-Cd exchange equilibria in soils. *Journal of the Indian Society of Soil Science.* 41(4): 636-641.	4.95
	Siyag, R.S.; Singh, H.; Sharma, M.K. and Poonia, S.R. 1993. Calcium-Potassium and Calcium-Potassium plus ammonium exchange equilibria in some soils of semi-arid and humid regions. *Journal of Potassium Research.* 9 (2): 95-104.	

	Sharma, M.K.; Mundra, M.C.; Siyag, R.S. and Poonia, S.R. 1994. Effect of sewage water on Ca-Zn and Ca-Cd exchange equilibria in soils. *Journal of the Indian Society of Soil Science.* 42 (1): 25-30.	4.95
	Sharma, M.K.; Poonia, S.R.; Gupta, R.K. and Siyag, R.S. 1994. Sodicity of irrigation waters in relation to precipitation/dissolution of $CaCO_3$. *Journal of the Indian Society of Soil Science.* 42 (2): 244-247.	4.95
	Yadav, S.; Sharma, M.K.; Siyag, R.S.; Poonia, S.R. and Pal, R. 1995. Predicting solubility of gypsum in aqueous salt solutions. *Journal of the Indian Society of Soil Science.* 43 (2):191-196.	4.95
	Deka, A.K.; Poonia, S.R.; Siyag, R.S. and Sharma, M.K. 1997. Effect of farm yard manure on cadmium sorption in soils from semi-arid and humid regions. *Journal of the Indian Society of Soil Science.* 45 (3): 490-494.	4.95
	Chawla, K.L.; Kumar, A.; Sharma, M.K.; Sharma, D.R. and Khosla, B.K. 1998. Response of sunflower to different planting techniques and salinity of irrigation water. *Journal of the Indian Society of Soil Science.* 46 (2): 338-340.	4.95
	Thomas, A.; Sharma, P.K.; Sharma, M.K. and Sood, A. 1999. Hydrogeomorphological mapping in assessing ground water by using remote sensing data – A case study in Lehragaga block, Sangrur District, Punjab. *J. Indian Soc. Remote Sensing* 27 (1): 31-42.	6.76
	Tomar, N.K.; Pundir, R.S. and Sharma, M.K. 1999. Residual efficiency of Diammonium orthophosphate and Ammonium polyphosphate to maize crop in wheat-maize-maize cropping sequence on a Typic Ustochrept varying in available phosphorus. *Annals of Agri.-Bio Research* 4 (2): 125-133.	2.91
	Dahiya, D.S.; Kumar, N.; Bhardwaj, J.; Kumar, P.; Nandwal, A.S. and Sharma, M.K. 2003. Interactive effect of chromium and phosphorus on growth, dry matter yield and their distribution in wheat shoot. *Indian J. Plant Physiol*. 8 (2): 129-132.	4.66
	Kumar, Manoj and Mann, H.S. 2005. Effect of organic matter and clay content on zinc sorption in some soils from semi-arid region. *Environment & Ecology* 23 (1): 94-98.	4.09
	Kumar, Pawan; Yadav, S.K.; Kumar, Manoj; Rinwa, R.S. and Singh, K.P. 2007. Breaking yield barriers in pearlmillet (*Pennisetum glaucum (L)*)-wheat (*Triticum aestivum (L)*) cropping system through agronomic operations in semi arid Haryana. *Indian J. Agric. Sci.* 77: 479-482.	6.14
	Kumar, Anil; Chugh, L.K.; Yadav, Dev Vart; Malik, R.S. and Kumar, Manoj. 2016. Effect of farmyard manure, organic manure and balanced fertilizers application on the productivity and soil fertility in pear millet (*Pennisetum glaucum*)-mustard (*Brassica juncea*) cropping sequence in sandy loam soil of semi-arid regions. Paper published in *Indian Journal of Agricultural Sciences* 86(2): 220-6.	6.14
	Kumar, Anil; Hooda, R.S.; Yadav, H.P.; Chugh, L.K.; Kumar, Manoj and Gera, Rajesh. 2009. Compensating nutrient requirement in pearl millet (*Pennisetum glaucum*)-wheat (*Triticum aestivum*) cropping system through manures and	6.14

	biofertilizers in semi-arid regions of Haryana. *Indian Journal of Agricultural Sciences* 79(10): 767-71.	

Book Chapter	
1.	Narwal, R.P., Malik, R.S., & Yadav, H. K. (2017) Micronutrients in soils and plants and their impact on animal and human health. Edit by Singh, B.R., McLaughlin, M.J., Brevik, E. 2017: The Nexus of Soils, Plants, Animals and Human Health- Catena- Schweizerbart, Stuttgart pp 64-71.
2.	Malik, R.S., Narwal, R.P., Yadav, H. K., & Panghal, D (2017) Zinc deficiency in soils and plants and its implications for global human health. Edit by Singh, B.R., McLaughlin, M. J., Brevik, E. C : The nexus of soils, plant, animal and human health- Catena- Schweizerbart, Stuttgart pp 72-86
3.	Babli, Devi, M., Kumar, P. and Kumar, M. (2018). Sustainable production by crop residue management in the context of conservation agriculture under intensive cropping system. In: *Agricultural, Allied Sciences & Biotechnology for Sustainability of Agriculture, Nutrition & Food Security*: 57-60.
4.	Dixit, M.L. and Sharma, M.K. 2003. Jo Mein Urvarak- Prayog. *In*: *Mrida Vigyan Prashanotri*, An Extension Book, published by Directorate of Extension Education, CCS Haryana Agricultural University, Hisar. pp.124-129.
5.	Yadav, S.K.; Kumar Pawan; Kumar Manoj and Singh, K.P. 2008. Viability of different cropping systems in semi-arid regions of Haryana. *In: Diversification of Arid Farming Systems* (Pratap Narain *et al.*: eds.) Arid Zone Research Association of India and Scientific Publishers (India), Jodhpur. pp.148-152.
6.	Kumar, Pawan; Yadav, S.K. and Kumar, Manoj. 2011. Efficient alternative cropping systems: Zone 3. Trans Gangetic Plains, *In: Efficient alternative cropping systems*, Eds: B, Gangwar and Anil Kumar Singh, Published by Project Directorate for Farming Systems Research, Modipuram, India. pp. 59-68.
7.	Yadav, S.K.; Kumar, Pawan; Nanwal, R.K.; Kumar, Manoj and Rana , V.S. 2012. Diversification in Agriculture - issues and actions. *In: Crop Science and Technology for Food Security, Bioenergy and Sustainability* (Eds. R.K. Behl, L. Bona, J. Pauk, W. Merbach and A. Veha) pp 345-350, Published by Agrobios (International), Jodhpur.
8.	Kumar, Pawan; Kumar, Manoj and Yadav, S.K. System based state-wise issues and technologies of pulse production (Haryana). *In "Enhancing Pulses Production-Technologies and Strategies"* by Babooji Gangwar and Anil Kumar Singh, pp 141-160.
9.	Sharma, Manoj Kumar 2014. Problem soils: Problem soils and their distribution in India, Characteristics and reclamation of these soils. *In Course Manual on ICAR-JRF (PGS) in Agriculture-Agronomy Eds* A.K. Dhaka, K.S. Bangarwa, S.S. Dhankhar and R.K. Pannu, CCS HAU, Hisar 2014, pp 370-380.

10.	Kumar, Pawan; Sharma, Manoj Kumar; Yadav, S.K. and Nanwal, R.K. 2015. Organic nutrient management package for crop yield, soil fertility, nutrient uptake and crop quality in mungbean-wheat cropping system on a Haplustalf of Hisar. *In Mimiogram No. 1/2015*. Published by ICAR-Indian Institute of Farming Systems Research, Modipuram. pp. 163-183.
11.	Kumar, Pawan; Sharma, Manoj Kumar; Nanwal, R.K. and Yadav, S.K. 2015. Long-term integrated nutrient management in pearl millet – wheat cropping system. Chapter in Book entitled "Long-term integrated nutrient management in cereal based cropping systems" by B. Gangwar, Kamta Prasad, N. Ravishankar and J.P. Singh, published by ICAR-Indian Institute of Farming Systems Research, Modipuram. pp. 301-317.

Papers abstracted in Conferences/Seminars/Symposia/Workshops

1	Kumar, K. and Phogat, V.K. (2017). Online resources and open source tools for remote sensing and GIS applications in water resources management. 51st Annual Convention of Indian Society of Agricultural Engineers (ISAE) and National Symposium on õAgricultural Engineering for Sustainable and Climate Smart Agricultureö, Feb 16-18, 2017, CCS HAU, Hisar, Haryana
2	Sheoran, H.S., Phogat, V.K. and Dahiya, R. (2017). Evaluation of the effects of organic and conventional farming systems on soil properties. Golden Jubilee Celebration and regional Conference on õSpace technology for sustainable developmentö, March 21-22, 2017, HARSAC, Hisar, Haryana.

Bulletins/ Manuals/Technical folders

1	Narwal, R.P., Malik, R.S., Mahlotra, S.K. and Singh, B.R. 2017. Micronutrients and Human health. Encyclopedia of Soil Science, Third Edition, 2017: 1443- 1448
2	Malik, R.S., Dahiya, R.R., Sangwan, S.S., Yadav, H.K. and Yadav, Rajpaul. 2017. Zinc status in soils of Haryana and amelioration of its deficiency in crops, Department of Soil Science, CCS H.A.U., Hisar, Pp: 1- 6
3.	Malik, R.S., Dahiya, R.R., Yadav, H.K. Sangwan, S.S and Yadav, Rajpaul. 2017. Current scenario of Iron deficiency in soils of Haryana and its amelioration in crops, Department of Soil Science, CCS H.A.U., Hisar, Pp: 1- 6
4.	Pawar, N., Kumar, R., Kumar, R. Sharma, M and (2017). Kisano ke samridhi ke liye farm parbandhan. KVK, Rohtak. Pp:1-4.
5	Kumar, R., Pawar, N., Kumar, R. and Sharma, M (2017). Rabi faslon main beej upchar. KVK, Rohtak. Pp:1-4.
6.	Kumar, R., Kumar, R. Pawar, N., Sharma, M and Siwach, M. (2017). Mitti parkikshan kayon v kaise. KVK, Rohtak. Pp:1-4.

Popular articles

1.	Goyal, N.K., Sangwan, P.S., Malik, R.S. and Tomar, Dinesh. 2017. Khet ki bhoomi khet mei, khet ka paani khet mei- sureskshekt bhvisay. Krishi Sanwad, March: 18- 21
2.	Goyal, N.K., Malik, R.S., Sangwan, P.S. and Tomar, Dinesh. 2017. Plant fruit trees by using essential nutrient. Krishi Sanwad, March: 22-23
3.	Goyal, N.K., Sangwan, P.S. and Malik, R.S. 2017. Balanced fertilization in sugarcane is very much essential. Krishi Sanwad, April: 24-25
4.	Narender, Yadav, H.K. and Malik, R.S. 2017. Make composed from organic source and maintain soil health. Haryana Kheti, 50 (7): 1- 3
5.	Panghal, Dheeraj and Malik, R.S. 2017. Management of irrigation and fertilizers in oilseed crops. Khad Patrika, 58(10): 18-28
6.	Panghaal, Dheeraj and Malik, R.S. 2017. Nutrient and water management in rabi oilseeds. Khad Patrika, 58(10): 18- 28
7.	एच.के. यादव , नरे और आर . एस. मलिक (2017) ऴसू म पोषक त व : मह वंह ह रयाणा खेती,

	चौधरी चरण सह ह रयाणा कृषि वि वि ालय हिसार- पृष्ठ सं 29˙30 (जनवरी अंक)
8.	Goyal, N.K., Sangwan, P.S. and Malik, R.S. 2017. Importance of soil organic matter for soil health. Haryana kheti, 50(11): 28-32
9.	Pangaal, Dhireej., Jangeer, Chetan Kumar and Malik, R.S. 2018. Role of sulphur in raya and mustard. Haryana Kheti, 51(1): 3
10.	Goyal, S.K., Malik, R.S. and Grewal, M.S. 2018. Integrated Nutrient Management for Sustainable Soil Health. Haryana Kheti, 51(2): 29-30
11.	Pangaal, Dhireej, Jangind, Ghetan Kumar and Malik, R.S. 2018.Deficiency of micronutrients in soils and their management. Haryana Kheti, 51(2): 1 & 5
12.	Goyal, N.K., Kumar, Rakesh and Malik, R.S. 2018. Bio- Fertilisers- The beneficial Micro-organisims. Haryana Kheti, 51(3): 27
13.	Pawar, N., Kumar, R. and Kumar, R. (2017). Pardhan Manti fasal bema yojna- Kisano ke liye sanjeevani. Haryana Kheti, 49(7): 11-12
14	Rani, S. Kumar, M. and Yadav, P. (2018). Pramukh poshak tatv podhon ke liye kitne aawshyak? *Rajasthani Kheti*, 3:30-33.
15	Rani, S. Shrama, M.K., and Rani, P. (2017). Mrida swashthya: Labhkari krishi ke liye abhin ang. *Haryana Kheti*, 12:11-12.
16	Ankush, Ramprakash and Singh, Vikram. (2017). Krishi bhumi ki samshaya avam samadhan. *Krishak Jagat*, 14: 5.
17	Ankush, Singh, Vikram and Ramprakash. (2017). Revitalizing techniques for saline soil. *Indian Farmer,* 4(8): 706-709.
18	Ankush, Singh, Vikram, Kumar, Vinod and Ramprakash. (2017). An overview of drip fertigation technology. *Indian Farmer,* 4(10): 744-747.
Radio/TV Talk	
1.	Malik, R.S. 2017. Use of balanced fertilization. A radio talk from AIR, Hisar under phone in programme
2.	Harendra Yadav (2017) Importance of Micronutrient in *Rabi* crops. 11.12. 2017 Community Radio Station, CCS Haryana Agricultural University, Hisar
3.	Goyal, V. (2017). Balanced fertilization in Rabi crops: 30.11.2017, CRS, CCS HAU, Hisar

E-COURSE MANUAL

on

FUNDAMENTALS OF
SOIL SCIENCE

(AS PER V DEANS' COMMITTEE SYLLABUS)

V.K. PHOGAT
(Emeritus Professor)

DEPARTMENT OF SOIL SCIENCE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR– 125004

E-Course Manual

on

FUNDAMENTALS OF SOIL SCIENCE
(As per V Deans' Committee Syllabus)

by

DR. V.K. PHOGAT
EMERITUS PROFESSOR

DEPARTMENT OF SOIL SCIENCE
COLLEGE OF AGRICULTURE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR- 125004
2021

CONTENTS

Chapter 1

Land and soil, although related, are two different entities. Land (part of the earth not covered by water) is a two-dimensional body having length and breadth, representing geographical area and landscape while soil is a three-dimensional body with length, breadth and depth, and hidden below the land surface.

The Concept of soil

The Vedas, Upanishad and other Indian literature mentioned soil as synonymous with land– the Mother– supporting and nourishing life on earth. But depending upon the interest, the soil has been perceived differently by different users, and defined accordingly. For a layman, soil is the dirt or dust on the earth's surface. A farmer considers soil as a top few centimeters of earth's surface that can be used for growing crops. With the advancement in knowledge, the concept of soil has been changing. For example, Whitney (1892) developed the concept of soil as "a nutrient bin which provides the nutrients required for plant growth". With the development of Science of Geology, a new concept came into existence during early nineteenth century. According to geologists, soil is a superficial unconsolidated material of the earth's crust formed due to weathering of rocks that they excavate before reaching the material for their interest. A mining engineer considers soil as "debris covering the rocks" while for a civil engineer, it is "any unconsolidated material removed in excavations and used for filling or providing foundations to roads, railways, airports, bridges, buildings and other structures". For a Soil Scientist, soil is "a three-dimensional dynamic natural living body, composed primarily of minerals mixed with varying amounts of organic matter (living and dead)".

Definitions

Soil is considered as a weathered product in nature (pedological approach) or a medium for plant growth (edaphological approach) and defined accordingly.

i) *Pedological definition:* The term pedology comes from the Greek word *pedon*, which means soil or earth. Pedology studies origin and classification of soil without emphasising on its practical use. Earlier soil

scientists used pedological concept to define the soil. Dokuchaiev (1900) Father of Soil Science, defined soil as "a natural body composed of mineral and organic constituents, having a definite genesis and a distinct nature of its own". Joffe (1936*)* described soil as "a natural body of mineral and organic constituents differentiated in to horizons of variable depth, which differs from the material below in morphology, physical makeup, chemical properties and composition, and biological characteristics" while Jenny (1941) perceived soil as "a naturally occurring body that has been evolved due to combined influence of climate and living organisms acting on parent material as conditioned by relief over a period of time".

ii) *Edaphological definition:* The term *edaphology* also comes from Greek word '*edaphos*', which means soil or ground. Edaphology studies soil from plant production point of view. Edaphologically, soil is defined as "an unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for plant growth".

Soil Science Society of America (1970): "Soil is (i) the unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of land plants, (ii) the unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of parent material, climate (including moisture and temperature effects), macro- and micro-organisms and topography, all acting over a period of time and producing a product, *i.e.,* soil, that differs from the material from which it is derived in many physical, chemical, biological and morphological properties and characteristics".

Pedology focuses on study of rocks and minerals, their weathering, soil forming factors and processes, soil survey, mapping, description, and classification while edaphology, an applied branch of Soil Science, intends to study the soil as a medium for plant growth and includes study of physics, chemistry, microbiology, fertility and technology.

Soil as a Three Dimensional Dynamic Natural Living Body

Soil is a three dimensional (length, breadth and depth), dynamic (keeps on changing) natural (formed primarily by a combination of natural forces) and living body (habitat for diverse community of living organisms- soil flora and soil fauna). Soil flora and soil fauna are collectively called *soil life*, *soil*

biota or *edaphon*. Soil is composed of minerals mixed with varying amounts of organic matter (living and dead) providing nourishment to life.

Soil Science and its Branches

Soil Science is the study of soil as a natural resource on the earth's surface including properties and processes occurring in soil (soil formation, classification and mapping; physical, chemical, biological and fertility properties of soils *per se*) and in relation to the use and management of soils for crop production. Soil Science has been divided into different branches such as: Soil Physics, Soil Chemistry, Soil Fertility, Soil Microbiology, Pedology, etc.

Chapter 2

Soil Forming Rocks and Minerals

The earth's crust was formed due to the cooling and consolidation of molten mass, *magma, i.e.,* melted rocks of the planet earth. During the process of cooling, the elements of molten mass began to combine in a natural systematic manner and consolidated into large masses giving rise to a variety of minerals and rocks.

Mineral

Mineral is a naturally occurring inorganic crystalline solid having an orderly (systematic) internal arrangement of elements (characteristic geometric form), definite chemical composition and physical properties. The mineral may be composed of an element or various elements but most minerals consist of two or more elements. Examples: quartz (SiO_2), magnetite (Fe_3O_4), olivine ((Mg, Fe)$_2$ SiO_4), calcite ($CaCO_3$), hematite (Fe_2O_3), gypsum ($CaSO_4.2H_2O$), etc. Minerals consisting of only one element may be a metal, such as copper, iron, aluminium or a non-metal such as silicon, carbon, sulphur.

General Characteristics of Minerals Used for Identification

General characteristics of mineral include:

a) *Colour:* Reflection of certain colour which is exhibited by ordinary light. Mineral may be white, black, pink, yellow, green or even colourless. For example: Quartz– colorless, calcite– white, orthoclase– pink, magnetite– black iron pyrite– yellow. A mineral may occur in a wide variety of colors, e.g. quartz as a result of impurities, therefore, colour is not a good characteristic for describing and identifying minerals.

b) *Lustre:* Shining of an individual mineral- metallic or non-metallic. Metallic lustre possesses the lustre of a metal, *e.g.,* iron pyrite. Non-metallic lustre is of various types, *e.g.,* rock crystal– vitreous, talc– resinous, zeolite– pearly, gypsum– earthy, apatite– waxy, asbestos– silky lustre.

c) *Light transmission*: The property of mineral to transmit light through it i.e. Transparent, opaque or translucent. If the outline of the object appears distinct and clear through a mineral, it is called transparent (mica, calcite

rock salt crystal) and if it does not appear clear and indistinct, it is called translucent (flint, milk quartz). If no light passes through a mineral, it is called opaque (iron pyrite, copper pyrite, magnetite).

d) **Hardness:** Hardness is the resistance offered by a mineral to scratching. Mohr has developed a scale of hardness (Mohr's scale) for different minerals. Relative hardness (1 to 10) of some minerals in increasing order is: Talc (1 i.e. softest), Gypsum (2), Calcite (3), Fluorite (4), Apatite (5), Feldspars (6), Quartz (7), Topaz (8), Corundum (9) and Diamond (10 i.e. hardest). *(Roughly, the hardness of a finger nail 2, glass piece 5.5, and sharp steel (knife) is 6.5)*

e) **Streak:** Colour of the line drawn by rubbing the mineral against a coarse hard plane surface which may be different from the colour of mineral. Normally white minerals have white streak, e.g. rock salt crystal. A mineral's streak color is a more reliable characteristic for identification of mineral than its color. Streak of some of the important minerals are:

Mineral	Mineral colour	Streak colour
Rock salt	White	White
Orthoclase	Pink	White
Iron pyrite	Yellow	Green
Haematite	Black	Cherry red
Magnetite	Black	Black

f) **Specific gravity:** It is the "ratio of the weight of mineral to the weight of equal volume of water" providing information regarding heaviness of a mineral. Minerals vary widely in their specific gravities. Some minerals are very light having specific gravity of 2.65 (quartz) while some may have specific gravity of even > 5.0 (haematite).

g) **Tenacity:** It is the persistence of a mineral against an external force on it. A mineral may be brittle (breaks into small pieces), flexible (easily bent) or malleable (flattened) against an external force on the mineral.

h) **Cleavage:** Tendency of a mineral to break along planes of weakness in the chemical bonds. If breakage is parallel to crystal faces, it results in more or less smooth surfaces. Cleavage may be perfect (diamond) or imperfect (pyroxene).

i) **Fracture:** It is the non-planar breakage of minerals providing even, uneven, or conchoidal surface. A fracture is *conchoidal* if the resulting

surface is more or less curved. If the surface of the fractured plane is smooth and plane, they are called *even* otherwise *uneven.*

j) **Form and structure:** If a definite form is developed, it is called crystalline (olivine, orthoclase, quartz, calcite) otherwise massive or amorphous (haematite, gibbsite). Depending on the size of axes and angles between axes of the crystal, a mineral may be subdivided into six different forms: .i) monometric (cubic, isometric, regular), ii) dimetric (octahedron, tetragonal), iii) trimetric (orthorhombic), iv) monoclinic, v) triclinic and vi) hexagonal. The arrangement of crystals gives rise to several types of structures, e.g. granular, lamellar, columnar, reticulated, stellated or drusy.

The arrangement of crystals of mineral gives rise to several kinds of pattern called structure such as granular, laminar (plate like) and columnar (needle or column like)

k) **Chemical nature:** The minerals are found in form of oxides, carbonates, silicates, sulphates, etc., as will be explained later in this chapter.

Classification of Soil Forming Minerals

The minerals may be classified on the basis of mode of formation, abundance (amount of mineral in the rock), specific gravity and chemical composition.

1. *Mode of formation:* The minerals are categorized as primary and secondary minerals based on their mode of formation.

Primary mineral	Description
Primary minerals: Form an original component of igneous rocks. Anhydrous in nature and most prominent in coarser fractions (sand and silt) of the soil.	
Quartz	☐ Simple in chemical composition i.e. an oxide of silicon (SiO_2) ☐ Highly resistant to weathering with dense structure preventing any form of substitution ☐ Next to feldspars in abundance.
Feldspars	☐ Most abundant among primary minerals and constitute nearly 61% of minerals that are found

	• in earth's crust.
	☐ Structure of feldspars is more open which makes less dense than quartz.
	☐ Source of Na, K, Ca and many trace elements in soils.
	☐ Depending upon the presence of diagnostic ions, feldspars are divided into two groups- orthoclase and plagioclase. Orthoclase feldspar is mainly potash feldspar, e.g. Microcline ($K_2O.Al_2O_3.6SiO_2$ or $KAlSi_3O_8$). Plagioclase feldspars are soda, calcium/lime or soda-lime feldspars, e.g. Albite- soda feldspar ($Na_2O.Al_2O_3.6SiO_2$); Anorthite- calcium feldspar ($CaO.Al_2O_3.6SiO_2$) and Oligoclase- soda-lime feldspar ($Na_2O. CaO.Al_2O_3.6SiO_2$).
Pyroxenes and amphiboles Hornblende 	☐ Also known as *ferromagnesian* minerals because of the presence of Fe, Mg and Ca in their structures, though, a small amount of Mn and Zn is also present.
	☐ Pyroxenes have the general formula- $R_2 (Si_2O_6)$ where R stands for mainly Ca, Mg and Fe. Examples: augite $CaO.2(Mg,Fe)O.(Al,Fe)_2O_3.3SiO_2$; diopside $Ca(Mg,Fe)(SiO_3)_2$; hypersthene $(Mg, Fe)SiO_3$ and enstatite $(MgSiO_3)$.
	☐ Amphiboles are chemically complicated; therefore, their chemical characterization is not simple as in case of pyroxenes.
	☐ Example: hornblende- $Ca_4(Na_2)(Mg,Fe)_{10}(Al,Fe)_2SiO_{14}O_{44}(OH),F)_4$.
	☐ Amphiboles are easily weatherable and main source of micro-nutrients (Mn, B, Cu, Zn, Fe, Ni), Ca and Mg
Mica	☐ K bearing ferromagnesian mineral having plate like structure and source of Fe and Mg

	☐ Mica is sub-divided into two groups: biotite and muscovite ☐ Biotite $(K_2O.4(Mg,Fe)O.2(Al,Fe)_2O_3.6SiO_2)$ is usually dark in colour and richer in Fe and Mg than muscovite $(K_2O, 3(Al, Fe)_2O_3.6SiO_2)$.

Secondary minerals: Formed as a result of weathering and recombination of primary rocks/minerals. Unlike primary minerals, these minerals are generally hydrous in nature and dominate mainly in the clay fraction but in some cases in the silt fraction of the soil also.

Secondary mineral	Description
Clay minerals 	☐ Clay minerals are naturally occurring layered silicates having structure of sheet type, e.g. illite, montmorillonite, chlorite, vermiculite, kaolinite, etc. ☐ Contain K, Mg and Fe in large amount in addition to O, OH, Al and Si. ☐ In clay minerals like montmorillonite and vermiculite, the structural sheets are not strongly bound together and water molecules enter in their crystal lattice causing considerable swelling. Such clay minerals are termed as swelling-shrinkage type like in black cotton soils (*Vertisols*) of India. ☐ Vertisols are, therefore, characterized by deep and wide cracks on the surface during dry conditions. ☐ These minerals carry a considerable net negative electrical charge on their surfaces which attracts cations. These cations are not bounded permanently and may be exchanged with other cations in the soil-water system. The amount of charge depends upon the type of clay mineral.
Hematite (Fe_2O_3)	☐ Haematite (ferric oxide) have metallic lustre with hardness of about 5, red to blackish red in colour

11

	• and a reddish streak.
	☐ Occurs as a coating on the sand particles and acts as a cementing agent.
	☐ Its presence in the rock is suggestive of quick chemical change.
	☐ Generally, swells on wetting and alters to form limonite (hydrated iron oxide)- $2Fe_2O_3.3H_2O$, magnetite-$FeO.Fe_2O_3$, or Fe_2O_4 (ferrous-ferric oxide) pyrite-FeS_2, siderite-$FeCO_3$ and goethite-$(FeO(OH).nH_2O)$.
	☐ Paramagnetic nature and becomes strongly magnetic when heated.
Limonite ($2Fe_2O_3.3H2O$)	☐ Also known as Bog iron
	☐ Usually yellow to brown in colour.
	☐ Final product of most iron minerals
	☐ On absorption of more water goethite get changed to limonite.
	☐ Hardness is 5.3.
Goethite ($Fe_2O_3.nH_2O$)	☐ Goethite, $2FeO(OH)$ i.e. iron oxide-hydroxide or $Fe_2O_3.H_2O$, i.e., hydrated ferric oxide.
	☐ Yellow to brown in colour and present in abundance.
	☐ An important colouring and cementing agent in soils
	☐ Final product of most of the iron minerals, therefore, resistant to any further change except for absorption of water.
	☐ On dehydration, it forms haematite, and on reduction and carbonation, produces soluble iron.
	☐ May be present in form of iron concretions.
Gibbsite ($Al_2O_3.3H_2O$)	☐ Most common aluminium mineral in soils.
	☐ White in colour.

	□ Hardness is 5.0-5.5 and specific gravity varies 3.3- 4.3.
	□ Most Abundant in highly weathered soils of the tropical zones, called *Laterites*.
	□ Colour may be light grey, light green, reddish white, reddish yellow (impure)
Calcite ($CaCO_3$)	□ The calcite is formed when $Ca(OH)_2$ combine with CO_2 or carbonic acid (H_2CO_3): $Ca (OH)_2 + CO_2 \longrightarrow Ca CO_3 \text{ (calcite)} + H_2O$ $Ca (OH)_2 + H_2CO_3 \longrightarrow Ca CO_3 + 2H_2O$
	□ White in colour with hardness of 3.
	□ Commonly present in sedimentary rocks and decomposes easily to soluble calcium bicarbonate as: $CaCO_3 + CO_2 + H_2O \longrightarrow Ca (HCO_3)_2$
Dolomite $Ca.Mg (CO_3)_2$	□ Dolomite is resistant to decomposition than calcite.
	□ Major source of Mg in soils.
	□ Mohr hardness of 3.5-4.
	□ Specific gravity 2.8-2.9
	□ Primary component of the sedimentary rock called 'dolostone' and metamorphic rock called, 'dolomitic marble'.
Siderite ($FeCO_3$)	□ A weathered product of iron-bearing minerals and alters to haematite or limonite.
	□ Having hardness of 4.
	□ An important mineral in waterlogged soils.
Iron pyrite (FeS_2)	□ Golden colour (Fool's gold)
	□ Most abundant sulfide mineral.
	□ Streak is greenish black to brownish black.
	□ Possesses metallic lustre.
	□ Mohr hardness of 6.0-6.5.

	☐ Specific gravity of 4.9-5.2.
Gypsum $CaSO_4 \cdot 2H_2O$	☐ A mineral of sulphate group. ☐ Common mineral in desert soils and sedimentary rocks having hardness of 2. ☐ Slightly soluble in water and is not easily leached. ☐ Precipitates as fine, powdery mycelium where the ground water is rich in Ca^{2+} and SO_4^{2-}. ☐ Used as an amendment to reclaim sodic soils. ☐ Source of Ca and S for plants.
Apatite $Ca_3(PO_4)_2$	☐ Also known as 'Rock phosphate' ☐ Primary source of phosphorus in soils. ☐ Hardness is 5. ☐ Decomposes readily under the influence of H_2CO_3. ☐ Becomes immobile in soils by easily combining with clay, Fe-Al hydrous oxides, calcium carbonate, and become unavailable to plants.
Native elements Sulphur (S) Copper (Cu)	☐ Apart from the free gases in Earth's atmosphere, some 20 elements occur in nature in a pure or nearly pure form, known as the native elements ☐ These are partitioned into three families, *viz.,* metals, semimetals and nonmetals. ☐ The most common native metals, characterized by simple crystal structures, make up three groups, *viz.*, the gold group consisting of gold, silver, copper and lead; the platinum group composed of platinum, palladium, iridium and osmium; and the iron group containing iron and nickel-iron. ☐ Mercury, tantalum, tin, and zinc are other metals that have been found in the native state.

2. *Abundance:* Minerals are classified into two categories based on their relative amount in the rocks.

Essential minerals	Accessory minerals
☐ Constitute major part (95-98%) of a rock. ☐ Characteristic components of the rock ☐ Made up of silicon-oxygen atoms in various combinations, therefore, also known as silicate minerals. ☐ Examples: quartz, feldspars, pyroxenes, amphiboles and micas, etc.	☐ Occur only in minor fraction (2-5%). ☐ Do not affect the characteristics of the rock. ☐ They are not composed of silicates but phosphate, sulphate, oxides of iron and aluminium. ☐ Important source of several plant nutrients. ☐ Examples: apatite, pyrite, magnetite, gypsum, etc.

3. *Specific gravity:* The minerals are classified into *light* and *heavy* minerals depending on their specific gravity.

Light minerals	Heavy minerals
Specific gravity < 2.85 such as quartz (2.60), feldspar (2.65) and muscovite (2.50-2.75).	Specific gravity > 2.85 such as olivine (3.5). limonite (3.8), pyrite (5.0) and haematite (5.3),

4. *Chemical composition:* The minerals are grouped into several categories depending upon their chemical composition. Their properties have been discussed in the previous section.

Category	Examples
Oxides and hydroxides	Quartz (SiO_2), haematite (Fe_2O_3), gibbsite (Al_2O_3)
Carbonates	Calcite ($CaCO_3$), dolomite ($CaMg (CO_3)_2$)
Sulphides	Iron pyrite (FeS_2), Chalcocite Cu_2S, Chalcopyrite ($CuFe(S)_2$)
Sulphates	Gypsum ($CaSO_4.2H_2O$)
Phosphates	Fluorapatite ($Ca_5(PO_4)_3F$), chlorapatite ($Ca_5(PO_4)_3Cl$), hydroxyapatite ($Ca_5(PO_4)_3.OH,Cl$).
Silicates	Quartz, feldspars, amphiboles, pyroxenes, mica.
Native elements	Sulphur, copper

Rock

Rock is a naturally occurring hard mass consisting of one or more minerals that have been cohesively brought together by rock-forming processes and constitutes the earth's crust. The rocks that are composed of only single mineral are called *mono-mineralic rocks*. Majority of rocks are composed of several different minerals and absolutely pure mono-mineralic rocks do not exist in nature but some of them are reasonably 'pure' to be called mono-mineralic. Examples are anorthosite, limestone, sandstone, marble, etc. The rocks which are predominately composed of two or more minerals are designated as *multi-mineralic* rocks such as granite, basalt, gabbro, etc.

The branch of science which deals with the study of rocks is termed as *petrology* which is further sub-divided into *petrography* and *petrogenesis*. *Petrography* focuses on detailed descriptions and classification of rocks while *petrogenesis* studies origin and formation of rocks.

Types of Rocks

Rocks are of three types based on their origin: igneous, sedimentary and metamorphic constituting 95, 4.9 and 0.1% by weight of the lithosphere, respectively. However, the upper 5 km of the earth's crust is dominated by sedimentary rocks (74 %) followed by igneous (18 %) and metamorphic rocks (8 %) The processes of formation and transformation of different rocks is depicted in Fig. 2.1
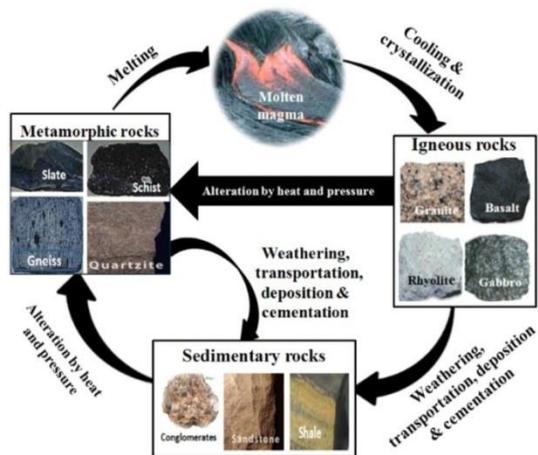
Fig. 2.1: Schematic diagram of rock cycle

1. **Igneous rocks (Fire rocks):** Igneous rocks are first formed in the earth crust by cooling and crystallization of magma (molten mass) on or beneath the surface of earth. These rocks are non-laminar, compacted and crystalline in structure, source of parent materials for other rocks and ultimately for the soils. These rocks consist mainly of primary minerals

(92%) like feldspars (58%), amphiboles & pyroxenes (16%), quartz (13%), micas (4%), etc. and therefore, also called as *primary rocks*.

Classification of igneous rocks: Igneous rocks are classified based on mode of formation and chemical composition.

i) **Based on mode of formation:** Based on mode of formation, igneous rocks are classified as extrusive (volcanic) and intrusive (plutonic) rocks.

    A. *Extrusive (volcanic):* The rocks which are formed by cooling of magma on the earth's surface such as basalt and rhyolite. As the magma comes to the surface, the pressure is released and the water turns into steam. Sometimes, the steam cannot escape and forms a globular cavity within the rocks, known as *vesicle*. The rocks which contain vesicles are called *vesicular rocks* or the *amygdaloidal rocks* if the vesicles are filled with some minerals (quartz, calcite, zeolite).

    The extrusive rocks are fine grained and may be highly porous due to escaping of volatile constituents such as pumice, a very light weight rock having a specific gravity of is < 1 making it to float on water. However, in composition pumice is comparable to rhyolite.

    B. *Intrusive (plutonic):* When the pressure subsides within the earth's crust, the magma starts moving back and on its way cools down to form rock beneath the earth's surface, called intrusive rocks, e.g. granite and gabbro. These rocks are coarse grained and compacted. Among these, the rocks consolidated at a much greater depth are called *plutonic rocks*, e.g. granite and diorite. Sometimes, the molten mass is forced into the cracks of the pre-existing rocks and a new rock is formed. The rock consolidated in vertical cracks forming wall like masses are called *dykes*. The rocks formed in horizontal cracks are known as *sills* whereas the rocks formed in irregular and narrow cracks are called *vein*.

ii) **Based on chemical composition:** Depending upon the relative amounts of acid (silicic acid or silica) and basic components (Na, K, Ca, Mg, iron oxides, etc), igneous rocks are divided into four classes as acidic, neutral, basic and ultra basic (Table 2.3).

Table 2.3: Classification of igneous rocks based on silica content

Type of rock	Silica (%)	Examples
Acidic/ over-saturated/ felsic	65-75	Granite, pegmatite, rhyolite
Neutral/ saturated/ intermediate	55-65	Diorite, syenite, andesite
Basic/ under-saturated/ mafic	45-55	Basalt, gabbro, dolerite
Ultra-basic/ ultra-mafic	<45	Olivine, peridolite

Some examples of the volcanic and plutonic rocks and their characteristics are:

Volcanic or extrusive rocks		*Plutonic or intrusive rocks*	
Basalt	Pumic	Granite	Gabbro
Most abundant, fine grained, dark basic rock (silica=45-55%) mainly composed of feldspars and ferromagnesian minerals.	Highly porous, very light weight (specific gravity <1) rocks and comparable to granite/rhyolite in composition.	Coarse grained light colored acidic rock (silica = 65-75%) mainly composed of quartz minerals.	Basic. Diorite Neutral.

2. **Sedimentary rocks (Aqueous, clastic, stratified rocks):** The rocks which are formed from the sediments of igneous rocks. The sediments are transported and deposited in new arrangement in lakes and seas by blowing wind, flowing water, glaciers and gravity where it is cemented to form sedimentary/secondary rocks. The cementing materials to compact the sediments are silica, oxides of iron, lime. These rocks are also called *stratified* rocks as the sediments are usually deposited in layers, clastic rocks (fragment) and aqueous rocks as water is the main

agent in their formation. Thus, the formation of sedimentary rocks takes place through four stages: *weathering, transportation of sediments, deposition* to new place, and *compaction and cementation*. The process of transformation of unconsolidated sediment to consolidated hard rock mass involving compaction due to overburden pressure of upper layers and subsequently cementation of the sediments by cementing agents refers to as *diagenesis*.

Examples of some of the common sedimentary rocks are:

Sand stone	Shale	Lime stone	Conglomerate
Mainly composed of quartz with cementing agents- $CaCO_3$, iron oxides and clays, light to red coloured, usually granular and porous structure. If quartz and feldspars predominant then it is called *arkose*.	Mainly composed of clay minerals, quartz and cementing agents as in sand stone, light to dark coloured and has thinly laminated structure.	Composed mainly of calcite mineral with clays, some iron oxides, phosphate and organic matter, light grey to yellow in colour, fine grained with compact structure.	Highly variable in composition, shape, structure, colour & texture, mainly composed of quartz, feldspars along with more or less rounded sediments of varying sizes. If the sediments are more angular than rounded, the rock is called *breccias*.

Sedimentary rocks constitute 4.9% of lithosphere (shale 4%, sandstone 0.7%, limestone 0.2%).

Classification sedimentary rocks: Based on their origin whether formed by the deposition and cementation of sediments; cooling, evaporation or direct chemical precipitation of material dissolved in sea or lake water or

accumulation and partial decomposition of organic remains under anaerobic conditions, the sedimentary rocks are classified into six types.

#	Type	Description	Example
1	Arenaceous	Formed due to deposition of coarse particles (quartz and feldspars) carried by the water. Depending upon the nature of cementing materials, some rocks are hard and refractory but most are loose and undergo weathering easily, e.g. sandstone, conglomerate, etc.	Sandstone
2	Argillaceous	Formed from small sized particles consisting of hydrated silicate of alumina (clays), calcareous materials, and other silicates. Deposition of clay mainly consisting of silicate of alumina is called as *Kaolin (China clay),* e.g. Shale, mudstone, etc.	Shale
3	Calcareous	Usually consisted of carbonate of Ca and/or Mg, formed by deposition and cementation of sediments, chemical precipitation or organic agency but mainly composed of debris from plants and animals when formed by the organic agency. When formed by chemical precipitation, the calcareous materials get deposited in form of sheets. Initially, the precipitate is soft but soon acquires a hard and compact structure, e.g. Limestone, dolomite, etc.	Limestone

4	Carbonaceous	Formed from decomposition of vegetation under anaerobic conditions in lower layers of earth, mainly consist of carbon. During decomposition, major proportion of the carbonaceous matter is retained and slowly converted into coal, e.g. Peat, lignite, antracite, coal, bituminous, etc.	 Lignite
5	Siliceous	Deposits of organic origin formed from silica-secreting minute plants and animals like diatoms, radiolarian, etc., deposited in salty or fresh water. These are mainly consisting of microscopic SiO2, dense, hard and fine grained, *e.g.*, Chert, and some are soft and friable, *e.g.,* diatomite.	 Chert
6	Precipitated	Mainly deposits formed by cooling, evaporation or direct chemical precipitation on or beneath the earth surface. Examples: *Oxides*- hematite, bauxite, quartz *carbonates*- limestone *sulphates*- gypsum *phosphates*- phosphorite *chlorides*- rock salt	 Gypsum

3. **Metamorphic rocks:** The physical and/or chemical changes in igneous and sedimentary rocks by the action of internal heat and/or pressure lead to the formation of metamorphic rocks. The constituent minerals of the rock are changed into more stable minerals having better structural arrangement. The structure and mineral composition of these rocks depend on the composition of the original rocks and the kind of metamorphism. The rocks formed by the action of heat- *thermal*

metamorphic, the action of pressure- *dynamo metamorphic* and the combined action of heat and pressure are called as *dynamo-thermal metamorphic rocks*.

Classification of metamorphic rocks

Based on the structure and composition, metamorphic rocks can be grouped as *foliated* and *non-foliated* rocks.

i) *Foliated metamorphic rocks:* These rocks are characterized by foliation (*arranged in parallel or sub-parallel pattern, thick in the middle and thin at the edges*). Bands of alternative dark and light coloured minerals are characteristics of the foliated metamorphic rocks. Examples: Gneiss and slate.

ii) *Non-foliated metamorphic rocks:* The non-foliated metamorphic rocks consist of minerals which are more or less equi-dimensional in shape. Examples: Marble and quartzite.

Some of the important metamorphic rocks with their characteristics are:

Gneiss	Marbles	Slate	Schist	Quartzite
Thermal metamorphism of granite (igneous), Foliated structure with light and dark bands of ferromagnesian minerals.	Thermal metamorphism of limestone/ dolomite (sedimentary), compacted, non-foliated structure with different colours.	Dynamo metamorphism of shale (sedimentary), foliated structure and grey to black in colour.	Dynamo metamorphism of Basalt + Shales (igneous + sedimentary), foliated structure and light to dark in colour.	Dynamo-thermal metamorphism of sandstone (sedimentary), non-foliated, light to red in colour and extremely resistance to weathering.

22

Chapter 3

Weathering of Rocks and Minerals

Weathering refers to natural disintegration (break down) and decomposition (chemical alteration) of the exposed rocks and minerals by the combined actions of water, wind, temperature and biological agents, leading to the formation of regolith (unconsolidated weather rock). Weathering over years leads to formation of soil. Depending upon the agents taking part in weathering processes, it is classified into three types, i.e. physical, chemical and biological weathering.

1. Physical weathering

Physical weathering is disintegration of consolidated rocks into smaller pieces without changing its chemical composition. It is caused by the mechanical force of water, air, temperature and biological agents.

a) *Water:* Water causes physical weathering in many different ways:
   i)   Falling rain drops and hailstorms beat the surface of rocks and cause some abrasions

   ii) Moving water has a tremendous carrying and cutting capacity. Water moving at a speed of 15, 30, 120 and 900cm /sec can carry fine sand, gravel, stones(I kg), and boulders of several tons, respectively. The greater the amount of suspended material, quicker will be the disintegration of rocks. Therefore, the disintegration of rocks is greater near the source of river than its tail where it slows down steadily before meeting the sea.

   iii) Water due to its erosive action can remove weathered parts of rocks and exposes fresh surfaces to weathering.

   iv) When water present in joints and cavities in the rock gets frozen in cold regions, it expands (about 9% v/v) and creates a mechanical force within the rocks and breaks them apart.

   v)   Some minerals expand on wetting and shrink on drying (hydrothermal process). The alternate expanding and shrinking or wetting and drying make the rock loose and eventually disintegrate the rocks.

vi) In cold regions, glaciers during their movement as a result of the change in temperature and/or slope gradient cause cutting and crushing of the rocks over which they pass.

b) *Wind*: Like water, wind also plays mechanical role in weathering:

i) Wind laden with fine materials (fine sand and silt) causes abrasive action on rocks and ultimately breaks the rocks.

ii) Wind in combination with ocean waves cause weathering along the sea coasts.

c) *Temperature:* Variations in temperature, especially if sudden and wide, greatly influence the disintegration of rocks.

i) Rocks get heated by the sun and expand during the day. At night, the temperature drops and the rocks get cooled and contract. The alternate expansion and contraction due to diurnal (day-night) changes in temperature in hot and desert regions weakens the surface of rocks and disintegrates them as rocks are not good conductor of heat.

ii) The rate of expansion and contraction of the minerals within a rock also vary greatly. Example: The cubical expansion of quartz is twice to that of feldspars.

iii) The dark coloured rocks undergo fast changes in temperature as compared to the light coloured rocks. This differential expansion of minerals in a rock surface generates stress between the heated expended and the cooled unexpanded parts, resulting in fragmentation of rocks. With time, this process may cause the surface layer to peel off from the parent mass and the rock may ultimately disintegrate. This phenomenon is called *exfoliation*.

d) *Atmospheric electrical phenomena*: Lightening during rainy season breaks the rocks and/or widens the cracks.

d) *Biological agents:* Biological agents such as plants (root penetration), animals (burrowing action and movement, particularly of larger animals) and cultivation also results in physical weathering.

2. Chemical weathering

The chemical weathering is a process of decomposition by various chemical processes in which the original rocks and minerals are

24

transformed into new compounds having different chemical composition and physical properties.

— Chemical weathering becomes more effective as the surface area of the rock increases because most of the chemical reactions take place on surface rocks.

— The effectiveness of chemical weathering is very closely related to mineralogical composition of rocks. For example, quartz (SiO_2) responds very slowly to the chemical reaction than olivine $(Fe,Mg)_2SiO_4$ because of their structural differences.

— The rate of chemical reaction increases with increase in CO_2 and other solvents in water, and temperature.

— The intensity of chemical weathering is highest in tropics where both water and temperature conditions are more favourable while in deserts (lack of water) and cold regions (low temperature) the intensity of chemical weathering is low.

— Plants, animals and other organisms also contribute directly or indirectly to chemical weathering since they produce CO_2 and certain acids that react with rock constituents.

The important processes of chemical weathering: The chemical weathering is brought about by solution, hydration, hydrolysis, oxidation, reduction, carbonation, etc.

1. *Solution:* Water is a universal solvent. The action of solution is considerably increased when the water is acidified by the dissolution of organic and inorganic acids. For example: Some substances like halite present in a rock are directly soluble in water. When the soluble substances are removed continuously by water, the rock no longer remains solid and form holes, rills or rough surfaces and ultimately breaks into pieces or decomposes.

   $NaCl + H_2O \longrightarrow Na^+, Cl^-, H_2O$ (dissolved ions)
   (soluble salt)
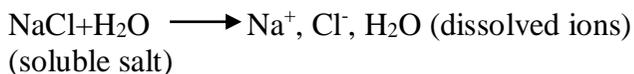
2. *Hydration***:** Hydration is the chemical attachment of water molecule with a particular rock or mineral. Primary minerals usually do not contain any water (anhydrous). They undergo hydration when exposed to humid conditions. Minerals like feldspars, amphiboles, micas become hydrated and form hydrous compounds. Example:

25

$Fe_2O_3 + 3H_2O \longrightarrow Fe_2O_3.3H_2O$
(Haematite, red)   (Limonite, yellow)
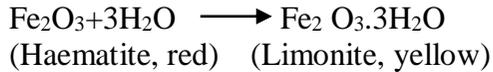
Hydration is always accompanied with increase in volume of the rock and mineral. Hydrated minerals lose their luster and become soft and susceptible to weathering. It is the most common natural process that occurring with secondary minerals.

3. *Hydrolysis:* Hydrolysis is a double decomposition process. It involves the splitting of water molecule into H^+ and OH^- ions, and reaction of minerals with water to form hydroxides and other new substances that are usually more soluble than the original mineral. Water, thus, acts like a weak acid on silicate minerals. Example:

$KAl\,Si_3O_8 + HOH \longrightarrow HAl\,Si_3O_8 + KOH$
(Orthoclase)   (Acid silicate)
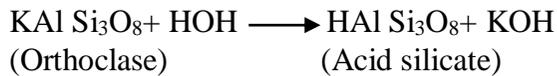
Water often contains CO_2, reacts with minerals to produce insoluble clay minerals, cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), anions (OH^-, CO_3^{2-} and HCO_3^-) and some soluble silica which are made available to plants.

4. *Oxidation:* Oxidation is the addition and combination of oxygen to minerals. It is an important chemical reaction occurring in well aerated rock where oxygen supply is high and biological demand is low. Oxidation process is particularly important in iron containing rocks and minerals as iron is easily oxidizeable. In most of the primary minerals, iron is present in ferrous (Fe^{2+}) form. On oxidation, it changes to haematite.

$4FeO + O_2 \longrightarrow 2Fe_2O_3$ (Haematite)
(Ferrous oxide)   (Ferric oxide)
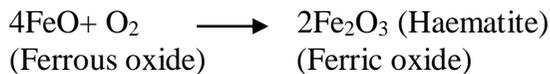
Rocks containing ferromagnesian silicates such as pyroxenes, hornblende, biotite and chlorite are susceptible to oxidation. Similarly, minerals containing manganese and sulphide group are also susceptible to oxidation.

5. *Reduction:* Reduction is the reciprocal of oxidation i.e., removal of oxygen from the mineral under water saturated conditions (such as below water table) where oxygen supply is low. The net effect of these conditions is to reduce a metal, e.g. ferric oxide to ferrous oxide which is highly soluble and mobile. If ferrous iron persists in the system, it tends to form sulphides (ferrous sulphide, FeS_2) and other ferrous compounds such as chalcopyrite, $CuFe(S_2)$.

26

6. *Carbonation:* Carbonic acid, although a weak acid of CO_2 but is an important agent in chemical weathering of rocks and minerals as it increases the solubility of minerals. The decomposition of organic matter liberates CO_2. Carbonation tends to produce carbonates and bicarbonates:

$H_2O + CO_2 \longrightarrow H_2CO_3$ (Carbonic acid)
$CaCO_3 + H_2CO_3 \longrightarrow Ca(HCO_3)_2$
(Calcite)   (Calcium bicarbonate)
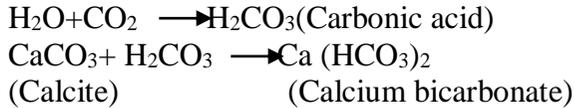
The solubility of $Ca(HCO_3)_2$ is considerably higher than calcite. In soils, H^+ present on clays are also available for such reactions. Example:

$Ca\ Al\ Si_2\ O_8 + H$ | Micelle | $\longrightarrow H_2AlSi_2O_6 + Ca$ | Micelle |
(Anorthite)   (Acid silicate)
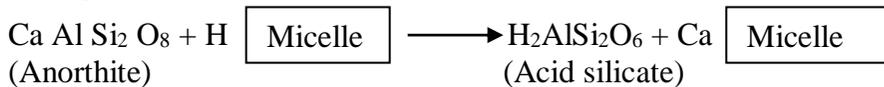
The H^+ of acid clay replace the bases of the minerals.

3. Biological weathering

It is, in fact, not a process of weathering itself but it is the biological agent which causes weathering either physically and/or chemically.

– Bacteria, fungi and actinomycetes in rocks and minerals produce appreciable amounts of H_2SO_4, HNO_3, and organic acids which activate the solution and cause the chemical weathering of the rocks and minerals.

– Roots of higher plants exert pressure in rock cracks and cause disintegration i.e. physical weathering of the rocks.

– Plant roots produce organic acids and cause chemical decomposition of rocks & minerals.

– Plant roots also serve as food for microbes which act as biological agents for weathering.

   a) *Disruptive or abrasive action of plants*:
      ☐ Keep the rock moist when covered with vegetation
      ☐ Acidic secretion from plant roots
      ☐ Penetration of roots into cracks of rocks
      ☐ Oxidation due to decomposition of organic matter
      ☐ Production of HNO_3 by nitrifying bacteria

b) *Animals by burrowing action cause weathering:* The animals like rabbits and rats burrow in the weak parts of rocks and increase the exposed surface area of rock to physical and chemical weathering.

c) *Human activities:* Activities like cultivation also cause weathering of rocks and minerals.

All the three types of weathering occur simultaneously in nature. Minerals present in rocks differ in their degree of weathering. A generalised sequence of the minerals in order of their weathering resistance is "quartz (most resistant) > muscovite, K-feldspar > Na and Ca feldspar > biotite, hornblende and augite > olivine > dolomite and calcite > gypsum (least resistant)". The degree of weathering may vary depending upon the climate and other environmental conditions.

Chapter 4

<div align="right">**Soil Formation**</div>

Soil formation is a process of transformation of rocks and minerals into soil. Soil formation starts with the weathering of rocks and minerals into regolith and subsequently the formation of true soil by combined action of soil forming factors and processes. The weathering processes are primarily destructive in nature and change the consolidated rocks to unconsolidated material called *parent material*. The soil forming processes are constructive and results in development of soil profile.

The soil formation can be shown as:

Rock	→ Weathering →	Regolith	→ Soil forming factors and processes →	True soil
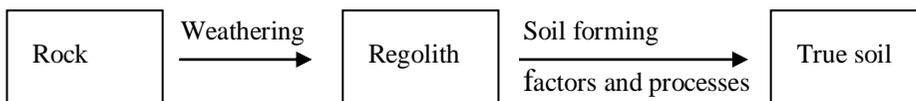
Soil Forming Factors

At any specific location, at least five factors act simultaneously to form soil. These are:

1. Parent material
2. Relief or topography
3. Time or age
4. Climate
5. Biosphere (vegetation and organisms)

All these factors are not of equal significance in development of soils, some of them are more effective in determining the nature of soils under specific conditions. These factors are inter-related to each other. The relationship of these five factors to the soil properties has been expressed by Hans Jenny (1941) as:

$$S = f\,(c, b, r, p, t, \ldots)$$

where S denotes soil or any soil property (organic matter content, pH, soil texture, etc.); c, climate; b, biosphere; r, relief; p, parent material; t, time/age and … additional unspecified factors.

Thus, any soil property is a function of the collective effects of all the five soil forming factors. Joffe (1949) divided these factors into two groups, viz. active and passive.

A. **Active***:* Active soil forming factors are climate and biosphere. Active factors represent the driving forces acting upon the parent material to form soil and promote the processes causing changes in soil properties. Soils are often defined in terms of these factors as "*dynamic natural bodies having properties derived from combined effect of climate and biological activities as modified by relief acting on parent material over a period of time*".

  A. *Climate:* Climate is the most important factor that affects soil formation directly through precipitation and temperature, and indirectly through different types of floral and faunal activities. Depending upon the amount of precipitation, temperature and evapo-transpiration the climatic regions are:

  i) *Arid:* The precipitation is less than the evapo-transpiration and soils remain dry for most of the time in a year.

  ii) *Humid:* The precipitation is more than the evapo-transpiration. The excess water causes leaching of salts (mainly bases) followed by the translocation of soil colloids in lower depths in soil profile.

  iii) *Temperate:* The cold, humid conditions with warm summers.

  iv) *Tropical and Subtropical:* Warm to hot and humid.

  a. *Rainfall:* Rainfall influences the process of soil formation in several ways.

  i) Higher level of rainfall/moisture favours hydration and hydrolysis of rocks and minerals causing rapid weathering. It also provides conditions for better growth of vegetation and microorganisms.

  ii) Soils of humid regions are poor in soluble constituents due to leaching of basic cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), and therefore, generally acidic in nature (low pH).

  iii) Well-drained and well-developed soils of humid regions are characterized by iron hydroxides in various stages of hydration, therefore, the soils of such region vary in their colour from brown to dark brown.

iv) Soils formed in humid regions have high cation exchange capacity as these soils are rich in clay and humus colloids.

v) Soils of arid regions have high amount of soluble salts because of less leaching due to limited rainfall. Therefore, soils are generally alkaline in reaction (high pH) and have accumulation of carbonates of Ca and/or Mg at shallow depths.

vi) Many arid soils show very limited profile development and contain low organic matter and clay content, therefore, possess low exchange capacity and exchangeable cations. The cations present in these soils are mainly Ca^{2+}, Mg^{2+}, Na^+ and K^+.

b. *Temperature:* Mean annual temperature has significant influence on soil formation.

i) As per Vant Hoff's temperature rule, the rate of chemical reaction increases by a factor of about 2 or 3 for every $10^{\circ}C$ rise in temperature.

ii) Ramann (Ramann's weathering factor) expresses chemical weathering as a hydrolytic decomposition of the silicates. As temperature increases, the relative degree of dissociation of water increases which enhances the chemical weathering of rocks and minerals leading to faster formation of soil.

iii) Organic matter content of soil decreases as the annual temperature rises. Humus cannot build up in soils of regions having temperature above $25^{\circ}C$ due to fast decomposition of organic matter. In soils with temperature less than $10^{\circ}C$, organic matter can be greater than 20% due to poor microbial activities/slow decomposition.

It may be concluded that climate influences soil formation directly and indirectly through precipitation and/or temperature, e.g., highly leached soils are developed under tropical and subtropical climates with high precipitation. The soils formed in humid temperate regions are grayish in colour which often modifies to black or brown depending upon the amount and nature of organic matter and iron oxides. In tropical regions, soil derived specially from igneous and metamorphic rocks is yellow and dark red in colour.

B. **_Biosphere:_** Vegetation, microbes, animals and human beings all have a great influence in soil formation and modifying its properties.

   i) Vegetation influence soil formation through the amount and nature of organic matter. Soil developed under forest has more horizons and less humified organic matter than the soils which have developed under grassland.

   ii) Microorganisms decomposing soil organic matter are dominant in forest and grasslands as compared to deserts.

   iii) Burrowing animals, rodents, earthworms, ants and termites are important in soil formation as they mix soil within the soil profile.

   iv) Human beings through their land use activities cause both deteriorating and beneficial effects on soil formation.

2. **Passive:** Passive soil forming factors are parent material, relief and time (age). These factors represent the source of soil forming material and the conditions acting upon it.

   A. **_Parent material:_** The parent material is the unconsolidated weathered mineral matter and organic materials from which the soil is developed by pedogenic processes. It determines the development of soil profile and properties of soils.

   The rate of soil formation will depend on the mineralogical nature, composition and size of particles of parent material.

   a. _Nature:_ Some minerals undergo weathering easily while others are resistant to the weathering. The order of resistance of minerals to weathering is "Quartz > K-Feldspar > Na and Ca-Feldspar > Biotite > Hornblende > Amphiboles > Pyroxenes > Olivine (orthosilicate) > Calcite > Gypsum".

   b. _Composition:_ If the parent material is composed of quartz and feldspars (resistant to weathering), the time taken for development of soil will be long and the soil formed will be coarse in texture. If the parent material is composed of amphiboles, pyroxenes, olivine or calcite i.e. less resistant to weathering, the time taken will be short and the soil formed will be fine in texture.

The elements released during weathering of rocks have specific effects on soil formation as:

i) Silicon and aluminum provide the skeleton for the formation of clay colloids.

ii) Fe and Mn are important for oxidation and reduction reactions, and influence the soil colour.

iii) Sodium acts as dispersing agents for clay and humus colloids.

iv) Ca and Mg have high flocculating power and provide stable soil structure.

c. *Size of particles:* The size of particles influences the soil formation by controlling the rate of percolating water through the parent material.

i) If the parent material is composed of coarse particles, water will pass quickly through the parent material causing fewer chemical changes.

ii) If the parent material is composed of fine particles, less water will enter and pass through the parent material resulting in fewer chemical changes.

iii) If the parent material is composed of medium sized particles, optimum amount of water enters and available within the parent material which results in higher chemical changes in parent material leading to fast development of soil.

Soil properties influenced by the parent material: Different parent materials affect profile development and produce different soils.

i) Acidic igneous rocks (granite) usually weather slowly and result in light textured (coarse) sandy soils (podzolic soils) with low base saturation and fertility.

ii) Basic igneous rocks (basalt, rich in Ca, Mg) weather rapidly giving rise to fertile and fine textured soils, e.g., black cotton soil (Vertisols) in central India.

iii) Sedimentary rocks formed from basic igneous rocks normally weather to form fine textured soils with high degree of base saturation. Montmorillonite type of clay and fertile soils are formed from these parent materials.

iv) Pure hard limestone results in shallow and coarse textured soils whereas impure soft limestone yields to deeper and finer textured soils.

v) The influence of parent material on soil characteristics gradually diminishes with the advanced development and excessive leaching.

The parent materials may be transported from the place of their origin and deposited somewhere else. The material transported and deposited by water is known as *alluvium*. The material transported and deposited by gravity is known as *colluvium*. The colluvium is poorly sorted material near the base of steep slopes. *Lacustrine* deposits consist of materials that have settled in the stagnant water of lakes. The materials blown by the wind are known as *loess* if texture is silty and Aeolian when deposits are primarily sand. *Glacial drift* consists of the materials which is picked up, mixed, disintegrated, transported and accumulated by the action of glacial ice and/or water resulting from melting of glaciers. The materials deposited by the melting glaciers vary widely in particle size and are called *till* or *moraine*.

B. **Relief or topography:** The relief or topography refers to the configuration of the land surface. The relief units are geomorphologically distinct areas such as an alluvial plain or an undulating plain. Relief is described in terms of relative relief and slope angle. The topography refers to the differences in elevation of the land surface on a broad scale. The prominent types of topographic designations as per FAO guidelines (1990) are:

Land surface	Slope
Flat to almost flat	0-2%
Gently undulated	2-5%
Undulating	5-10%
Rolling	10-15%
Hilly	15-30%
Steeply dissected	>30% with moderate elevation (<300 m)
Mountainous	>30 % with greater elevation (>300 m)

Flat to almost flat topography: On flat topography, rain water percolates through the soil. The soils formed under such conditions may have well developed soil profiles with distinct horizons.

Undulating topography: With similar rainfall and parent material, the soils formed on steep slopes are generally shallow, stony and have weakly developed profiles with less distinct horizons. It is due to removal of surface material by runoff, reduced percolation of water through soil, and lack of water for plant growth which is responsible for the checking erosion and promoting soil formation.

The steep slopes and accelerated erosion often promote downward movement of soil mass under the influence of gravity. This process is known as *solifluxion* or *soil creeps* and produces soils, termed as *Colluvial*.

Depression: The low lying areas in semi-arid and sub-humid regions have more moisture than the areas on level topography favouring higher vegetation growth and slower rate of decomposition of organic matter resulting in the formation of dark coloured soils rich in organic matter. The low lying areas in humid regions remain wet for longer period favouring the development of organic (peat or muck) soils. If the accumulating water dissolves salts from the surrounding soils, the depression may become salt marsh with unique salt tolerant plants, or it may develop unfavourable conditions for plant growth. When soils in the catchments are strongly acidic, iron may leach from them and get deposited in depressions to form the limonite (bog iron). Red soils are formed on granite rocks at higher topographic positions; the black cotton soils are developed on alluvium derived largely from basalt rocks at lower topographic positions.

Soil formation and exposure: Topography affects soil formation by affecting temperature and vegetation through slope exposures (aspect). In the northern hemisphere, soils on south and west facing slopes receive more direct sun-rays and are warmer and drier than north and east facing slopes. In arid climates, these drier south and west facing slopes are often less productive than the soils on north and east facing slopes. The opposite slopes are affected in the southern hemisphere. In cold and wet areas, these warmer sites may be highly productive. Higher temperature on south and west slopes results in greater loss of water by evaporation. The soils on southern

exposures (facing the sun) are warmer with high fluctuations in temperature and moisture. The northern exposures, on the other hand, are cooler and more humid.

Soil catena: Catena (*Latin* word, chain) is used for a sequence of topographically-related soils with similar parent material, climate and age, showing different characteristics due to variation in relief and drainage.

C. **Time:** The duration of time from the stage of weathered rock i.e. regolith to the present stage is called *age of soil*. The length of time required for soil formation/horizon development depends upon climate, nature of the parent material, relief, etc. Soil formation is a very slow process. Under ideal conditions, a recognizable soil profile may develop within 200 years whereas in less favorable circumstances, it may take thousands of years. An approximate age of soil can be assessed by *radio carbon dating*, etc.

The development will be faster in warm and humid climate, under forest and if the parent material is permeable. Extreme climatic conditions (hot, dry and cold), impermeable parent material, and very steep slopes delay in formation of soils.

Under favourable climatic environments, the soils developed on sandy parent material (Spodosols or Podzols), usually advance faster towards maturity than those derived from clayey material (Vertisols).

The term *young soil* means the soil where the soil forming processes are still in operation and the processes have not made a prominent impression on the soil profile. A *mature soil* represents a steady state of parent material (no change of parent material) with environment and different soil horizons are distinctly visible. In young soil, clay from primary materials is still being formed and its content decreases with depth whereas in mature soil, the clay is more or less in equilibrium with the primary minerals and its content increases with depth, accumulating at an intermediate depth.

In India, soils in the alluvial regions were classified on the basis of age of alluvium as *Khadar* (young) and *Bhangar* (old).

Interaction of Soil Forming Factors

The formation of soil is a diverse and complex process which is brought about by the five major factors working in combination. For instances, soil with good drainage, mild temperature and high rainfall will probably support high level of vegetation which, in turn, decompose, producing carbon dioxide that combines with water from rainfall to form carbonic acid. The resulting acidity increases the solubility of parent materials causing leaching of basic cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) leading to formation of acidic soils. High rainfall also translocates some clays and organic colloids deeper into the soil profile.

The same climate and parent material might produce waterlogged soil in low lying areas (different topography). The poor drainage results in stagnation of water which limits soil aeration, decreases plant growth and rate of organic matter decomposition. The accumulating water also leads to increase in the concentration of dissolved salts. The soil development from common factors but differing topography will be very different.

The regions of high rainfall and good drainage develop acid soils having surface horizon with high organic matter, and the accumulation of soil colloids in the deeper horizon. If the soils have been developing for a long time, they tend to have high clay content, well differentiated horizons, acidity in wet climates, and salt accumulation in some soils of arid regions.

Soil Forming Processes

Pedogenic processes are simply the reorganization and rearrangement of mineral and organic soil constituents in to different layers under the influence of various pedogenic factors. These processes are extremely complex and dynamic involving chemical and biological reactions, and usually operate simultaneously. One process may counteract another and two different processes may work together to achieve the same result. Although, all the five genetic factors contribute to the development of soil, no single soil is influenced by all pedogenic processes. A pedogenic process is distinguished by the way it works, not the kind of soil it produces. For instance, a given process operating in sandstone or limestone area may produce different results because of difference in parent material. The collective interaction of soil forming factors under different environmental conditions set a course to certain recognized soil forming processes. There are generally two categories of pedogenic processes involved in the

formation of well-developed soil i.e., *fundamental/basic soil forming processes and specific soil forming processes.*

The basic processes involved in operation of soil forming processes are:

a. *Addition or gain* of water, mineral and organic matter in the soil

b. *Loss* of water, mineral and organic matter in the soil

c. *Transformation* of mineral and organic materials within the soil

d. *Transfer or translocation* of *mineral and organic* materials from one point to another within the soil through solution and in suspension of clay, organic matter and hydrous oxides.

All these processes promote horizon differentiation by way of transformation of soil materials (mineral and organic matter) resulting in the release of soluble salts, carbonates, sesquioxide, silica, clay minerals and organic acids and their subsequent translocation with percolating water and deposition at various depths.

The major changes that retard horizon differentiation are due to:

a. Mixing of material by human and burrowing animals

b. Removal of surface soil by water and/or wind erosion

c. Creep (shifting old materials and its replacement by new materials) and

d. Accumulation of sediments in cultivated flood-plain areas, for instance silting of the irrigated areas in the Mesopotamian Plain.

1. **Fundamental soil forming processes:** The basic processes involved in soil formation are found in all soils and operate simultaneously. These are:

    i) *Humification:* Humification is "the process of decomposition of organic matter and synthesis of new organic substances", *i.e.* the process of transformation of raw organic matter into humus. It is an extremely complex process involving various organisms (bacteria, fungi, actinomycetes, earthworm and termites). The waxy pine needles after falling on the ground are attacked by microorganisms which cause the breakdown of complex plant compounds. Initially, the simple compounds, such as sugars and starches are decomposed followed by the proteins, cellulose, and then very resistant compounds such as tannins, and finally dark coloured substance known as *humus* is formed. In contrast, the decomposition of the

leaves of deciduous trees by earth worms and bacteria is much faster and may be completed within a year, leaving little organic matter at the surface.

ii) *Eluviation/emigration:* Eluviation (washing out) is "a process of removal of soil constituents (clay, Fe_2O_3, Al_2O_3, SiO_2, humus, $CaCO_3$, other salts) in suspension or solution by the percolating water from the upper to lower layers in the soil" resulting in textural differences which lead to horizon differentiation or development of soil. The upper layer where loss of soil constituents occurs is termed as *eluvial layer* (A-horizon or E-horizon). The lower layer, where soil constituents accumulate is termed as *illuviation* layer or B-horizon. The translocation depends upon the relative mobility of the constituents and the depth of percolation. Order of mobility of inorganic soil constituents expressed relative to chloride, taken as 100 is SO_4 (57.1) > Ca (3.0) > Na (2.40) > Mg (1.30) > K (1.25) > SiO_2 (0.20) > Fe_2O_3 (0.04) > Al_2O_3 (0.02).

iii) *Illuviation/immigration:* Illuviation is "the process of deposition of soil materials removed from the eluvial horizon in the lower layer". The horizons formed by this process are termed as *illuvial* horizons. The process leads to textural contrast between upper and lower horizons, and higher fine clay in the illuvial horizon.

2. **Specific soil forming processes:** The specific soil forming processes are:
   1) *Podzolization:* It is a process of translocation of iron and aluminium oxides, organic material and clay from the A-horizon to the B-horizon producing an acid soil with whitish grey *silicious* A-horizon and yellow to brown compact and impervious B horizon (podzols and podzolic soils). The favourable conditions for podzolization are:

O
Ah
E (ash colour)
Bh (black colour)
Bs (red colour)
Yellow colour
C (parent material
R (bed rock)
Na, K, Ca, Cl & SO_4 ions

   a. Temperature, rainfall, vegetation and other factors that favour an abundant surface accumulation of organic matter are favourable for podzolization. For example, coniferous forest under cold and
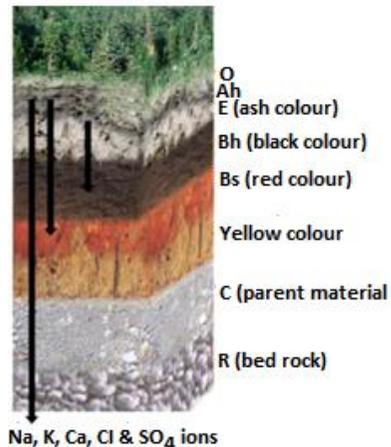
humid climatic conditions is favorable for podzolization. Under such conditions, leaching removes cations as soon as they are released by weathering.

b. Siliceous (sandy) parent material having poor reserves of weatherable minerals, favours the process of podzolization as it helps in easy percolation of water.

c. There must be sufficient moisture for leaching of organic horizon downwards through the mineral layer below. The decomposition of organic matter produces various organic acids. The organic acids, thus, formed react with sesquioxides and the remaining clay minerals, forming organic-sesquioxide and organic-clay complexes, which are soluble and move with the percolating water to the lower B-horizon. Aluminium ions in water hydrolyze and make the soil solution very acidic.

$$2Al^{3+} + 6H_2O \longrightarrow 2Al(OH)_3 + 6H^+$$

As the iron and aluminum move out, the A-horizon gives a bleached grey appearance.

Acids produced also dissolve and remove the carbonates from the mineral layer resulting in lowering of soil pH to 4.0-4.5. Under such pH, the solubility of iron and aluminium is optimum and are removed from the upper mineral horizon.

d. Acid producing vegetation such as coniferous pines and hemlock favours podzolization.

2) **Laterization:** Laterization means brick-like. Laterization is "the soil formation process that removes silica, instead of sesquioxides from the upper layer". The alumina and ferric oxides become hydrated and accumulate (to extent of 70-80 % of total mass) in the soil. Such soils become hard like a brick when dried and are called the *laterites* or *latosol*.
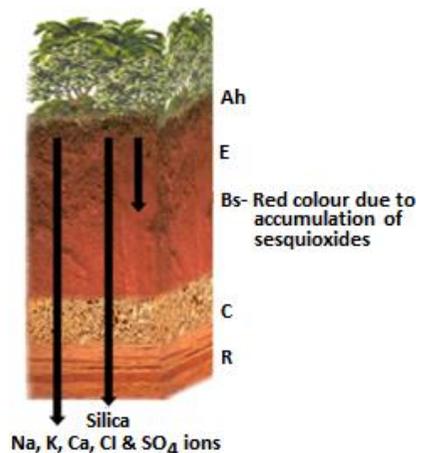
The conditions leading to

Ah

E

Bs- Red colour due to accumulation of sesquioxides

C

R

Silica
Na, K, Ca, Cl & SO$_4$ ions

40

laterization are:

a. *Climate:* Unlike podzolization, the process of laterization is most favouable in warm and humid (tropical) climate with 2000-2500 mm rainfall and continuous high temperature ($25^{\circ}C$) throughout the year. In tropical regions, warm and humid climate causes intense weathering of rocks and minerals producing silicic acid, aluminium and iron hydroxide or hydrated oxides of iron and aluminum by hydrolysis and oxidation.

b. *Natural vegetation:* The rain forests of tropical areas are most favouable.

c. *Parent material:* Basic parent materials, having sufficient iron bearing ferromagnesian minerals (pyroxenes, amphiboles, biotite and chlorite) which on weathering release iron are favourable for the development of laterites.

d. *Soluble bases:* Calcium, magnesium, sodium and potassium are quickly released in initial stages upon the hydrolysis of minerals. Neutral and even alkaline conditions result in the upper layer due to mobility of these cations and pH becomes near to 7. In neutral and alkaline solution, solubility of silica is encouraged and removed from silicate minerals. Iron, aluminium and manganese oxides are left behind together with quartz.

Laterization in conjunction with podzolization has resulted in the development of six zonal soils in the warm temperate and tropical regions. These are: Laterite, Redish brown laterite, Yellowish brown laterite, Red podzol, Yellow podzolic soils and Terra rossa

3) *Calcification:* Calcification process involves precipitation and accumulation of $CaCO_3$ or $MgCO_3$ after mobilization from upper soil layers in some part of the profile, approximately to the depth to which water percolates. Calcification process occurs in arid and semi-arid climates due to restricted rainfall. Rainfall is insufficient to leach much of the calcium and divalent cations from the soil profile which

A

Bk- Soft white powder of Ca CO3

Bk- Hard nodules of CaCO 3

C

Na, K, Ca, Cl & SO_4 ions

results in the redistribution of Ca and Mg carbonates. Surface soil has sufficient calcium to maintain the soil colloids in a high degree of base saturation.

The accumulation of $CaCO_3$ may result in the development of *calcic* horizon. Calcium is readily soluble in acid soil and when CO_2 concentration (liberated from plant root or microbial activity) is high in root zone as:

$$CO_2 + H_2O \longrightarrow H_2CO_3$$
$$H_2CO_3 + Ca \longrightarrow Ca(HCO_3)_2 \text{ (soluble)}$$

But again due to lack of microbial activity and moisture due to prolonged dry weather, the process is reversed and results in the precipitation of $CaCO_3$.

$$Ca(HCO_3)_2 \longrightarrow CaCO_3 + CO_2 + H_2O$$
$$\text{(precipitates)}$$

The process of precipitation after mobilization is called *calcification* and resulting illuviated horizon of carbonates is designated as *Bk (earlier Bca) horizon*.

4) **Decalcification:** It is the reverse of calcification, *i.e.*, the process of removal of $CaCO_3$ or Ca^{2+} from the soil by leaching.

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$$
(insoluble)   (soluble)

5) **Salinization:** Salinization is "the process of accumulation of salts such as sulphates and chlorides of calcium and magnesium in the form of salty (*salic*) horizon leading to development of saline soil". A soil is considered as saline, if ECe (salinity of saturation extract) > 4.0 dS m^{-1}, pH < 8.5 and exchangeable sodium percentage (ESP) < 15. These soils are also called *white alkali* soils.

These soils are formed under arid and semi-arid climates where evaporation losses are more than precipitation.

42

Due to high evaporation rate, upward movement (through capillary rise) of salts released during weathering and from shallow saline ground water takes place which results in accumulation of the salts at the soil surface or in root zone. Salt accumulation may also result from inundation with seawater in marine and coastal soils, and irrigation or seepage in areas of impeded drainage. Although, physical condition of saline soil is good due to presence of Ca (cause flocculation) but high osmotic pressure due to excess soluble salts in soil solution restrict availability of water and nutrients to plants resulting in poor growth.

6) *Desalinization:* It is "the removal by leaching of excess soluble salts from horizons or soil profiles by ponding water and improving the drainage conditions by installing artificial drainage network".

7) *Solonization or alkalization:* The process involves "the accumulation of Na^+ on the exchange complex of the clay and organic matter resulting in the formation of alkali soils (sodic/*Solonetz*)". These soils are also called *black alkali soils* and contain mostly CO_3^{2-} and HCO_3^- of Na and fewer amounts of Cl^- and SO_4^{2-} of Ca and Mg. All cations in soil solution are engaged in a reversible reaction with the exchange sites on the clay and organic matter particles. As the soil dries, most of the CO_3^{2-} of Ca and Mg precipitate before that of Na due to higher solubility of sodium carbonate. Thus, the sodium remains in soil solution and its adsorption on exchange sites (clay and organic matter) increases.

In sodic soils, the ESP of soil increases to a value > 15 which causes dispersion of clay leading to low permeability to air and water, and increase in soil pH (>8.5). High pH adversely affects the availability of nutrients to plants and dissolves the soil organic matter forming a thin friable layer on soil surface. This is followed by a dark coloured clay illuviated impermeable horizons having a typical columnar structure, a characteristic feature of sodic soil.

8) *Solodization or dealkalization:* The process refers to "the removal of Na^+ from the exchange sites which cause dispersion of soil". Much of the dispersion can be eliminated if Ca^{2+}
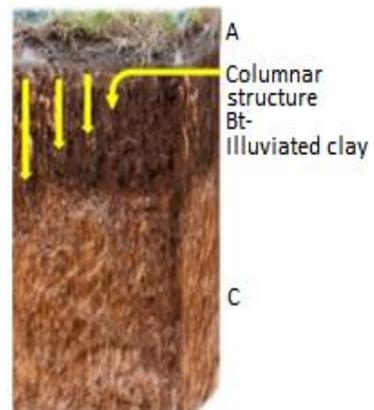
and/or Mg^{2+} are concentrated in the water used to leach the solonetz. These ions result in flocculation of clay colloids. The dealkalization process is shown as:

$$2NaX + CaSO_4 \longrightarrow Na_2SO_4 + CaX,$$
$$\text{(leachable)}$$
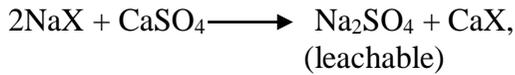
where X represents the exchange sites of clay or organic matter

9) **Gleization:** Under conditions of depression, flood plain and imperfect drainage anaerobic conditions develop and reduction of ferric to ferrous compounds takes place resulting in the development of *glei* (or gley) horizon in lower part of the soil horizons. This process is called *gleization*. This process is not dependent on high rainfall and humid regions but on drainage conditions. The gleization involves:
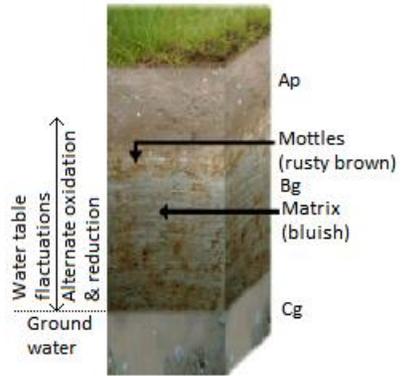
i) Reduction of ferric compounds

ii) Translocation of ferrous compounds

iii) Precipitation of Fe as mottled sand

iv) Gleization gives rise to mottled soils

10) **Pedoturbation:** Pedoturbation is "the process of mixing of the soil" taking place in all soils to a certain extent. Pedoturbation may be of *faunal* (animals- ants, earthworms, moles, rodents and human being), *floral* (plants as in tree tipping that forms pits and mounds), *argillic* (churning caused by swelling-shirking clays) and *cryo* (frost churning due to freezing and thawing) types.

Chapter 5

The most obvious part of any soil is its surface through which matter and energy are transported between soil and the atmosphere. But soil surface does not describe the character of the soil as a whole. To characterize soil as a whole, it is necessary to examine the soil in depth which can be done by digging a trench.

Soil Profile

Soil profile is a vertical section of the soil from its surface to the parent material (Fig. 6.1). In deep soils, it may be considered up to a depth of 1.8 m while in shallow soils, it is up to the bed rock/parent material or up to water table in the case of waterlogged soils.

Soil Horizons

The profile consists of a sequence of more or less distinct layers of soil almost parallel to the surface of soil varying in physical properties, chemical composition and biological characteristics from adjoining layers due to soil forming processes are called soil horizons.

Master Horizons

Maximum five master soil horizons may be observed in soil profiles which are designated using the capital letters O, A, E, B and C. Any particular profile may exhibit only part of horizons. In addition, it may exhibit more detailed sub-horizons as indicated in the (Fig. 5.1). The sequence of horizons and their characteristics within a soil profile are:
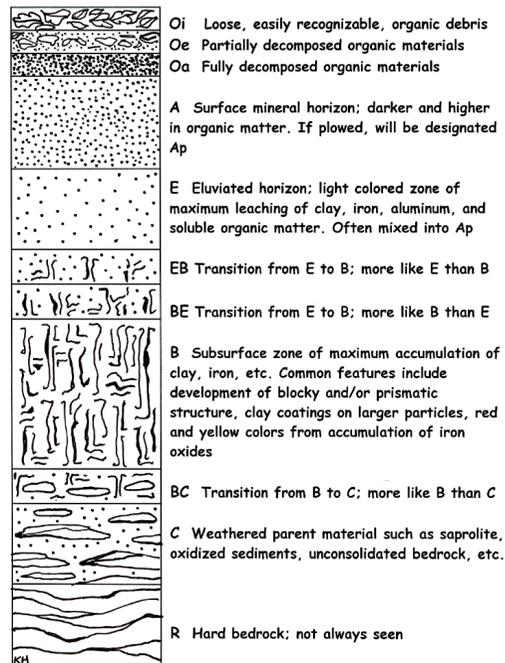
Fig.5.1: Schematic representation of a hypothetical soil profile showing horizons and sub-horizons

O-horizon: It is the upper most *organic horizon* formed above the mineral soil from the waste resulting from dead plants and animals. This horizon is typically occurs in soils developed under forests and generally absent in cropland and grassland regions. O-horizon is further divided into O_i, O_e and O_a depending upon the degree of decomposition of organic material i.e. slightly, moderately and highly decomposed, respectively.

A-horizon: A-horizon is the topmost *mineral horizon* mixed with partially decomposed (humified) organic matter which lies at or near the soil surface. Due to high organic matter, this horizon is normally darker in colour than the lower horizons. A-horizon is the zone of major biological activities, maximum leaching and most fertile zone of soil but also vulnerable to erosion by water and wind. It is also called as a zone of *eluviation.*

E-horizon: The E-horizon lies below A-horizon. Certain colloidal materials (silicate clays, oxides and carbonates) are removed continuously from this horizon by leaching leaving a higher amount of resistant minerals, such as quartz, in the coarser fraction, *i.e.,* sand and silt sizes. This horizon is also known as a zone of *eluviations,* usually found in forest areas and generally lighter in colour than the A-horizon. E-horizon is further divided into E and EB. The EB horizon is transition to B, more like to E than B-horizon.

B-horizon: The B-horizon lies immediately below the A-horizon/E-horizon characterized by less amount of organic matter than A-horizon. It is the zone of *illuviation* in which maximum accumulation of colloidal materials leached from the above lying horizons occurs. This horizon is often thicker than the A-horizon. Pressure of the overlying soil tends to reduce the porosity of this horizon. The B-horizon is further divided in to BE, B and BC. The BE is transition to E, more like B than E- horizon and BC is transition to C, more like B than C-horizon.

C-horizon: The unconsolidated material underlying the solum or B-horizon is called C-horizon which may or may not be the same as the parent material. If the soil is formed from the bedrock *in situ*, the C horizon consists of a weathered and fragmented rock material. In other cases, the C-horizon may consist of alluvial, aeolian or glacial deposits. In a young soil, the B-horizon is absent but in a developed matured soil, A- and B-horizons are more prominent and at times the C- horizon may disappear. In a recent alluvium, hardly any profile differentiation is apparent. The horizons A, E, and B are collectively termed as solum (true soil) whereas horizons O, A, E, B and C are collectively termed as regolith.

R layer: The R layer is underlying consolidated bedrock not the master horizon.

The sequence of horizons with different properties is the record of events happened to that soil since it begins to form. The specific properties and sequence of horizons that a soil acquires in the process of its development are determined by the nature of parent material from which it developed and the influence of climate, vegetation and topography which acted over a period of time to transform the parent material into soil. Soil profile is the key for the soil classification and forms the basis for the practical utility of soils.

To serve as a favorable medium for plant growth, the soil must store and supply water and nutrients and be free of excessive concentrations of toxic substances. The inherent capacity of a soil to supply nutrients to plants in adequate amounts and in suitable proportions is known as *soil fertility* whereas the ability of a soil to produce a crop is known as *soil productivity*. Productive soils are always fertile but chemically fertile soils may or may not be productive. A soil which contains adequate amount of various substances (nutrients) required in plant nutrition in available form, not excessively acidic or alkaline and is free of toxic agents can be considered to possess chemical fertility but such fertility does not by itself ensure the success of a crop. The suitability of a soil as a medium for plant growth depends also upon the state and movement of water and air and upon mechanical support of soil and its thermal regime. The soil must be loose, soft and friable to prevent root development without any mechanical obstruction. Therefore, for higher productivity, the soil in addition to chemical fertility should also possess physical fertility. Examples of soils which are chemically but not physically fertile are:

i) Soil rich in all essential plant nutrients is a desert if water is absent,

ii) Fertile low-lying land becomes worthless if flooded for a long time due to deficiency of oxygen, and

iii) Nutrients and water of the subsoil remain unapproachable to the crops if a dense plough layer restricts their root penetration.

Chapter 6

Soil Composition

The ultimate disintegrated product of rocks is called *soil mechanical separates* or *primary particles*. Plant and animal remains and residues, left on the soil as organic matter, are decomposed by micro-organisms to form *humus*. Humus and other mineral-binding agents, such as calcium carbonate, oxides of iron and aluminum, and clays, etc., bind soil separates to form *secondary soil particles* called *aggregates*. Both, primary and secondary particles form a soil matrix, in the pores of which both air and water move and are retained. The soil, thus, formed acts as the basic substrate of life on the earth and serves not only as a medium for plant growth and microbiological activity *per se* but also as a sink, and recycles many waste products which might otherwise accumulate to poison the environment. In addition, the soil supports our building and provides materials for construction of earthen structures such as dams and roadbeds.

Soil Components and Phases

Most soils consist of four basic components and three phases (Fig.6.1). The four components include inorganic solids (mineral matter), organic solids (organic matter), water, and air. Inorganic components are primary and secondary minerals derived from the parent material. Organic components are derived from plants and animals. The liquid component consists of a dilute aqueous solution of inorganic and organic compounds. The gaseous component includes soil air comprising nitrogen, oxygen, carbon dioxide, methane, nitrous oxide, and other inert gases. Under optimal conditions for growth of upland plants, the solid components (inorganic and organic) constitute about 50% of the total volume, while liquid and gases comprise 25% each. Rice and other aquatic plants are exceptions to this generalization. The organic component for most mineral soils is
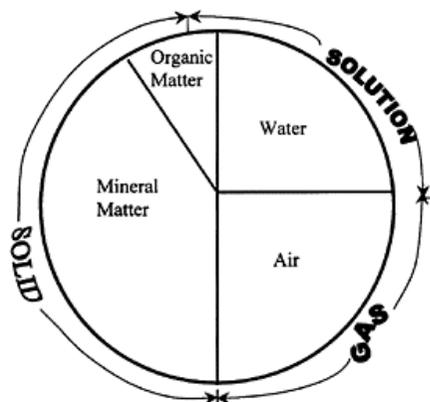
Fig. 6.1 Components and phases of soil

about 5% or less. Immediately after rain or irrigation, the entire pore space or the voids in between the solids are completely filled with water, and the soil is saturated.

When completely dry, the water in the pores is replaced by air or gases. Both air and water are highly variable and inversely related. Under optimal conditions for some engineering functions, such as foundation for buildings and roads or runways, the pore space is deliberately minimized by compaction or compression. For such functions, the solid components may comprise 80–90% of the total volume. All four components are always changing in their relative mass, volume, spatial and energy status due both to natural and management factors. General properties of the components and phases of soil are given in Table 6.1.

Table 6.1: General properties of components and phases of soil

Phase	**Component**	**Composition**	**Property**
Solid	Inorganic	Products of weathering-quartz, feldspars, pyrite, hornblende, gypsum, calcite, apatite, alumino-silicates, etc.	Skeleton, matrix, $\rho_s = 2.6\text{–}2.7$ Mg m^{-3}
	Organic	Remains of plants and animals, living organisms, usually $< 5\%$ in mineral soils	Large surface area, very active, affects CO_2 in the atmosphere $\rho_s = 1.1\text{−}1.3$ Mg m^{-3}
Liquid	Soil solution	Aqueous solution of ions (Na, K, Ca, Mg, Cl, NO_3, PO_4, SO_4)	Heterogeneous, dynamic, discontinuous $\rho_w = 1.0$ Mg m^{-3}
Gas	Soil air	N_2, O_2, CO_2, CH_4, C_2H_6, H_2S, N_2O, etc.	Variable, dynamic $\rho_a = 1.0\text{–}1.5$ kg m^{-3}

ρ_s=particle density, ρ_w=density of H_2O, ρ_a=density of air.

Soil as a Dispersed Three Phase System

The three phases existing in nature are solid, liquid and gaseous. Systems in which at least one of the phases is composed of numerous small sized particles are called *disperse systems*. Soil is a dispersed three-phase system

as it is made up of solids, liquids and gases. The soil is a heterogeneous, polyphasic, particulate, disperse and porous system.

At the interface of two phases in the soil, many physical phenomena such as adsorption of water and nutrients, capillarity, ion-exchange, dispersion, flocculation, aggregation, swelling, shrinkage, heat of wetting, etc., occur.

Composition and Importance of the Phases

1) *Solid phase:* The solid phase consists of inorganic (mineral) and organic particles. The inorganic fraction is composed of discrete rock and mineral particles varying in chemical and mineralogical composition, size, shape and orientation. It also contains amorphous compounds such as hydrated iron and aluminium oxides. Generally, the proportion of the amorphous material is small. Organic fraction of the solid phase is consists of the organic residues in different stages of their decomposition (undecomposed materials, partially decomposed materials and well decomposed products) along with vast varieties of millions of living as well as dead micro-organisms. Undecomposed materials include roots, stems, leaves, etc., and well-decomposed products are polysaccharides, humus, lipids, gums, etc.

Importance of solid phase
Mineral fraction:
☐ Forms the matrix of the soil system
☐ Provides the seat for most of the physico-chemical reactions, like ion-exchange, adsorption, etc.
☐ Shapes the pores which control the movement of air and water, and penetration and development of roots in the soil
☐ Acts as an ultimate fertility sources
☐ Provides mechanical support to the plants

Organic fraction:
☐ Organic matter helps in soil aggregation and largely responsible for the loose and friable conditions of soils
☐ Provides the essential element (nutrients) for plant growth
☐ Increases the water holding capacity of soils and available plant water
☐ Imparts soils its dark colour
☐ Main source of energy for soil microorganisms

2) *Liquid phase*
   - Water held within the soil pores dissolves the minerals present in the soil and make the soil solution.
   - Nutrients get dissolved in water and become available to plants.
   - Nutrients move from soil to root through water and from roots to leaves.
   - Water meets out the hydrogen requirement of the plants
   - Important for all the biochemical processes occurring in the plants.
   - Controls soil aeration, temperature of soil and plant, and microbiological activities in the soil.

3) *Gaseous phase (soil air):* Soil air is not continuous as atmospheric air because it is located in the soil pores separated by soil solids, therefore, its composition varies from place to place in the soil. Soil air has higher moisture than the atmosphere, the relative humidity approaches 100% at optimum moisture. The concentration of CO_2 is generally higher and that of O_2 is lower than their respective concentration in the atmosphere. In general, the CO_2 is ten times more concentrated than the 0.03%, commonly found in the atmosphere. The O_2 decreases accordingly and in extreme cases, it may not be more than 10-12 % as compared to 20.6 % of the atmosphere.

Importance of gaseous phase:
   - Soil air provides oxygen for the respiration of roots and soil micro-organisms
   - Oxygen of the soil air transforms the mineral elements into the plant available forms, for example, nitrogen to nitrate ($N-NO_3$); sulphur to sulphate ($S-SO_4$), etc.
   - Nitrogen of the soil air is fixed in the soil by microbes to make it available to the plants.

Chapter 7

Volume-Mass Relationships of the Soil Constituents

To understand the volume-mass relationship of the soil constituents, the three phases of soil are schematically shown in Figure 7.4 along with the connotations of their respective mass and volume.
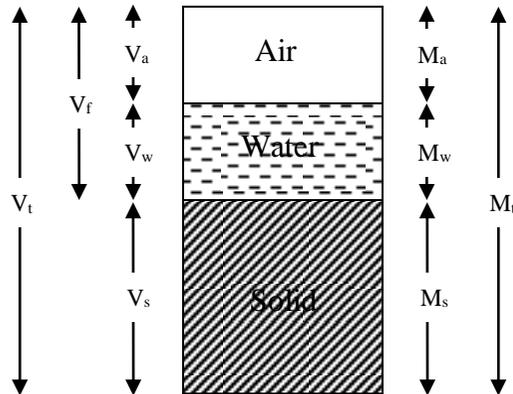
Fig. 7.4: Schematic diagram of soil as a three-phase system

The complete histogram represents the total volume and mass of soil. It is divided into three sections which are, in general, quantitatively unequal, the lower section represents the solid phase, the middle section represents the liquid phase and the top section represents the gaseous phase. The masses of these components are marked on right hand side: the mass of air, M_a; the mass of water, M_w; the mass of solid, M_s; and the total mass, M_t. The volume of the respective components is indicated on the left of the diagram. The volume of air, V_a; the volume of water, V_w; the volume of pores, $V_f = V_a + V_w$ (volume of water and volume of air constitute the total volume of pores); the volume of solids, V_s; and the total volume V_t of the soil.

Particle density (ρ_s)*:* The particle density of a soil is "the oven dry mass of the soil per unit volume of soil solid only". It is also called *density of solid particles* or *mean particle density* or *true density.* Sometimes, the density is expressed in terms of the specific gravity, being the ratio of the density of material to the density of water at 4ºC and at atmospheric pressure (760 mm

of Hg). Since the density of water at $4°C$ is unity, the specific gravity is numerically (though not dimensionally) equal to the density.

$$\rho_s = \frac{M_s}{V_s}$$

The particle density depends on the chemical and mineralogical composition of soil. In most mineral soils, ρ_s is of the range of 2.60 to 2.70 Mg m^{-3} and for most purposes an average value of ρ_s is taken 2.65 Mg m^{-3} which is close to the density of quartz mineral. Quartz is a dominant mineral in the coarsest fraction of the soil which is prevalent in sandy soils. Aluminosilicate clay minerals also have a similar particle density. The presence of iron oxides and of other heavy minerals increases the average value of ρ_s whereas the presence of organic matter lowers the value of ρ_s as organic matter is very light in weight as compared to mineral particles.

Bulk density/dry bulk density (ρ_b): Bulk density of a soil is "the oven dry mass of the soil per unit volume of soil which may be expressed as the ratio of the weight of oven dried soil to its total volume".

$$\rho_b = \frac{M_s}{V_t} = \frac{M_s}{(V_s + V_w + V_a)}$$

The ρ_s is always greater than ρ_b because V_t is greater than V_s. If the pores constitute half of the volume, ρ_b is half of ρ_s, therefore, the value of ρ_b will range between 1.30 to 1.35 Mg m^{-3}. The ρ_b of soil is influenced by soil texture, structure, moisture content, organic matter and land management practices. In coarse textured soils, ρ_b varies from 1.40 to 1.75 Mg m^{-3} and in fine textured soils it normally ranges from 1.10 to 1.40 Mg m^{-3}. Increase in organic matter content lowers the bulk density of soil. Bulk density normally decreases as mineral soils become finer in texture. High bulk density indicates compaction of the soil. The bulk density is generally higher in lower depths in the soil profile due to lower organic matter content and higher overburden of the upper soil layers. In swelling soils, bulk density decreases with increase in moisture content and vice versa. Bulk density is of greater importance than particle density in understanding the physical behavior of the soils. It is used for calculating the weight of a furrow slice of soil in a given area.

Wet bulk density (ρ_t): It is the ratio of the mass of a moist soil to the volume of the moist soil. The wet bulk density of the soil depends more on the soil moisture content as compared to its dry bulk density.

$$\rho_t \; = \; \frac{M_t}{V_t} \; = \; \frac{M_s + M_w}{(V_s + V_w + V_a)}$$

Specific volume (V_b): Specific volume is "the ratio of the volume of soil to the dry mass of soil" i.e. it is the volume of unit mass of dry soil and is expressed as cm^3g^{-1} or m^3Mg^{-1}. The V_b is an index of the degree of compaction or looseness of the soil. A higher value of V_b indicates lower levels of compaction. The values of V_b for agricultural soils may vary from 0.55 to 0.70 m^3Mg^{-1} for coarse and 0.70 to 0.90 m^3Mg^{-1} for fine textured soils.

$$V_b \; = \; \frac{V_t}{M_s} \; = \; \frac{1}{\rho_b}$$

Porosity (f): Porosity is defined as "the volume occupied by pores per unit volume of soil". The porosity is an index of the relative pore volume in the soil and generally expressed as percentage.

$$f \; = \; \frac{(V_w + V_a)}{(V_s + V_w + V_a)} \; 100 \; = \; \frac{V_f}{V_t} 100$$

Its value lies between 30 to 60 per cent. Porosity is less in coarse/light textured soils than in fine textured soils but the size of individual pores is larger in coarse textured soils than in fine textured soils. In clayey soils, the porosity is highly variable as the soil alternately swells, shrinks, aggregates, disperses, compacts and cracks during wetting and drying.

Porosity is related to bulk density and particle density of the soil and the relationship is given by the following equation.

$$f \; = \; \left(\frac{\rho_s - \rho_b}{\rho_s}\right) 100 \; = \; \left(1 - \frac{\rho_b}{\rho_s}\right) 100$$

The relationship of porosity with bulk density and particle density can be derived as:

$$f = \left(\frac{V_f}{V_t}\right)100 = \left(\frac{V_t - V_s}{V_t}\right)100 = \left(\frac{V_t}{V_t} - \frac{V_s}{V_t}\right)100 = \left(\frac{V_t}{V_t} - \frac{V_s}{V_t}\frac{M_s}{M_s}\right)100$$

$$= 1 - \left(\frac{M_s}{V_t}\frac{V_s}{M_s}\right)100 = \left(1 - \frac{\rho_b}{\rho_s}\right)100$$

Two types of pores- macro and micro, occur in soils without any clear demarcation. Usually, pores larger than about 0.06 mm in diameter are considered as macropores and those smaller than this are called as micropores or capillary pores. Macropores allow readily air and water movement, whereas movement of water and air is restricted to some extent in micropores. Pore space directly controls the amount of water and air in the soil and indirectly influences the plant growth. Distribution of different sized pores rather than total pore space is more important for crop production. For optimum growth of plant, the existence of approximately equal proportion of macro and micropores is needed, which influence aeration, permeability, drainage and water retention favorably. Porosity of a soil can be changed easily.

Capillary and non-capillary porosity: The pore spaces in the soil include both capillary and non-capillary pores which remain filled by water when the soil is saturated. As the soil dries, the non-capillary pores (macro pores) are emptied first. *Capillary porosity* is the volume of soil pores which can retain water at 50 cm tension. And it is, therefore, determined by finding the volume of water retained in soil at 50 cm tension. The *non-capillary porosity* is determined by subtracting the capillary porosity from the total porosity. Capillary pore spaces are important as water retained in these pore spaces is available to the plants for their growth.

Void ratio *(e):* Void ratio is defined as "the volume occupied by pores per unit volume of soil solids rather than the total volume of soil". It is also an index of relative volume of soil pores. While porosity is largely used in agriculture, void ratio is preferred in engineering. Void ratio is greater than porosity because V_s is smaller than V_t and its value varies from 0.3 to 2.0.

$$e = \frac{(V_w + V_a)}{V_s} = \frac{V_f}{(V_t - V_f)} = \frac{V_f}{V_s}$$

Void ratio and soil porosity are related to each other as:

$$e = \frac{f}{(1-f)}\ ;\ f = \frac{e}{(1+e)}$$

The relationships between void ratio and porosity may be derived as:

1. $e = \left(\dfrac{V_f}{V_s}\right)$

$$= \left(\frac{V_f}{V_t - V_f}\right)\ \because \theta f = \left(\frac{V_f}{V_t}\right)\ \text{or}\ V_f = f\,V_t,\ \therefore\ e = \left(\frac{f\,V_t}{V_t - f\,V_t}\right)$$

$$= \left(\frac{V_t.f}{V_t\left(1-f\right)}\right) = \left(\frac{f}{1-f}\right)$$

2. $f = \left(\dfrac{V_f}{V_t}\right) = \left(\dfrac{V_f}{V_f + V_s}\right)\ \because\ V_f = e\,V_s\ \therefore\ f = \left(\dfrac{e\,V_s}{e\,V_s + V_s}\right)$

$$= \left(\frac{e\,V_s}{\left(1+e\right)V_s}\right) = \left(\frac{e}{1+e}\right)$$

Degree of saturation *(s):* Degree of saturation is "the volume occupied by water per unit volume of pores and expressed as percentage". It ranges from zero in dry soil to 100% in completely saturated soil. However, complete saturation is seldom attained in field conditions since some air is always trapped even in a very wet soil.

$$s = \frac{V_w}{(V_w + V_a)}\ 100 = \left(\frac{V_w}{V_f}\right)100$$

Air-filled porosity *(f$_a$):* Air-filled porosity is "the volume occupied by air per unit volume of soil and expressed as percentage". This is an important criterion of soil aeration.

$$f_a = \frac{V_a}{(V_s + V_w + V_a)}\ 100 = \left(\frac{V_a}{V_t}\right)100$$

Air-filled porosity is related to the degree of saturation of soil and relationship between the two is given as:

$$f_a = f\,(1\text{-}s)$$

Relationship between air-filled porosity and degree of saturation may be derived as:

$$f_a = \left(\frac{V_a}{V_t}\right) = \left(\frac{V_f - V_w}{V_t}\right) = \left(\frac{V_f}{V_t}\right) - \left(\frac{V_w}{V_t}\right) = f - \left(\frac{V_w}{V_t}\right)$$

$$= \left(f - \left(\frac{V_w}{V_t}\frac{V_f}{V_f}\right)\right) = \left(f - \left(\frac{V_f}{V_t}\frac{V_w}{V_f}\right)\right)$$

$$= f - fs = f(1 - s)$$

Mass wetness or gravimetric water content *(θ_g):* Mass wetness is "the mass of water per unit mass of oven dry soil and often referred as the *gravimetric water content*". It is expressed as a fraction or percentage.

$$\theta_g = \left(\frac{M_w}{M_s}\right) 100$$

In mineral soils, mass wetness or gravimetric water content at saturation (when all the pores are filled with water) ranges between 0.25 – 0.60 (25 – 60 %) depending on the bulk density. The saturated water content is usually taken as maximum water holding capacity of the soil. It is generally higher in clayey than sandy soils. In the case of organic soils, such as peat and muck, the saturation water content on mass basis may exceed 100%.

Volume wetness or volumetric water content *(θ_v):* Volume wetness is "the ratio of volume of water present in the pore spaces to the total volume of soil and expressed as a fraction or percentage".

$$\theta_v = \left(\frac{V_w}{V_t}\right) 100 = \left(\frac{V_w}{V_s + V_f}\right) 100 = \left(\frac{V_w}{V_s + V_w + V_a}\right) 100$$

Volumetric water content can be computed from the gravimetric water content by multiplying it with soil bulk density. At saturation, volumetric water content is equal to the porosity of soil. In sandy soils, the value of θ_v at saturation ranges from 40 to 50%; in medium textured soils, it is approximately 50%; and in clayey soils, it can be up to 60%. In clayey soil, the relative volume of water at saturation may exceed the porosity of the dry soil since clayey soil swells upon wetting.

The volumetric water content is related to gravimetric water content as:

$\theta_v = \theta_g\, \rho_b$. The relationship may be derived as:

$$\theta_v = \left(\frac{V_w}{V_t}\right) \quad \because\ V_w = M_w \text{ as density}\quad \text{of water is 1.}$$

$$\theta_v = \left(\frac{M_w}{V_t}\frac{M_s}{M_s}\right) = \left(\frac{M_w}{M_s}\frac{M_s}{V_t}\right) = \theta_g\, \rho_b$$

Similarly, the relationship of volume wetness with degree of saturation and air-filled porosity is derived as:

1. Relationship of degree of saturation with volume wetness:

$$s = \left(\frac{\theta_v}{f}\right)$$

$$s = \left(\frac{V_w}{V_f}\right) = \left(\frac{V_w}{V_f}\frac{V_t}{V_t}\right) = \left(\frac{V_w}{V_t}\right)\left(\frac{V_t}{V_f}\right) = \left(\frac{\theta_v}{f}\right)$$

2. Relationship of air-filled porosity with volume wetness:

$$f_a = f - \theta_v$$

$$f_a = \left(\frac{V_a}{V_t}\right) = \left(\frac{V_f - V_w}{V_t}\right) = \left(\frac{V_f}{V_t}\right) - \left(\frac{V_w}{V_t}\right) = f - \theta_v$$

The expression of moisture content on volume basis is more useful and convenient as volumetric water content is directly involved in calculating water flux, volume of water added to the soil by rain or through irrigation and volume of water extracted from the soil by the process of evaporation and transpiration by plants. The expression of water on volumetric basis also expresses moisture content in terms of depth of water per unit depth of soil.

Depth of water *(d$_w$)*

$$d_w = \frac{V_w}{A} \text{ where A = area, cm}^2$$

As $V_t = A\, d_t$ $\therefore$ $A = \dfrac{V_t}{d_t}$ where d_t = depth of soil, cm.

$$d_w = \frac{V_w}{(V_t/d_t)} = \left(\frac{V_w}{V_t}\right)d_t \quad \because\ \theta_v = \frac{V_w}{V_t} = \theta_v d_t \quad \because\ \theta_{v=}\ \theta_g.\rho_b = \theta_g\, \rho_b d_t$$

Chapter 8

Soil Texture

Soil consists of solid, water and air. The content of water and air is highly dynamic but the solid phase is a permanent component of the soil which does not change much with time. It includes discrete mineral particles of various sizes and the amorphous material. The amount of amorphous material which is usually attached to the mineral particles and sometimes coats the particles is generally small, therefore, the solid phase is considered as consisting of distinct mineral particles. The largest mineral particles are visible to the naked eye and the smallest are colloidal which can only be observed by means of an electron microscope.

Solid phase forms the matrix and responsible for various properties of soil, therefore, the major interest is in finding shape, size and chemical/mineral composition of individual particle.

Soil Separates

The array of mineral particles of a soil is divided into three conveniently separable groups according to size on the basis of their equivalent diameter because soil particles are not spherical but are irregularly shaped. Therefore, for larger particles that are separated by mechanical sieving, *equivalent diameter or effective diameter* is equal to the diameter of a sphere that will pass through a given sized opening of the sieve. (*The smallest cross-sectional area of irregularly shaped particles determines the size of the material which passes through the sieve and an average diameter for such a group of particles may not be very exact*). Smaller particles are separated by sedimentation techniques and the equivalent diameter of smaller particles refers to the diameter of a sphere that has the same density and velocity of settling in a liquid medium. The various groups are termed as *separates, primary particles, textural fractions or size groups*, namely sand, silt and clay. Each of the group, thus, includes particles within a certain size range.

Soil Texture

The term soil texture is an expression of the prominent size group of particles and has both *qualitative* and *quantitative* meaning. Qualitatively soil texture refers to "the feel of soil whether it is coarse or fine when rubbed

between thumb and finger". Quantitatively, *soil texture refers to "the relative proportions of different size groups or soil separates, specifically referred to as sand, silt and clay in soil".*

The texture of a soil is more or less a static property i.e. does not change appreciably with time. Hence, texture is considered as an inherent property of a soil affecting almost all other soil properties. It determines the economic value of the land to an appreciable extent and largely governs the water and nutrient supplying capacity of soils. Land use capability and soil management technologies are largely depend on soil texture.

Mechanical Composition of Soil

The term mechanical composition is often used interchangeably with soil texture. It refers to "the ultimate mineral soil particles, such as sand, silt and clay, not to the aggregates and organic particles".

Classification of Soil Particles

Soil particles may be classified on the basis of shape, density, chemical composition or size. The classification based on shape, density and chemical composition is no longer in use. Only size of the particle is conveniently used to classify the soil particles. An essential criterion for determining soil texture is the upper limit of the particle size that is to be included in the definition of 'soil material'. Some soils contain large rocks that obviously do not behave like soil but if large rocks are numerous then they might affect the behavior of the soil in bulk. The conventional definition of *soil material* includes particles < 2.0 mm in equivalent diameter. This material is also called *fine earth*. Particles larger than 2.0 mm are generally refers to as *gravel*, and still larger rock fragment, several centimeter in diameter are called *stone* or *cobbles*, and if very large then they are called *boulders*.

Only soil material is normally considered in chemical and mechanical analysis of soils. Several schemes exist for the classification of soil particles according to particle diameter ranges (Table 8.1). Each scheme has different limits for each size fraction. The classification of the International Society of Soil Science (ISSS) (renamed as the International Union of Soil Sciences. IUSS) and the United States Department of Agriculture (USDA) are widely in use.

Table 8.1: Classification of soil fractions according to particle diameter ranges (mm)

ISSS/IUSS		USDA		European System	
Fraction	**Diameter**	**Fraction**	**Diameter**	**Fraction**	**Diameter**
Coarse sand	**2.0**–0.2	Very coarse sand	**2.0**–1.0	Coarse sand	**2.0**-0.6
Fine sand	0.2–0.02	Coarse sand	1.0–0.5	Medium sand	0.6-0.2
Silt	**0.02**–0.002	Medium sand	0.5–0.25	Fine sand	0.2-0.06
Clay	**< 0.002**	Fine sand	0.25–0.10	Coarse silt	**0.06**-0.02
		Very fine sand	0.10–0.05	Medium silt	0.02-0.006
		Silt	**0.05**–0.002	Fine silt	0.006-0.002
		Clay	**< 0.002**	Coarse clay	**0.002**-0.0006
				Medium clay	0.0006-0.0002
				Fine clay	<0.0002

In India, ISSS/IUSS system of classification of size fractions is largely in use. The general characteristics of each size fraction as per IUSS are provided in (Table 8.2).

Table 8.2: General characteristics of different size fractions of soil

Fraction	General characteristics
Sand	☐ Individual particle feels gritty when the soil is rubbed between thumb and finger ☐ Not plastic or sticky when moist ☐ Settle to the bottom of Bouyoucos cylinder in 40 minutes
Silt	☐ Individual particle feels smooth and powdery when the soil is rubbed between thumb and finger but gritty to the teeth. ☐ Not plastic or sticky when moist ☐ Settle to the bottom of Bouyoucos cylinder in 2 hrs.
Clay	☐ Individual particle feels smooth and powdery when the soil is rubbed between thumb and finger and not gritty to the teeth. ☐ Plastic or sticky when moist and forms hard clods when dry ☐ Remain suspended in water for very long period of time.

The clay may be subdivided into coarse or non-colloidal clay of 0.002–0.0002 mm and fine or colloidal clay of <0.0002 mm in diameter. There is no sharp line between colloidal and non-colloidal clay but the boundary is arbitrarily set at 0.0002 mm.

The ISSS/IUSS classification was first suggested by Atterberg (1912). In this classification, upper size limit of clay fraction of 0.002 mm is based primarily on the expression of the physical and chemical properties associated with surface activities of particles. Clay is a surface active fraction with high degree of chemical and physical activities. On the other hand, sand and silt separates don't exhibit marked physical and chemical activities. The relatively inert sand and silt fractions may be called *the soil skeleton* while the clay, by analogy, can be regarded as *the flesh* of the soil. All three fractions of the solid phase constitute *the matrix* of the soil as they are combined in various configurations.

Important Physical Properties of Soil Separates

1. *Size and shape:* The size limits of different soil separates have already been discussed in the preceding section. Sand and silt particles are primary minerals, generally spherical or cubical in shape. Clay particles are platy or needle like and are secondary minerals.

2. *Density:* Density of soil separates ranges between 2.6-2.7 Mg m^{-3} as these separates are composted of minerals like quartz, mica, feldspars, etc. having the density of about 2.65 Mg m^{-3}. Therefore, the average value of particle density of soils is nearly 2.65 Mg m^{-3}. The particle density of soil may be higher if it contains large amount of minerals like iron oxide and other heavy minerals. Depending on the amount of humus, the particle density of soil may change as the density of soil organic matter is generally low (1.1-1.3 Mg m^{-3}). The actual particle density of soil with a considerable amount of humus content may be calculated using the following expression:

$$\rho_s = \rho_m f_m + \rho_o f_o$$

where ρ_s = particle density of the soil
   ρ_m = density of the mineral matter
   f_m = fraction of the mineral matter
   ρ_o = density of organic matter
   f_o = fraction of organic matter in the soil.

3. *Mineralogical and chemical composition***:** Silica and silicates constitute the largest part of the mineral fraction of soil. Chemical composition of soil particles varies greatly from soil to soil. Sand and silt contain mainly primary minerals (predominantly quartz) which are highest in silica. Silts

62

consist of particularly K-bearing minerals. The clay is highly active and contains substantial amount of K, Ca and Mg, etc.

The clay minerals are classified into two groups: layered aluminosilicates and non-layered aluminosilicates. Layered aluminosilicates clays are built up of two types of building blocks: aluminum octahedron and silicon tetrahedron. They are mainly of three types depending on the proportion of these two types of blocks, *viz*, 1:1, 2:1 and 2:2. The first number stands for tetrahedron and the second for octahedron.

The examples are:
   1:1 or two layered clays: Kaolinite and Halloysite (Non expanding)
   2:1 or three layered clays:
      i. Expanding: Montmorillonite, Vermiculite, Saponite, Nontronite, Hectorite.
      ii. Non-expending: Illite
   2:2 or four layered clay: Chlorite

The dominant minerals are quartz in sand; quartz and feldspars in fine sand and silt; and vermiculite, montmorillonite, kaolinite and amorphous colloids in clay.

4. *Specific surface*: The specific surface is the surface area of particles per unit mass or per unit volume of soil particles, and expressed as cm^2/g or cm^2/cm^3 of soil particles.

Most of the chemical reactions and physical processes like adsorption of water, swelling, shrinkage, plasticity, soil strength, cation exchange capacity, availability of nutrients, etc., depend on the specific surface of particles. Extent of these reactions and processes is approximately proportional to the specific surface. For spherical particles:

$$S_s = \left(\frac{\text{Surface area}}{\text{Volume}} \right) = \left(\frac{4\pi r^2}{\frac{4}{3}\pi r^3} \right) = \left(\frac{3}{r} \right)$$

where S_s is the specific surface area of a spherical particle (cm^2/cm^3) and r is the radius of the spherical particle (cm). If the particles are cubical in shape, then specific surface is:

$$S_c = \left(\frac{\text{Surface area}}{\text{Volume}} \right) = \left(\frac{6L^2}{L^3} \right) = \left(\frac{6}{L} \right)$$

63

where Sc is the specific surface of a cubical particle (cm^2/cm^3) and L is the side of the cubical particle (cm).

The specific surface increases as the size of the particle decreases. For the same volume, the specific surface increases the times the size of the particle decreases. For example, if the side of a cubical particle is 1 cm i.e. L = 1

$$S_c = \left(\frac{6}{1}\right) = 6 \text{ cm}^2/\text{cm}^3$$

If we divide this cube into 10 smaller cubes whose sides are 0.1 cm or say 1 mm, then:

$$S_c = \left(\frac{6}{0.1}\right) = 60 \text{ cm}^2/\text{cm}^3$$

Thus, the specific surface area of sand particles of 1mm in size and cubical in shape would be 60 cm^2/cm^3 only, whereas clay particles of 0.001 mm (1µm) in size would have specific surface of 60,000 cm^2/cm^3 i.e. 1000 times more specific surface than sand particles.

As clay particles are plate shaped, therefore, their specific surface area would be even considerably larger. Besides size and shape, type of clay minerals also affect specific surface

Specific surface of soil particles, clay minerals and different textured soils are:

Size fraction/ soil	Diameter (mm)	Specific surface (cm^2/g)	Clay mineral	Specific surface (m^2/g)
Coarse sand	2.0-0.2	45	Kaolinite	37-45
Fine sand	0.2-0.02	446	Illite	120-170
Silt	0.0-0.002	4458	Chlorite	130-180
Clay	10^{-4} -10^{-6}	1000×10^4	Montmorillonite	580-750
Sandy loam		1×10^4- 4×10^4	Vermiculite	780-900
Loam		50×10^4- 100×10^4		
Clay		150×10^4-250×10^4		

5. *Other properties*: Sand particles exhibit practically very low plasticity, cohesion (stickiness), adsorption of water and nutrients, heat of wetting, surface tension, capillarity etc. On the other hand, clays exhibit high degree of these phenomena. Silt fraction possesses some plasticity, cohesion, etc., but to a much lesser extent than the clay.

Mechanical Analysis

Mechanical analysis is the procedure of determining the relative proportion of sand, silt and clay. The procedure involves two major steps:

1. Separation of all particles from each other, *i.e.,* complete dispersion into ultimate particles.

2. Fractionation i.e. measuring the amounts of each sized fraction in the sample.

   1. *Separation:* The primary soil particles which are often aggregated are separated and made discrete. It is done by removal of binding/cementing agents such as organic matter, calcium carbonate, and/or oxides of Fe and Al, and subsequently deflocculating the clay particles.

      a. *Removal of binding materials:* For the removal of organic matter, the soil is oxidized with H_2O_2. The $CaCO_3$ and oxides of iron and aluminum are removed by treating the soil with dilute HCl. The following reactions occur and the binding agents are converted to gaseous or brought into soil solution.
      O.M. $+ 2H_2O_2 = CO_2 + 2H_2O$
      $CaCO_3 + 2HCl = CaCl_2 + CO_2 + H_2O$
      $Al_2O_3 + 6HCl = 2AlCl_3 + 3H_2O$
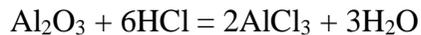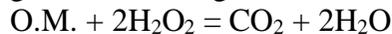
      b. *Removal of salts:* Salts already present in the soil and those formed during reactions with dilute HCl are removed through filtration with distilled water. The silver nitrate ($AgNO_3$) test is usually performed to ensure complete removal of chlorides from the sample. The $AgNO_3$ gives white precipitation in the presence of chloride in the solution.

      c. *Separation of clay particles:* Mechanical stirring in water suspension separates the clay particles from each other.

      d. *Deflocculation of clay particles:* Once the clay particles are separated, they should remain separated but they have the tendency to re-unite. Therefore, to keep the clay particles deflocculated, a small amount of a dispersing agent such as NaOH or sodium hexa-meta-phosphate or Calgon solution (Calgon solution consists of sodium hexa-metaphosphate with sufficient amount of sodium carbonate to give pH > 8.3) is added.

2. ***Fractionation:*** Fractionation means separation of soil particles into different size groups and measurement of the amount of soil material in each size group. Soil particles can be separated into different size groups by sieving them through graded sieves up to a particle of approximately 0.05 mm in size (size of sand). Sieves of different sizes having circular holes are used for particle sizes > 0.5 mm. For the smaller sized particles, wire mesh screens are used. Since the thickness of the wire for screens changes, there is no definite relationship between the number of mesh per inch and the size of screen openings.

Usually, the relation $\left(\dfrac{16}{\text{number of mesh per inch}} \right)$ is used to convert mesh number into size of sieve openings or the particle size in mm.

For separating still smaller particles (<0.05 mm), the method of sedimentation is usually used which is based on measuring the relative settling velocity of particles of different sizes in an aqueous suspension.

After complete dispersion of soil sample in water suspension, the settling velocity of the particles or the density of the suspension from which the particles are settling are measured based on the principle of Stokes' Law.

Stokes' Law (G.G. Stokes, 1851)

"The terminal velocity of a spherical particle settling under the influence of gravity in a fluid of a given density and viscosity is proportional to the square of the particle radius", and is represented by equation (1):

$$v = \left(\frac{2}{9} \frac{r^2 (\rho_s - \rho_f) g}{\eta} \right) \qquad (1)$$

where v = terminal velocity of falling particles, cm sec^{-1}

ρ_s = particle density, 2.65 g cm^{-3}

ρ_f = density of fluid (water), 1 g cm^{-3}

g = acceleration due to gravity, 981 cm sec^{-2}

r = radius of the falling particles, cm

η = viscosity, poise (0.0015)

Derivation of Stokes' Law:

A spherical particle falling in a vacuum will encounter no resistance and its velocity will be accelerated by gravity. The velocity of the falling particle, thus, will increase as it falls. On the other hand, the particle falling in a fluid will encounter a frictional resistance (F_r) in upward direction which is directly proportional to its radius (r) and velocity (v), and viscosity of the fluid (η). The resisting force due to friction, F_r, is:

$$F_r = 6\pi \eta \; rv \qquad \uparrow \qquad\qquad (2)$$

Initially, as the particle begins to fall, its velocity increases due to gravity and eventually a point is reached at which the increasing upward frictional resistance force equals the constant downward force due to gravity. At this point of time, the particle continues to fall without acceleration at a constant velocity known as the *terminal velocity*.

The downward force on a spherical particle due to gravity, F_g, is given by:

$$F_g = \frac{4}{3}\pi r^3 \rho_s g - \frac{4}{3}\pi r^3 \rho_f g \qquad \downarrow$$

$$= \frac{4}{3}\pi r^3(\rho_s - \rho_f)g \qquad\qquad (3)$$

where $\frac{4}{3}\pi r^3$ is the volume of the spherical particle.

When the termination velocity is reached, the downward force equals to upward frictional force. Setting the two forces equal, i.e. $F_r = F_g$

$$6\pi \eta \; rv = \frac{4}{3}\pi r^3(\rho_s - \rho_f)g$$

$$\text{or } v = \left(\frac{2}{9}\frac{r^2(\rho_s - \rho_f)g}{\eta} \right) \text{ which is the Stokes' Law} \qquad (4)$$

For a given fluid and falling particles, ρ_s, ρ_f, η and g are constant at specified temperature, the equation (4) simplifies to equation (5).

$$v = kr^2, \text{ where k is a constant} \qquad\qquad (5)$$

Thus, the sedimentation velocity is directly proportional to the square of the radius of the particles. The Stokes' Law is applicable to a solid sphere or soil

particle falling through a liquid or gas or to a drop of liquid falling through a gaseous medium.

If d is the diameter of the particle and assuming that the terminal velocity is attained almost instantly, one can obtain the time t needed for the particle to fall through a height h:

$$t = \left(\frac{18\,h\,\eta}{d^2 g\left(\rho_s - \rho_f\right)} \right) \text{ because } v = \frac{h}{t} \text{ and } r^2 = \frac{d^2}{4} \qquad (6)$$

Rearranging the equation (6):

$$d = \sqrt{\frac{18\,h\,\eta}{t\,g\left(\rho_s - \rho_f\right)}} \qquad (7)$$

One way of measuring particle size distribution is to use a pipette to draw samples of known volume from a given depth in the suspension at specific times after sedimentation has begun. An alternative method is to use a hydrometer to measure the density of the suspension at a given depth as function of time. With time this density decreases as the largest particles and then progressively smaller ones, settle out of the region of the suspension being measured.

Assumptions and Limitations of Stokes' Law

1. *Particles must be spherical, smooth and rigid.* But clay minerals are plate like and fall slower than spherical particles of the same mass. Particles of other shapes fall faster or slower.

2. *Size of particles must be larger than the size of the molecules of liquid* so that Brownian movement will not affect the falling velocity. The largest limit of particle exhibiting Brownian movement is approximately 0.0002 mm. In the gravitational field particles from 0.10 to 0.0002 mm in size can be determined with the sedimentation method. Soil particles down to 0.00002 mm can be separated using a centrifuge.

3. *Fall must be unhindered.* Many fast falling large particles may drag finer particles down along with them. Particles falling very near the wall of the container (0.1 mm distance) are also slowed down in their fall. However, the concentration < 3 % of solids in the suspension may reduce such hindrances.

4. *Particles must be of uniform density.* Density of majority of the mineral particles in most soils varies from 2.6 to 2.7 g cm^{-3} with an average of 2.65g cm^{-3}. This particle density can be used for reasonable accuracy.

5. *The suspension must be still without any turbulence*. Particles >0.05 mm diameter settle quickly and cause turbulence, therefore, analyzed using other procedures. Any movement of the suspension will alter the velocity of fall.

Methods of Mechanical Analysis

There are several methods of mechanical analysis such as feel method, elutriation, decantation, test tube shaking, international pipette method and hydrometer method but the *international pipette method* and the *hydrometer method* are commonly in use. Both methods are based upon the differential rate of settling of soil particles in water and the accuracy of the methods depends upon various conditions and assumptions. The international pipette method is based on the principle of sedimentation, i.e. different sized particles having different weights fall at different velocities. If a sample of soil suspension is taken at a given depth at a particular time, this will contain all the particles which are still in suspension at that depth.

The international pipette method is regarded as a standard method for particle size analysis because of its accuracy. It is very time consuming, therefore, usually not employed where large number of samples is to be analyzed.

Hydrometer (Bouyoucos, 1927) method is based on the principle that there is a continuous decrease in the density of soil suspension with time as the rate the particles fall below the level of the hydrometer. The density of the suspension progressively increases downward. So, by measuring the density of soil suspension at required times with a calibrated hydrometer, the proportion of different sized particles can be determined. The hydrometer method is considerably faster and sufficiently accurate for most purposes. But it should not be used for saline, organic and calcareous soils or soils which are difficult to disperse because as there is no pre H_2O_2 and acid treatments, and the soluble salts are not removed through filtration.

Soil Textural Classes

The overall textural designation of a soil is called the *textural class*. It is normally determined on the basis of the relative proportion of sand, silt and clay on weight basis. Soils with different proportions of sand, silt and clay are assigned to different classes as shown in *Textural triangle* (Fig. 8.1).
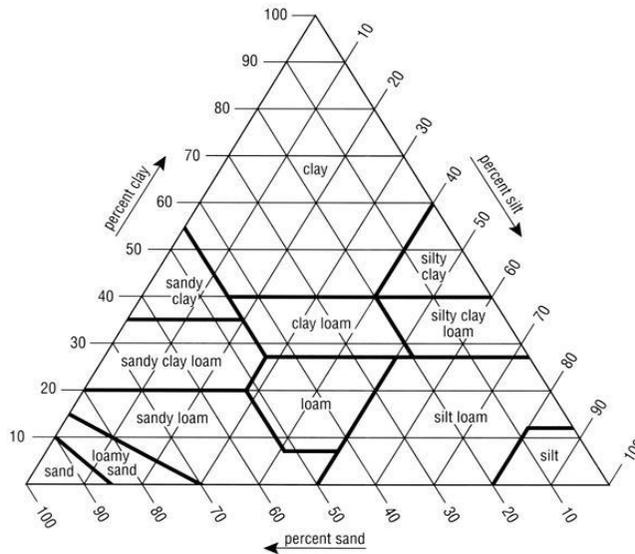
Fig. 8.1: Textural triangle (sand, silt and clay particle sizes of 2-0.02, 0.02-0.002 and < 0.002 mm, respectively)

The common textural classes in order of increasing fineness are: sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay and clay. It is important to mention that silty clay loam is finer in texture than clay loam.

There are three *broad primary textural groups* of soils: namely, sandy, loamy and clayey soils. Within each of these three broad groups, specific textural classes have been categorized based on the relative proportional of sand, silt and clay particles. There are *twelve* main textural classes.

To illustrate the use of the textural triangle, assume that a soil is composed of 40% sand, 45% silt and 15% clay. First find the point for 15% clay on the left side of the triangle. Draw a line from this point across the graph going parallel to the base of the triangle. Next, find a point for 40% sand on the base of the triangle and draw an inward line from this point going parallel to the right side of the triangle. The two lines intersect at a point corresponding to 45% silt. The name of the compartment in which these two lines intersect indicates the textural class of the soil sample i.e. *loam*.

Broad primary textural group to describe texture in relation to basic soil textural class names

Textural group	Texture	Soil textural class
Sandy soils	Coarse	sand
		loamy sand
Loamy soils	Moderately coarse	sandy loam
		fine sandy loam*
	Medium	very fine sandy loam*
		loam
		silt loam
		silt
	Moderately fine	sandy clay loam
		clay loam
		silty clay loam
Clayey soils	Fine	sandy clay
		silty clay
		clay

* not included in textural triangle diagram. These soils are usually treated separately because of their fine sand content.

Sandy soils: Includes all soils in which sand content is >70% and clay content is <15 % by weight. Two specific textural classes are *sand* and *loamy sand*. Sandy or coarse-textured soils are loose, low water retentive, well drained, well aerated and easy to cultivate. These soils are also called as *light* soils.

The expression of light and heavy soil is based on the relative energy required to pull tillage equipment for preparation of seed-bed tilth and other soil operations. Energy required for tillage is much less in light soils as compared to that in heavy soils. These terms have been abandoned now because they tend to be confusing as coarse textured soils are generally denser than the fine textured soils, and thus, are heavier in weight per unit volume as compared to fine textured soils.

In general, sandy soils have low water and nutrient holding capacity, low organic matter content, little or no swelling and shrinkage, poor sealing properties for ponds and dams, high leaching of nutrients and pollutants. The fine sands are easily blown by wind while coarse sands resist erosion by water.

71

Loamy soils: The loamy soil group contains seven sub-divisions- *sandy loam, loam, silt loam, silt, sandy clay loam, clay loam* and *silty clay loam.* To qualify for the modifier sandy or silt, a soil must have at least 40-50% of these separates. Thus, a loam in which sand is dominant is classified as sandy loam.

An ideal loam is defined as a mixture of sand, silt and clay particles that exhibits the properties of these separates in equal proportions. This definition does not mean that the three separate are present in equal amounts. From agricultural point of view, loam soil is most favorable soil as its capacity to retain water and nutrients is better than that of sand while its drainage, aeration and tillage properties are more favorable than those of clay. However, under certain specific environmental conditions and for some specific plant species, sand or clay may be more suitable than a loam.

The medium textured soils dominating in silt content have medium to high water and nutrient holding capacity, moderate aeration, slow to medium drainage, medium to high organic matter content, usually good supply of plant nutrients, moderate leaching of pollutants and nutrients. These soils are easily blown by wind and susceptible to water erosion, easily compacted, have little swelling and shrinkage and are moderately difficult to till after rain.

Clayey soils: A soil to be designated as clayey soil must contain at least 35% of the clay separates. This group is further divided into three sub-divisions. If per cent of clay is 40% or more, class name is given either as *sandy clay, silty clay* or *clay* depending upon the sand and silt contents as compared to 40% of clay. Sandy clay contains more sand than clay. Similarly, silt content of silt clay is usually more than the clay fraction. Clayey/ fine textured soils tend to absorb and retain much more water, become plastic and sticky when wet, hard and cohesive when dry, difficult to cultivate and are called *heavy* soils.

The clayey soils have high water and nutrient holding capacity, poorly aerated, very slow drainage unless cracked, high to medium in organic matter content, medium to high shrinkage. These soils resist wind erosion and aggregated clays also resist water erosion. They have very good sealing properties. They are easily compacted and retard leaching of nutrients and pollutants.

Chapter 9

Soil Structure

Under natural condition, the *primary particles* (sand, silt and clay) do not exist as discrete particles but are attached together to form aggregates (*secondary particles)*. The aggregates are defined as "the naturally occurring semi-permanent groups of soil particles", also called *peds*. The intra-particles in an aggregate are bounded with a stronger force than the forces between adjacent aggregates. A coherent mass of irregular shape formed during tillage operations is called a *clod*.

Soil Structure

Soil structure is defined as "the arrangement of primary and secondary particles into a certain structural pattern".

Importance of Soil Structure

Soil structure as such is not a plant growth factor but it influences all plant growth factors including soil aeration, availability of water and nutrients to plant, soil temperature, root penetration and their development in soil, activities of soil microorganisms. Soil management practices like tillage, application of fertilizers, manures, amendments (liming, gypsum) and irrigation affect the soil structure. Stable soil structure decreases the detachment and transportation of soil particles by water or wind and reduces soil erosion.

Classification of Soil Structure

Many attempts have been made to classify soil structure but yet there is not a universally accepted system of its classification. It is because there is no satisfactory method of measuring soil structure. The methods available are in fact indirect methods i.e. measuring one or more soil attributes which are dependent upon soil structure.

Soil structure can be described and classified based on (i) *the type*, the shape and arrangement of peds; (ii) *the class*, the size of the peds and (iii) *the grade*, distinctiveness and durability of the peds. Soil structure may also be classified according to the size of pores.

Types of Soil Structure

Soil structure is classified into simple and compound structures based on the shape and arrangement of peds.

1. **Simple structure:** The natural cleavage planes are not present. Simple structure is of two types.

    a) *Single grained structure:* When the particles are completely unattached to each other or soil is said to be structureless. Since even a loose arrangement is also a sort of structure, the term single grained structure is preferred. This type of structure is found in loose sand.

    b) *Massive structure:* When the particles are bonded in large cohesive, non-structured blocks. The structure is considered to be massive. It is similar to single grained structure except it is coherent e.g. surface crust, plough pan, etc.

2. **Compound structure:** In compound structure, the natural cleavage planes are distinct. The shape of individual ped is described according to the relative length of the vertical and horizontal axes, and by the shape of their edges. Compound structures are classified into four principal types (Fig.9.1).

    a) *Cuboidal or blocky:* All three dimensions of peds are almost similar in size and the peds are of cube or block shape with flat or rounded faces. It is further sub-divided into two groups:
    (i) Angular blocky: Faces are flat, and edges and corners of the cube are sharp angular.
    (ii) Sub-angular blocky: Faces and edges are mainly rounded.

    The blocky structure usually exists in B-horizon and promotes drainage, aeration and root penetration.

    b) *Prismatic:* The vertical axes are more developed than the horizontal axes. Cleavage planes are predominantly vertical. It is sub-divided into two groups.
    (i) Prismatic: Tops of peds are relatively angular and flat.
    (ii) Columnar: Tops of peds are distinct and rounded.

    Prismatic structure is usually found in B-horizon of soils of arid and semi-arid regions.

c) *Platy:* Horizontal axes are larger than vertical axes, giving a plate like shape. Cleavage planes are predominantly horizontal. The thick units are called *platy* while thin units are called *laminar.* This type of soil structure is largely inherited from the parent materials.

d) *Spherical:* In spherical structure, all the axes are developed equally with the same length. The peds are rounded with curved and irregular faces. Generally, all rounded or spherical aggregates are <10 mm in diameter. It is again sub-divided into two groups:

   (i) Granular: It has rough surface and is less porous due to low organic matter.
   (ii) Crumb: When granules are especially porous due to high organic matter.
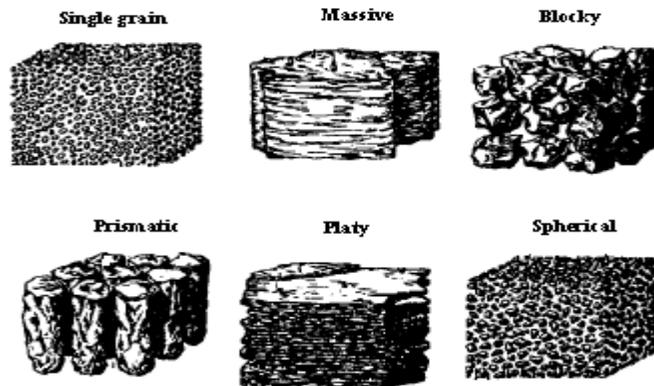
Fig. 9.1: Types of soil structure

The granular and crumb structure are characteristics of surface horizon. In spherical structure, the physical properties like infiltration, percolation, aeration, etc., are not restricted.

Classes of Soil Structure
Each type of soil structure is differentiated further in the following classes on the basis of sizes of their aggregates.

Very coarse	>10 mm
Coarse	5-10 mm
Medium	2-5 mm
Fine	1-2 mm
Very fine	<1 mm

Aggregates of sand size are more favorable for plant growth.

75

Grades of Soil Structure

Grade is the qualitative method of classification of soil structure. The grades of soil structure are determined by the durability and stability of aggregates. It reflects the ease of separation of aggregates by raindrop impact or under submerge condition. There are five grades:

a. *Poorly developed*: No noticeable aggregation, similar to the conditions exhibited by loose sand.

b. *Weakly developed*: Poorly formed, indistinct and not durable.

c. *Moderately developed*: Moderately well developed peds, fairly durable and distinct.

d. *Well developed*: Well developed peds, durable and distinct.

e. *Strongly developed*: Very well formed peds, quite durable and distinct.

The presence of high moisture, kaolinite clay, divalent cations and high organic matter content make the aggregates relatively softer.

The sequence of grade, class and type is followed for naming a soil structure, e.g. strong coarse angular blocky.

Genesis of Soil Structure

Genesis of soil structure refers to "*the causes and methods of formation of structural units or aggregates*". The processes involved in genesis of structure are flocculation and cementation

1. *Flocculation*: It is "an electro-kinetic phenomenon in which positive and negative charges are involved". Primary particles with a high zeta-potential repel each other when they collide in a suspension. On sufficiently lowering the zeta-potential, the collision of particles results in mutual attraction and formation of floccules. These floccules are stable till the flocculating agent is present. Flocculation is the grouping of the colloidal particles in a suspension. Colloidal particles of clay usually carry negative charges. When they come in contact with cations, floccules of silt size are formed. Dehydration, presence of divalent or trivalent cations and high soluble salt content favourable for flocculation.

2. *Cementation of floccules*: It refers to "the consolidation of clay floccules by cementing material so that they are not dispersed once they are flocculated". Since floccules are smaller than silt, therefore, flocculation would be unfavorable for plants unless they are further aggregated by

$CaCO_3$, oxides of Fe and Al and organic cementing materials (organic matter and humus). Though flocculation of clay particles is prerequisite for aggregation but not a sufficient condition for aggregation. *Aggregation is flocculation followed by cementation.*

Factors Influencing the Formation and Stability of Soil Structure

1. *Amount and type of clay minerals:* Silicate clays assist in cementing primary particles into stable aggregates, therefore, higher the amount of clay more will be the aggregation. Kaolinitic clays flocculate and form aggregates more readily than montmorillonite. Montmorillonite clays form aggregates of cuboidal or spherical in shape whereas kaolinite clays produce platy structure

2. *Texture:* A sandy soil containing a fair amount of silt and clay not sufficient enough for aggregation may result in a massive structure upon puddling. Silt loam soils having a fair amount of organic matter may be well aggregated but with low organic matter these soils have unstable structure and crust easily. The soils of very high clay content usually have massive structure due to high cohesiveness of clay particles.

3. *Nature of exchangeable and soluble cations***:** Calcium and magnesium are helpful in aggregation. Exchangeable sodium in sodic soils deflocculates the soil colloids when wet. When dry, the soils are massive, hard and compact, and form crusts. If salt concentration is high, as in saline and saline-sodic soils, the soil colloids are flocculated. Such soils have very friable and good structure. But due to high salinity, plant and microbial population is less and therefore, structure is not very stable.

4. *Organic Matter:* Fats, waxes, lignin, proteins, resins, etc., have a direct effect in stabilizing soil aggregates. Organic matter, being loose and porous, reduces the cohesion and plasticity of clay, and is therefore, responsible for the porosity of soil aggregates. Humus serves as cementing agent and helps in aggregation by forming clay-humus complexes in various ways. Only Ca-humus is flocculated due to its tendency to form complexes with organic compounds in linkage with metallic ions (chelation). The Mg and Na humus is deflocculated and does not help in soil aggregation.

5. *Dehydrated sesquioxides***:** Dehydration of hydrated sesquioxides form almost irreversible colloids and helps in formation of stable aggregates.

6. **Other inorganic cement:** $CaCO_3$ precipitates around soil particles and imparts stability to soil aggregates.

7. **Synthetic soil conditioners:** These are long-chain organic compounds generally used for soil aggregation. These compounds attach themselves to the exchangeable sites of the clay and link many clay particles. Addition of these compounds in relatively small amounts can cement and stabilize aggregates. These compounds are also used for reclaiming saline and sodic soils and producing good structure even in sandy soils.

8. *Plants and plant residues*: Plants help soil particles to aggregate in many different ways. One of the most important is the excretion of gelatinous organic compounds from the roots which bind the particles together. Root hair penetrates clods and creates points of weakness and ultimately breaks the soil clods into aggregates. Root hairs also help the soil particles stick together in granular form. Plant residues (roots and shoot) serve as food for microbes which play prime role in aggregate formation, and produce mucous substances upon decomposition.

9. *Micro- and macro-organisms***:** Algae, fungi, actenomycetes and bacteria which form the living matter in the soil, bind the soil particles together more effectively than any exchangeable ion. These microbes also help in aggregation, indirectly, by producing cementing materials during decomposition of organic matter.

   The small animals like rodents, earthworms, spiders, mites, nematodes, insects, centipedes, millipedes, etc., help in the soil aggregation by burrowing, turning the soil or thoroughly mixing the organic residues with the soil.

10. *Water:* Water molecules acts as dipoles which help in orienting charged particles. Water causes swelling and shrinking, and freezing and thawing of soil aggregates which help in developing planes of weakness and thus, formation of structure. Surface tension at air-water interface keeps the soil particles together. Sufficient water throughout the growing period assures maximum biological activity in the soil which is one of the prime requisites for the genesis of soil structure.

11. *Air:* Air affects aggregation through its physical, chemical and biological effects:

Physical: Dry aggregates attract water with a great force due to surface tension at air-water interface. During wetting, the air is compressed in the centre of the aggregate and tends to escape with minor explosions. Unless large pores are present, aggregate breaks up.

Chemical: Chemically, air assists in the precipitation of iron and aluminum colloids that act as cementing agents. The high content of CO_2 in the soil air solubilizes calcium and other ions in solution which form important links between the soil particles.

Biological: Biologically air is necessary for the respiration of roots and microbes. An extended period of flooding deteriorates soil structure.

12. *Temperature*: The type of clay formed and their zeta- potentials, exchangeable ions, soluble salts and organic matter are influenced by the temperature which in turn have direct effects on formation of aggregates and hence, soil structure.

13. *Tillage:* Optimum tillage promotes aggregation. Tillage operations make the soil loose and mix the organic matter well with the mineral constituents. Excessive tillage using heavy machineries tend to destroy aggregation by disruption of weak aggregates, quick decomposition of organic matter and through compaction. Ploughing a heavy soil in wet condition destroys the soil structure and creates the puddled condition. When soils are cultivated in too dry condition, large clods in heavy and fine dust in light soils are produced, respectively.

14. *Irrigation:* The amount, method and time of irrigation also influence soil aggregation. Heavy irrigation breaks the aggregates. The broken aggregates block the soil pores and forms hard surface crust on drying. The slower rate of water application, as in case of sprinkler and drip irrigation systems, allow the aggregates to wet slowly and the explosive action of entrapped air becomes very small. While in fast rate of water application, as in case of flood irrigation, the aggregates are completely immersed in water instantly and the explosive action of air is very high.

When irrigation is applied in relatively moist soil condition, the dispersion of aggregates is very less. Sometimes irrigation water, unlike rainwater, carries silt particles and blocks the spaces between aggregates leading to the formation of massive structure. In very sandy soils, these suspended materials may add sufficient silt to sand to allow aggregation.

79

Chapter 10

Soil Colour

The soil colour depends on the wave length of light (0.38-0.75 μm) that is reflected by soil to the eyes (visible light colours). Different wavelengths are associated with different colours, for example, the wavelength of 0.49-0.57, 0.57-0.60 and 0.62-0.75 μm is associated with green, yellow and red colour, respectively. Soil colours may vary from place to place in the landscape. Adjacent soils may even have different coloured surface horizon e.g., black and red soils existing side by side in Andhra Pradesh. The colour in a soil profile may change with depth through the different horizons. The horizons may have colours of same hue but of different chroma and value. It is an easily observable characteristic and have little influence on the behavior of soils but provide information regarding soil conditions and some properties of soils. For example, dark coloured surface soils absorb more solar radiation than light coloured soils and get warm up faster. It is important in soil classification, interpretation and description of soil profiles, and the processes involved in the soil formation. The presence of excessive salts, soil erosion, etc., may also be indicated by the soil colour. Hence, it is important to understand the causes and significance of soil colour.

Origin of Soil Colour

There are primarily three factors that provide a particular colour to a soil:

i) *Mineralogy and chemical constituents of mineral matter:* Mineral matter derived from the parent material of soils imparts colour to soil depending on its constituents. The soil colour is directly proportional to the total surface area of soil components. Since the colloidal fraction has the largest surface area, therefore, texture, has the greatest impact of soil colour.

ii) *Organic matter content:* Upon addition of organic matter, the colour of soil changes from brown to black with the progression of decomposition process by microorganisms. Humus is the dark coloured final product of organic matter decomposition. As a consequence, soil horizons high in organic matter are darker in colour than those of low in organic matter.

iii) Soil moisture condition: Soil colour becomes dark as the moisture changes from dry to moist. Red, yellow or brown colours are mostly related to the extent of oxidation, hydration and coating of iron oxides on the soil particles. Thus, yellow, red and brown colours are mostly due to the presence of goethite, hematite and magnetite, respectively. The oxygen determines the oxidation states of several elements, especially, of iron in its oxide forms. Minerals like manganese oxides and glauconite impart black and green colour, respectively to soils. Carbonates, such as calcite accumulating in soils of semi-arid regions impart a white colour to soil. Well drained soils generally have bright and uniform colours while waterlogged soils have bluish-gray colours often with mottling**.**

Description of Soil Colour

The most common method of describing soil colour is by using the *Munsell soil colour chart*. The Munsell system divides soil colour into three simple variables: *hue, value* and *chroma* (Fig. 10.1). A small piece of moist soil is compared to the standard colour chips in the soil colour chart. Each colour chip is described by hue, value and chroma.

i) **Hue** is the wavelength of the colour. It refers to the dominant spectral colour (purple, blue, green, yellow, orange, red). The symbol of hue is the letter abbreviation of the dominant colour such as P for purple, B for blue, G for green, Y for yellow, YR for orange (yellow-red) and R for red. Each dominant colour has four numerical values: 2.5, 5.0, 7.5 and 10. The colour intensity increases with the increase in number. Thus hue may be expressed as 10R, 7.5YR, 5Y or 2.5G.

ii) **Value** refers to the relative lightness or darkness of colour i.e. the tone of the colour. The lightness is compared with the absolute white. The value varies between 0 for black and 10 for white. The gray has value notation of 5.

iii) **Chroma** is the relative saturation of the dominant spectral colour. It defines the gradations of purity of colour which increases with decreasing greyness. It extends from /0 for neutral grey colour to /8 for strongest colour, although it may extend up to/20 for some bright colours.

The Munsell colour notations are systematic numerical and letter designation of each of these three variables. For example, the 10YR5/1 constitutes 10YR as *hue*, 5 as *value* and 1 as *chroma*. The equivalent soil colour name for this Munsell notation is 'grey' as shown in Fig 10.1.

The best time to determine soil colour is noon as at this time, a pure white light is received from the Sun. Further, soil colour should be determined when soil is moist to wet as at this moisture content soil colour shows maximum darkness. Water may be sprayed if soil is dry. If colour is determined when soil is dry, the moisture content should be specified to avoid error in the interpretation of soil colour.
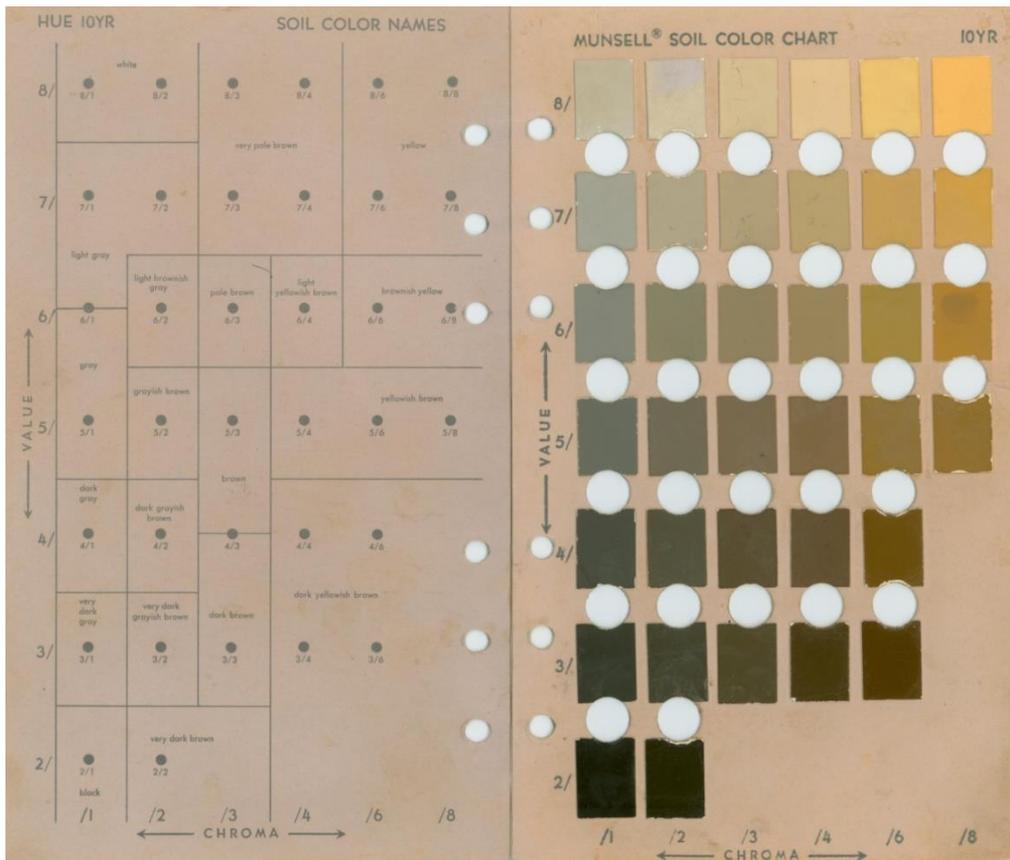
Fig. 10.1: Munsell soil colour chart (www.munsell.com)

Significance of Soil Colour

Soil colour is an important indicator of the following aspects of soils:

i) *Soil productivity:* Darker coloured soils are generally associated with higher productivity.

ii) *Nature of parent material:* The young soils developed from basic rocks are generally darker than those developed from acidic rocks. Soils rich in humus are darker in colour. In tropical conditions, black soils are low in organic matter but their black colour is due to a combination of base cations (Na, ca), humus and montmorillonite clays. Soils developed from quartz materials are light in colour.

iii) *Genesis of soils:* The colour helps in understanding the genesis of soil, particularly, mature soils. The colour indicates the climate under which the soil has been developed, for example, in tropics and subtropics, the soils are of red and yellow colour because of accumulation of oxides and hydro-oxides of iron and leaching of silica from surface horizons. Hydrated iron oxides provides yellow colour to the soil. The soils formed in humid temperate and cold conditions are light (greyish) coloured due to accumulation of silica and leaching of iron in surface horizons. Presence of mottles (spots or streak of a particular colour) indicates poor drainage conditions.

iv) *Stage of profile development:* Mature soils show distinct colour from one to another horizon while in young soils, the colour gradation is less pronounced.

v) *Soil classification:* The *Soil Taxonomy* system of classification uses terms based on soil colour such as *'alb'* (white) and *'umber'* (dark). Similarly earlier systems of classification, the great soil group are named based on soil colours like *chernozem* (black), *sierozen* (grey), *latosol* (red), *podzol* (ash grey), etc.

vi) *Soil erosion:* Eroded soils are clearly distinguished from uneroded soils by light colour due to loss of organic matter content.

vii) *Heat balance of soil:* Dark soils are warmer than light soils as they absorbed maximum heat energy from solar radiation and exhibit higher rates of evaporation.

viii) *Presence of excessive salts:* White surface colour indicates presence of excessive soluble salts in saline soil.

Chapter 11

<div align="right">**Soil Consistency and Plasticity**</div>

Soil Consistency

Soil consistency is the physical property of soil that is reflected in its resistance to deformation and rupture. It may be defined as "the resistance of soil to deformation at different moisture contents".

The cohesion and adhesion forces acting within the soil mass are responsible for soil consistency. The cohesion force (molecular attraction) is due to zeta potential or van der Wall's forces of attraction. The cohesion force is large when the particles lie close together having relatively large surface area in common, as in case of oriented colloidal clay. The cohesion force is greatest in dry soil and it decreases as water enters between the soil particles and keeping the particles apart. The adhesion force to holding particles together is due to surface tension, therefore, depends on the presence of both water and air. The adhesion is greatest where the meniscus is curved the most i.e. in soils of limited moisture content. At this moisture content the contact area of soil particles is fairly small, therefore, the cohesion force is small. As the moisture content increases, the adhesion force decreases a little, as a result consistency decreases. At a certain point in wet range, however, adhesion force decreases in such a manner that the increase of cohesion force due to increase in area of contact does not compensate it, consequently, consistency decreases. In saturated soil, the cohesion and adhesion forces are zero. A plot of consistence against moisture status of a soil would show two maxima and two minima. Consistency is large at the extreme low level of moisture due to cohesion and in the middle of the wet range due to adhesion.

These relationships hold good in soils with sufficient clay as silt and sand contents contribute little to molecular attraction. Once the consistency of a clay soil is destroyed and the soil particles are separated it can only be re-established after wetting the soil for re-orienting its particles again. Other factors affecting consistency are:

1. *Texture:* Surface area of a soil and hence its consistency increases with fineness of the particles.

2. *Type of clay:* Since consistency increases with increase in surface area, the montmorillonite clay has more consistence than kaolinite.

3. *Organic matter:* Clay particles are more cohesion than organic matter but cohesive forces are more in organic matter than sand and silt particles.

4. *Structure:* A well structured soil has less consistency than a puddle soil due to increased contact between the individual particles upon puddling. Puddling orients the clay particles so that they lie parallel to each other and fitting the large pores with soil particles thus decreasing pore space. Also disperse soil has more consistency than a flocculated soil.

5. *Presence of sesquioxides and hydroxides and calcium carbonate:* These constituents increase the consistency of soils.

Forms of Soil Consistency

At different moisture contents, different types of consistencies are formed.

1. *Hard or Harsh:* Hard consistency is observed in *dry soil* because at low moisture, the soil remains very hard and coherent due to cementation of the dried particles.

2. *Soft and friable:* Soft and friable consistency is observed in *moist soil* because of the decrease in coherence between soil particles due to adsorption of water molecules on their surfaces with increase in the moisture content. As particles stick together only slightly, therefore the soil mass becomes friable. The range of soil moisture in friable condition is optimum for tillage operations.

3. *Plastic:* It is observed in *wet soil*. At this moisture, soil can be molded to any shape and maintain even after the removal of deformation pressure without losing its coherence. It is an optimum range for puddling.

4. *Sticky:* It is observed in *very wet soil*. At this moisture content soil sticks to different objects. Sticky point is defined as "the moisture content of the soil when it ceases to stick to any foreign object".

Soil Plasticity

Plasticity is defined as "the property which enables a soil to take up water to form a mass that can be deformed into any desirable shape and to maintain the shape after the deformation pressure is removed". It results from the plate shape of clay particles and the binding and lubricating effect of adsorbed water molecules. Water forms thin films around the soil particles upon adsorption. The particles slide over each other when pressure or force is applied and held in that condition by the tension of moisture films even after the pressure is removed. Soils with < 15 % of clay do not exhibit plasticity in

any moisture range. This amount, however, depends on type of clay and amount of organic matter in the soil.

Atterberg's Consistency Limits

Atterberg (1911) devised simple empirical criteria of describing the relationship between soil consistency and soil moisture which are known as *Atterberg's limits*. He established three limits of soil consistency i.e. *shrinkage limit, plastic limit and liquid limit* (Fig.11 .1).

1. *Shrinkage limit (SL):* It is "the water content at which soil transforms from the semi-solid to solid state". Below this water content the change in soil volume with further decrease in water content is practically zero.

2. *Plastic limit (PL):* It is "the minimum moisture content at which a soil can be deformed without cracking", also called as *lower plastic limit*. It is the upper limit of moisture content for tillage operation for most crops, except rice. Tilling the soil at moisture content above the plastic limit results in smearing and puddling of soil.

3. *Liquid limit (LL):* The liquid limit is "the moisture content at which a soil ceases to be plastic", also known as *upper plastic limit.* It becomes semi fluid and tends to flow like a liquid under an applied force. This limit is used for classification of soils for engineering purpose.

There are some important terms used while describing soil consistency, which are plasticity index (PI) and friability index (FI).

Plasticity index (PI): "The difference in the moisture content between liquid limit (LL) and plastic limit (PL) is the range over which a soil remains plastic". It is difficult to till the soils having PI. Expanding clays (smectites) in soil increases liquid limits and plasticity indices also increases. Soil plasticity is determined by *liquid limit device*.

PI = LL-PL

The plasticity index is used in civil engineering as greater PI means greater soil compressibility.

Friability index (FI): It is the difference in moisture content between liquid limit (LL) and shrinkage limit (SL)

FI = PL-SL

It is a useful index in agriculture as it defines the water content range over which soil is friable. Larger value of FI indicates that soil remains friable over a larger range of water content and good for tillage.

Chapter 12

Different kinds of soils are formed as a result of various soil forming factors and processes. In order to understand the differences, similarities and relationship amongst different soils, it is necessary to group them in some orderly manner.

Soil Classification

Soil classification is "the grouping of soils in some orderly and logical manner". It is primarily based on differentiating characteristics of soils for their identification and study. The properties are selected in accordance with the purpose of the classification. These are called *differentiating characteristics* to separate one class from the others. For example, soils are classified as sandy, loamy or clayey soils based on their textures. For classifying the individual soils of a large and widely varying type, it is necessary to group the individuals into classes, and further into higher classes. This kind of grouping is called a *multi-categoric or hierarchical system of classification*. Therefore, the individual soils are grouped into classes of lower category (soil series) which are further grouped into classes of higher categories (great group or soil order). A large number of differentiating characteristics are used in defining the soils in lower categories (i.e. completely defined) but a few for higher categories. Within each class is a central core to which the individual soils are related to varying degree. It is called *typic*, the central concept which typifies the class.

Purpose of Soil Classification

The purpose of soil classification is to:

i)   Recognize properties of the soils

ii) Learn new relationships and principles of soils being classified

iii) To establish groups or subdivisions (classes) of the soils for practical and applied purposes in order to predict their behaviour, identify their potential use, estimate their productivity and transfer technologies from laboratory to land.

Evolution of Soil Classification Systems

1. ***Early systems of soil classification:*** Earlier systems of classification of soils were very simple and practical but of limited utility as these systems were based on a single character with little or no emphasis on profile characteristics of soils. These classification systems were:

   i) *Economic classification:* Grouping of soils based on their productivity and potential for irrigation for the purpose of taxation by revenue department. The system became outdated the moment land use changed.

   ii) *Physical classification:* Grouping of soils based on soil texture, a closely associated property with soil productivity and management aspects, e.g. sandy, loamy or clayey soil. This system was applicable only to the Zonal Soils.

   iii) *Chemical classification:* Grouping of soils based of chemical composition reflecting their behaviour, e.g. calcareous, gypsiferous, alkali, saline or acid soils. This system does not allow classifying all kinds of soils occurring in nature.

   iv) *Geological classification*: Earlier, Geologists after recongnizing the close relationships between soils and their parent materials grouped soils into two broad categories:

   a. *Residual or sedentary soils* which are developed *in situ* from the underlying rocks, e.g. basalt, granite, limestone.

   b. *Transported soils* which are developed from transported and deposited sediments like alluvium, aeolian or colluvium.

   This system unable to recognize the dynamic process of soil genesis controlled by climate and vegetation, e.g. the same parent material produces two different soils under varying climate and vegetation. However, many properties of a soil could be explained based on the characteristics of its parent material.

   v) *Physiographic classification*: This system considers the characteristics of landscapes and the soils are grouped as levee, basin, terrace, hilly, lowland, upland soils, etc. Though this system is largely in use as a base in modern soil survey and mapping programmes due to the existence of a close relationship between soil and landscape, yet has limited value as different soils may occur in one physiographic unit.

vi) *Other systems of classification*: Other systems were also advanced from time to time to classify soils based on different criteria. For example:
  a. *organic matter content* as organic and inorganic soils
  b. *soil structure* as single grained or aggregated soils
  c. *climate* as arid, humid or sub-humid soils
  d. *vegetation* as praire, grassland, cropland or forest soils

  All these systems address very little about soil itself, therefore, have limited use.

2. ***Recent systems of soil classification:*** The scientific systems of classification of soils were developed mainly in Russia and the United State of America. These systems are based on the study of the soil profile which is the ultimate product and reflection of all the soil forming factors and processes. The soils are classified into well defined categories indicating different levels of classification.

  i) *Dokuchaiev's Genetic System (1990):* A Russian scientist, V.V. Dokuchaiev (founder of modern pedology) while working in central Russian Upland observed that the uniform loess like parent material spread over hundreds of kilometres having an increasing temperature gradient from North to South and an increasing rainfall and moisture gradient from East to West, were associated with different vegetation patterns varying from forest to steppe (prairie), and left their imprint on parent material producing distinct soil differences. These observations led him to classify soils mainly giving emphasis on soil genesis and hence, the term *Genetic System* of soil classification came into existence.

  According to Genetic system of classification, Dokuchaiev (1900) divided soils into three categories: *Normal*, *Transitional* and *Abnormal*. These categories were later termed *Zonal*, *Intrazonal* and *Azonal* soils, respectively.

  a) *Zonal soils:* The soils termed as *zonal* that have fully developed soil profiles correspond to the climatic and vegetation zones of the region, e.g. Sierozem, Chestnut, Podzols and Laterites.

  b) *Intrazonal soils:* The soils occurring within the zonal areas having the characteristics that are determined by local conditions

such as topography, specific parent material, drainage, soluble salts are termed as *Intrazonal soils*, e.g. Calcimorphic and Hydromorphic soils.

c) *Azonal soils:* The soils which possess poorly developed profiles because of time as limited factor are termed as *azonal* soils. These soils include young soils without horizon differentiation. This may also be due to parent material or local condition, e.g., slope. The soils developed on recently deposited alluvium or colluvium belongs to this group.

The Russian approach had some inherent weakness of having undue emphasis on climate and vegetation rather than on the intrinsic properties of soil. The principles of the approach are, however, still used in different soil classification systems but at different categoric levels.

2. *Marbut's Morpho-Genetic System:* Murbat the renowned figure in the evolution of *soil taxonomy* in the USA. Marbut (1935) accepted the concept of Dokuchaiev's of Soil type, but renamed it as *Great Soil Groups*. He was the first to promote classification of soils based on intrinsic properties of soils rather than soil forming factors. His classification was based on the iron-alumina and lime contents and divided the Zonal Soils into two classes: *Pedalfers* and *Pedocals*. The *pedalfers* were presumed to occur in areas of high rainfall having excess leaching and accumulation of iron and aluminium oxides. The *pedocals* were assumed to occur in areas of high evaporation having deficit of water and accumulation of calcium carbonate.

He emphasized that soil classification should be based of soil morphology and stressed the need for examination of soils for their characteristics such as colour, texture, structure, consistency, thickness and arrangement of horizons, drainage condition, nature of parent material, occurrence of lime, soluble salts or organic matter, therefore system is called *Morpho-Genetic*.

Since his system was based partially on the assumptions concerning soil genesis and as such, many of the *soil series* recongnised in USA could not find a suitable place in the system, hence, not became widely acceptable.

3. *Baldwin and Associates' Genetic System:* Due to the limitations, the Morpho-Genetic system of Marbut was revised and elaborated by Baldwin *et al.* (1938) and Kellogg and Thorp (1949). They emphasized the Marbut's morphogenetic system and returned to *zonality* concept, pedocal-pedalfer concept was deemphasised and major emphasis was laid on soil as a three dimensional body and its own characteristics. A new category, *viz, Soil Family,* was introduced between *Great Soil Group* and *Soil Series* but they were not properly defined in terms of soil properties. Then, Throp and Smith (1949) revised the system by rearranging and developing new Great Soil Groups. The soils were grouped in three orders, *viz*, *Zonal* (normal soils with characteristics reflecting the effect climate and vegetation on well drained soils), *Intrazonal* (well developed soils showing influence of local factors such as age, parent material and relief) and *Zonal* (poorly developed soils).

The three Orders were further subdivided into 9 Suborders on the basis of specific climatic and vegetative regions. Each Suborder was divided into Great Soil Groups which were an expression of more specific conditions. The Great Soil Groups were further subdivided into numerous Soil Family, Series and Soil Types. The genetic system marked the beginning of the comprehensive systems of soil classification.

Major Limitations of the Genetic System of Soil Classification:

i) The two highest categories (Order and Sub-Order) were defined in genetic terms and not on the basis of soil properties.

ii) The concepts and definitions of the highest category, i.e., the Order, in terms of soil properties are not clear.

iii) The Great Soil Group concepts were qualitative and definitions were based on the environmental factors rather than on the soil properties.

iv) In definitions, more emphasis was given on properties of virgin soils which got modified by use

v) The nomenclature in the highest categories laid too much emphasis on colour or vegetation rather than the salient properties of the soils.

vi) The nomenclature was evolved from many languages and it was difficult to name the intergrades.

Hence, a desirable system soil classification should be based on combinations of soil characteristics known to be significant to genesis and behavior not directly on either genesis or behavior of soils.

Soil Taxonomy: A Comprehensive System of Soil Classification

In order to overcome the shortcomings of the Genetic Systems of soil classification systems, US Soils Survey Staff in cooperation with many other institutions had been working since 1951 to arrive at a classification system that narrows the differences in different viewpoints. Each year, starting from 1953, an approximation was produced and tested. In 1960, a comprehensive system of soil classification, popularly known as the 7th approximation (Soils Survey Staff, 1960) was published as *Soil Taxonomy* in 1975.

Soil Taxonomy is a system of classification of soil and designed for improving communication amongst soil scientists working at different parts of the world and other users of soils. It is useful in the context of soil survey interpretation and making predictions for land use planning or a soil map-unit. The system was put into official use in the USA and now being followed worldwide including India. A supplement of 7th approximation appeared in 1964 and another in 1967. The nomenclature of Soil Taxonomy is coined, largely from *Greek* and *Latin* words that fit in any modern European language without translation. The name of each *taxon* indicates the place of taxon in the system and connotes some of its most important properties. The system accommodates intergrades at subgroup level.

Soil Taxonomy was adopted in India in 1969 and since then, it has been introduced in the course curriculum of Agricultural Universities for teaching Soil Science and the pedologists classified the soils as per US Taxonomy.

Diagnostic Horizons of Mineral Soils (< 25% OM)

Diagnostic horizons are used to differentiate among soil orders, suborders, great groups, and sub groups. A diagnostic horizon is defined as one, formed through pedogenic processes and having distinct features that can be described in terms of measurable soil properties. The important diagnostic horizons and their characteristics are presented in Table 12.1. Based on their location in soil profile, diagnostic horizons are categorized into two categories.

a. ***Epipedons* (Gr.** *epidermis,* **skin;** *pedon,* **soil):** The diagnostic surface horizons are called *epipedons.* The epipedons are simply the upper most soil horizons and include the upper part of the soil darkened by organic matter. Nine epipedons, viz. *folistic, histic, melanic, mollic, anthropic, umbric, ochric, plaggen* and *gross arenic* are recongnized but only three of these, viz. *mollic, umbric* and *ochric* are of importance in the soils of India.

b. ***Endopedons* (Gr.** *endo,* **subsurface;** *pedon,* **soil):** The diagnostic subsurface horizons are called. The endopedons includes the lower part of the soil where soil materials accumulate. Nineteen endopedons, *viz, argillic, natric, agric, spodic, sombric, cambic, kandic, oxic, sulphuric, salic, placic, albic, glossic, calcic, gypsic, duripan, fragipan, petrocalcic,* and *petrogypsic* are recognized. Out of these 19, eight endopedons, *viz, argillic, natric, cambic, kandic, oxic, salic, calcic* and *gypsic* are commonly observed in India.

Table 12.1: Major features of important diagnostic horizons in mineral soils used to differentiate at the higher levels of soil taxonomy

Diagnostic horizon (and designation)	Derivation	Major features
Surface horizons- Epipedons		
Mollic (A)	L. *mollis,* soft	A thick (>25 cm) dark coloured, with high base saturation (>50%), strong structure, containing ≥1% organic matter with munsell colour values darker than 3.0 when moist. For sandy soils, it may be as shallow as 18 cm.
Umbric (A)	L. *umbra,* shade	Similar to mollic but <50% base saturation, dominantly saturated with H^+ and remains moist for >9 months in a year.
Ochric (A)	Gr. *ochros,* pale	Light in colour, <1% organic matter, hard or very hard when dry and do not qualify for any other horizon.
Histic (O)	Gr. *histos,* tissue	Layer with .20-30 % organic matter depending upon clay and water saturated for >30 days.

Melanic (A)	Gr. *melan*, black	A thick black horizon with high organic carbon (≥6 %), normally formed on volcanic ash deposits and aridic soil properties in top 30 cm.
Folistic (O)	Gr. *folia*, leaf	Layer with high organic matter and water saturated for < 30 days. Organic carbon content of 8-16% depending on clay content.
Anthropic (A)	Gr. *anthropikos*, human being	Developed by human altered or transported material and meets almost all the requirements of a *mollic* epipedon.
Plaggen (A)	*Gr. plaggen*, sod	Man-made surface layer of ≥50 cm thick produced by continued sod manuring, identified by artifacts (bricks, pottery, etc.), ≥0.6% organic carbon and remains moist for >3 months in a year.
Gross arenic (A)	*L. grossus*, thick*; arena,* sand	Sandy horizon of thickness ≥100 cm over an *argillic* horizon.
Sub-surface horizons- Endopedons		
Argillic (Bt)	L. *argilla*, white clay	Silicate clay accumulation. Clay content varies with the clay of the layer above.
Natric (Btn)	L. *natrium*, sodium	An argillic horizon with columnar or prismatic structure, ESP >15%, more exchangeable $Mg^{2+}+Na^+$ than Ca^{2+} with exchange acidity at pH 8.2.
Cambic (B)	L. *cambiae*, to change	A coloured structural B-horizon formed due to alteration by physical movement or chemical weathering.
Kandic (Bt)	Modified from kandite	An argillic horizon with or without clay skins of low CEC (<16 cmol (p^+)/kg soil at pH 7)
Oxic (Bo)	Fr. oxide	Highly weathered, primarily mixer sesquioxides and dominance of low charge clays (1:1) type, e.g., kaolinite

Salic (z)	L. *sal*, salt	A salt enriched horizon ≥ 15 cm thick, having EC_e of ≥ 30 dS m^{-1}).
Calcic (k)	L. *calcis*, lime	An illuvial horizon of $CaCO_3$ or $CaCO_3$, $MgCO_3$ accumulation.
Gypsic (y)	L. gypsum	Accumulation of gypsum ($CaSO_3$) having at least 5% more than the C horizon and ≥ 15 cm thick.
Spodic (Bhs)	Gr. *spodos*, ashes	Illuvial horizon of free sesquioxides and organic matter
Agric (A or B)	L. *ager,* field	Organic and clay accumulation just below plow layer resulting from cultivation
Duripan (m)	L. *duras,* hard	A subsurface horizon cemented by SiO2 and peds do not slake in water.
Fragipan (x)	L. *fragilis*, brittle and pan	Brittle pan, usually loamy textured, weakly cemented.
Albic (E)	L. *albus*, white	Eluvial horizon of ≥ 1 cm thickness formed by light coloured sand and silt
Petrocalcic	Gr. *petro*, rock and calcic	Cemented calcic horizon
Petrogypsic	Gr. *petro*, rock and gypsic	Cemented gypsic horizon
Sombric	Fr. *sombre*, dark	Humus horizon with colour and base saturation of *Umbric* epipedon accumulation
Glossic	Gr. *glossa*, tongue	Remnant of an argillic or kandic horizon from which clay and free iron oxides removed

Structure of Soil Taxonomy

The hierarchical system has six categories of classification. From the highest to the lowest level, the categories are grouped into two, i.e., higher and lower categories. The higher categories give general understanding of soils over large areas indicating world-wide relationships whereas the lower categories give local differences and are important for assessing productive capabilities of soils for utilization purposes. The various categories of Soil Taxonomy along with their differentiating characteristics in soil are given in Table 12.2.

1) Higher categories
   i) *Order:* The highest category in the system
   ii) *Sub Order:* Comparable to great soil groups of the Genetic System
   iii) *Great Group:* A basic category based on diagnostic subsurface horizons

2) Lower categories
   i) *Sub Group:* A new category designed to define the central concepts of great groups
   ii) *Family:* A practical category for making predictions and land use plans
   iii) *Series:* The lowest and most specific category

Table 12.2: Differentiating characteristics and description of categories in Soil Taxonomy

Category	Differentiating characteristics and description
Order	12 Orders (AVAGAMI HOUSE)* - a word to remember the names), Six of the orders are differentiated by the presence or absence of *diagnostic horizons* or other features. These features are characteristics of major processes of soil formation which are greatly affected by different climates, and indicated by the presence or absence of major diagnostic horizons.
Sub Order	68 suborders within 12 orders, differentiated largely based on presence or absence of additional properties and horizons associated with moisture and temperature regimes, parent material and vegetation. Suborder is distinctive to each order and not interchangeable to other orders
Great Group	More than 300 in number, based on presence and absence of diagnostic horizons and soil features. The differentiating horizons include those that have accumulated clay, iron and /or humus and that have pans which interfere with water movement or root penetration. The differentiating soil features are properties of clays, soil temperature, and major differences in content of calcium, magnesium, sodium, potassium, gypsum, and other salts.
Sub Group	More than 2000 in number, *Typic* is used to integrate great groups, suborders and orders, and the extra graded to 'not soil'.

Family	The properties most important for plant growth which meet the practical predictions for land use planning- texture, structure, consistency, permeability, thickness of horizon, temperature and pH of soil
Series	Lowest category in the system, collection of soil individuals essentially uniform in differentiating characteristics and arrangement of horizons (like colour, texture, structure, consistency, pH, EC) and most useful for making land use plans of a small area. The name of the soil series has no pedogenic significance but represents a prominent geographic name of river, town or area near where the series was first recognized.

* A- Alfisols, V- Vertisols, A- Andisols, G- Gelisols, A- Aridisols, M-Mollisols, I- Inceptisols, H- Histosols, O- Oxisols, U- Ultisols, S-Spodosols, E- Entisols

Salient Features of Soil Taxonomy:

☐ Unlike the Genetic System, it is based on measurable soil properties that exist today.

☐ It considers all such properties which are the outcome of soil genesis but it does not appear in the definition of soil taxa. Hence, soil genesis forms the backbone of the system.

☐ The words used in nomenclature are coined mainly from *Greek* and *Latin* languages which are most logical and help in relating the place of taxon in the system and making interpretations.

☐ The common definition of a class of taxonomic system is *type*.

☐ A new category, i.e., *subgroup*, has been introduced to define the central concepts of Great Groups and their intergrades in order to express and recognize more clearly that soils are in continuum and show gradual change in many properties.

Nomenclature

A name is essential for each class and/or category in soil classification systems. The nomenclature used in Soil Taxonomy is based on coined words from Greek or Latin, with a few from English, French and Japanese languages. The basic principles followed in coining the names are that the name should be as short as possible and most easily remembered, euphonic

and fitting readily in as many languages as possible, and suggest some properties of the soil and the place of taxon in the system.

In soil taxonomy, the twelve soil orders on the basis of formative elements, their derivative including the newly proposed Andisols and Gelisols are given in Table 12.3 and their extent in India is given in Table 12.4.

The names of the Orders are coined words having a common ending, sol (L. solum, soil) with a connecting vowel 'i' or 'o' for Latin and Greek words, respectively. A formative element is abstracted from the name of each order. It starts with first vowel and ends with last consonant preceding the connecting vowel. For example, 'alf' from Alfisol, the element starts with the first vowel (a) ands with the last consonant (f) preceding the connecting vowel (i).

This formative element (*alf*) is used as an ending for coining the names of all Sub Orders, Great Groups, Sub Groups and families within the Order *alfisol*.

Each Sub Order consists of two syllables, first is the suggestive of the class (Sub Order) and second is name of the Order, e.g. *Ust-alf*.

The names of Great Groups are made by *prefixing* an additional prefix, e.g. *Hapl-ustalf*.

The names of Sub Groups are made by prefixing one more adjective with the Great Group, e.g., *Typic Haplusalf*.

For family name, texture, mineralogy class and temperature regimes are included in order to the Sub Group, e.g., Fine, mixed, isohyperthermic *Typic Haplusalf*.

Series are named after a town, village, river near where they were first recognized therefore, named as, Hansi, fine, mixed, isohyperthermic *Typic Haplusalf*.

This soil has a fine texture, mixed mineralogy and high temperature. Its Sub Group is *Typic* and it belongs to *Alfisol* Order with Sub Order as *Udalf*. The Great Group of the soil is *Hapludalf*.

Table 12.3: Soil order names and their formative elements

Order	Formative element	Derivation	Mnemonicon (memory device)
Alfisol	*alf*	Nonsense symbol	Pedalfer
Andisol	*and*	Modified from ando	Andesite
Aridisol	*id*	L. *aridus*, dry	Arid
Entisol	*ent*	Nonsense symbol	Recent
Gelisol	*el*	Gr. *gelid*, very cold L. *gelare*, to freeze	Gelid Jell
Histosol	*ist*	Gr. *histos*, tissue	Histology
Inceptisol	*ept*	L. *inception*, beginning	Inception
Mollisol	*oll*	L. *mollis*, soft	Mollify
Oxisol	*ox*	Fr. oxide, oxide	Oxide
Spodosol	*od*	Gr. *spodos*, wood ash	Podzol; odd
Ultisol	*ult*	L. *ultimus*, last	Ultimate
Vertisol	*ert*	L. *verto*, turn	Invert

Table 12.4: Extent of land areas of different soil order in India

Order	Area (Mha)	Percentage of Total	Rank
Inceptisol	95.8	29.13	1
Entisol	80.1	24.37	2
Alfisol	79.1	24.25	3
Vertisol	26.3	08.02	4
Aridisol	14.6	04.47	5
Mollisol	08.0	02.43	6
Ultisol	00.8	00.26	7
Oxisol	00.1	00.03	8
Andisol	Very small extent		9
Histosol	Absent		
Gelisol	Absent		
Spodosol	Absent		

Out of 12 Orders, 9 Orders soils are occurring in India. The extent of Inceptisol, Entisol and Alfisol constitute more than 75 % area of the country.

Differentiating Properties of Soil Orders:

1. Entisols (recent soils)**:** These are very recently developed mineral soils with no diagnostic horizon other than an ochric or anthropic epipedon. The main feature of Entisols is slight degree of soil formation may be due to resistant parent material of lack of time for less time for development of significant profile (A-C horizons) or both. By virtue of plant growth and root penetration, Entisols show some mineral weathering and surface accumulation of organic matter. Entisols are having variable parent materials ranging from recent alluvium, through sand dunes, to a variety of rocks. Some are found on young geomorphic surfaces, such as floodplains and on steep slopes where erosion removes soil material as it is formed. They are formed under different climatic conditions. In rocky humid or sub humid mountain regions of Himachal Pradesh, medium textured Entisols are common. Sand dunes of Rajasthan, Haryana, and central Punjab are extremely sandy Entisols. The fluviatile Entisols are also observed in the recent flood plains. Some Entisols are too stony, infertile or poorly drained for cultivation. However, large areas in alluvial bottom lands are used for growing varieties of grains and vegetable crops.

2. Vertisols (L. *Verto-* turning): The vertisols are characterized by black soils having swelling clays (>30%). In dry seasons, deep and wide cracks are develop (> 1 cm wide) with high bulk density between the cracks. When it rains, water runs into the cracks and a significant amount of material from upper part of the profile may fall into the cracks before the whole soil becomes wet and results in a partial inversion of soil. Such processes account for the term 'invert' which is used to characterize this order, in general way. They are generally unsuitable for building, highway and even for agricultural purposes due to development of deep and wide cracks. These soils are sticky and plastic when wet and hard when dry. They are mainly found in Madhya Pradesh, Maharashtra, Gujarat, Andhra Pradesh, Tamil Nadu and Rajasthan. These soils are excellent for natural grazing and

100

with irrigation, they can be cultivated for two crops in a year. Under rainfed conditions, these soils can support one crop only. Important crop grown are cotton, corn, millets, sorghum, etc. in a year either during monsoon period or on stored moisture in winter season. Paddy is grown on Vertisols in lower topographic position where irrigation is available. These soils are very productive, provided they are very productive.

3. Inceptisols (*L. Inceptum- beginning*)**:** Inceptisols are soils representing early stage in soil formation. The profile development is more advanced in this order than that of Entisols but less than that of Alfisols. They may have some accumulation of clay in a subsurface horizon but it is not sufficient enough to qualify for an *argillic* horizon, which is diagnostic for Alfisols and Ultisols. Similarly, they may have dark coloured surface horizon which may be limiting in depth, organic matter or base saturation to be qualified for a mollic epipedon (Mollisols). The inceptisols are usually not dry and have one or more of the diagnostic horizons (cambic, umbic, or mollic with low base status). These soils occur almost throughout the world. In India, these are found all over except in hot and arid regions. Most of the inceptisols are agriculturally productive and provide excellent natural grazing grounds, but some have limited productivity because of poor drainage and/or sodicity. Most of the inceptisols (e.g. Ustepts) of Haryana and Punjab under assured irrigation conditions produce wheat up to 4.5 t/ha.

4. Mollisols (L. *Mollis-* soft): These are soils of grasslands vegetation under sub-humid to humid environment. They have dark coloured, well developed and base rich soils. The surface horizon is rich in organic matter, non-acid, poor in phosphate and characterized by a mollic epipedon. The surface horizons generally have granular or crumb structures and not hard even when soils are dry. Most of the Mollisols have developed under prairie vegetation. The sub-surface horizons, rich in illuviated clay (argillic), calcareous (calcic) or gypsiferous materials (gypsic) may be present. Characteristic features result

101

from decomposition of organic material, especially, fine roots of grassy vegetation, producing some stable dark compounds. Mollisols are predominantly observed in central USA, and from east to west across the Russia and central South America. In India, such soils are dominantly observed in the *Tarai* region of Uttar Pradesh and Uttaranchal and some regions of Himachal Pradesh and northern Bihar, and in Maharashtra and Madhya Pradesh. The Mollisols are inherently the best agricultural soils of the world. In India, these soils produce optimum yields both under irrigated and unirrigated conditions with minimum inputs. These soils are used mostly for grazing in drier areas and cultivated for crops like wheat, maize, sorghum, and vegetables, etc., in humid regions.

5. Aridisols (L. *Aridus*- dry): These mineral soils are mostly found in dry climates with high ground water table, and the soil layers are dry throughout the most of the year except in regions where water for irrigation water is available. Due to limited water availability, these soils have not been subjected to intensive leaching. They have an *ochric* epipedon of light colour and low organic matter. They may have horizon of accumulation of calcium carbonate (calcic), gypsum (gypsic), or even more soluble salts (salic). The Aridisols widely occur in the arid and semi-arid climatic environment, especially, in Asia, Africa Australia, America, and Russia. In India, these soils occur in some parts of Rajasthan, Gujarat and Haryana. In non-gypsiferous landscapes of Haryana and Punjab, they are used for growing usually pearl millet in a year by adopting water conservation practices during monsoon period or with stored moisture. The Aridisols have limitations of xerophytic climatic conditions and brackish groundwater which comes to surface due to high evaporative demand rendering the soils saline and unsuitable for plant growth, except for salt tolerant vegetation.

6. Spodosols (Gr. *Spodos*- wood ash): Spodosols are mineral soils which have a *spodic* horizon (white in colour), a subsurface horizon with an accumulation of organic matter, and sesquioxides. These soils develop under cool, humid climates and coarse textured siliceous parent material which favours free leaching conditions, and also formed in hot, humid tropical and worm humid regions where the parent material in sandy rich in quartz and ground water fluctuates.

102

The diagnostic feature of these soils is an illuvial horizon, enriched with sesquioxides and humus underlying an *albic* (light in colour) horizon justifies reference to wood ash. They occur only in humid climates and most common where it is cold and temperate. These soils are largely distributed in north-west Europe, northern and north-east USA and Canada. These soils have not been reported to occur in India because of the lack of typical parent material (siliceous) and/or environmental conditions (cold, humid) needed for their formation. In earlier system of soil classification, these soils were classified as Podzol, Brown Podzolic and Hydromorphic soils by recognizing the bleached ash coloured alluvial E-Horizon. Forests are the natural vegetation under which most of these soils have developed. Spodosols are not naturally fertile but these soils can become productive when fertilized.
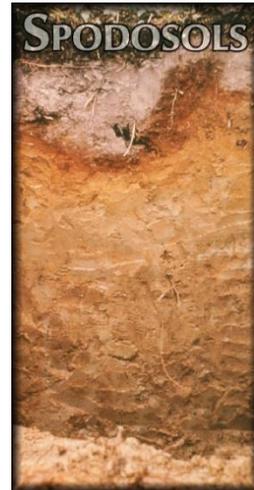
7. Alfisols (*Alfus-* from pedalfer of Marbut, weathered): Alfisols are base rich, mineral soils of sub-humid and humid regions. These soils are characterized by a light coloured *ochric* epipedon over a clay-enriched *argillic* subsurface horizon having more than 35% base saturation. Profiles of Alfisols are more developed than inceptisols but less than the Ultisols. These soils are widely distributed in the USA, South America, Northern Europe and South East Asia. In India, Red soils (Alfisols) are observed in different agro-ecological regions covering parts of the Sates like Andhra Pradesh, Assam, Bihar, Arunachal Pradesh, Himachal Pradesh, Orissa, Karnataka, etc. In the past, these soils were classified as Grey Brown Podzols, Planosols and Half Bog soils. The Alfisols are naturally fertile and productive because of high base saturation, favorable texture and location in moist semi-arid to humid region. In India, they are used for growing wheat, maize, sorghum, rice, mango, cashew, etc. The sodium rich Alfisols need amendments such application of gypsum.

8. *Ultisols* (L. *Ultimum*- latest): These are usually moist soils and developed under warm, humid and sub-tropical climates. The Ultisols are comparable with Alfisols except for having base saturation less than 35 % due to advances stage of weathering. They also have clay enriched *argillic* or *kandic* sub-surface horizon. Except wetter soils, the sub-surface horizons are commonly red or yellow in colour due to accumulation of free oxides of Fe. These soils are moistly found in south-east America, South America, South-East Asia, Central Africa and Coastal India in the States of Kerala, Tamil Nadu, Orissa, Assam and other north-eastern States.

Due to low fertility and base saturation, these soils are of limited agricultural use, mainly used for forestry but may be used for agriculture if fertilized and amended with adequate lime. In tropical regions, Ultisols are used for pineapple, sugarcane, coffee, coconut, rubber, etc. These soils can be cultivated for vegetables with adequate fertilization.

9. *Oxisols* (Fr. *Oxi*- oxides): These are highly weathered mineral soils of humid tropics. Most important diagnostic feature is the presence of a deep sub-surface horizon (*oxic)* dominated by kaolinitic and oxides of iron and aluminium. Weathering and intense leaching have removed a large part of the silica from the silicate minerals in this horizon leaving behind a high proportion of the oxides of Fe and Al. Most Oxisols have brick red colour but some are also yellow or grey. These soils are dominantly observed in central Africa, north-east South America and south East Asia. In tropical India, these soils are found in Kerala, Tamil Nadu, Orissa and Karnataka. In the past, these soils were classified as Laterites, Latosols and Groundwater Laterites. The Oxisols are chemical degraded and need careful management for agricultural use. These soils are mainly used for grazing and forestry and growing crops like coffee, rubber, cocoa, sugarcane and tropical fruits like pineapple, coconut, jackfruit, etc. Shifting agriculture is common practice in the areas of Oxisols. This practice is acceptable when the shifting cycle is more than 20 years, but due to

increasing population, the cycle has been reduced to 3-5 years which results in serious problems of soil erosion by water and nutrient depletion.

10. Histosols (Gr. *Histos* -tissue): The Histosols are formed on organic soil materials. A soil is also called as a Histosol, if the organic material rest on rock. These are organic rich soils with thick and peaty horizons (*histic* epipedon) that develop in lower topographic positions in permanent water saturated environment. The main process in their formation is the accumulation of peat which happens when production of organic matter by native vegetation is more than its decomposition in the soil. The amount of organic material required for a soil to be qualifies as Histosol depends on the clay content. They contain a minimum of 20% organic matter if the clay content is low (or nil) and 30% if the clay content is more than 50%. The Histosols occur in some parts of Europe, USA, Canada, and North West Asia.

The Histosols have not been reported in India. In the past, these soils were classified as Peat, Muck, and Bog soils. Based on the degree of decomposition of humus, the Histosols have been subdivided into four orders: hemists, fibrists, saprists, and folists. Most of the Histosols, located in depressions and plain areas have natural vegetation. The folists are well drained soils. Hemists have moderately decomposed organic matter, and are used as woodlands or rangelands.

11. Andisols (Japanese *an*, dark; *do*, soil): Andisols were first recognized in Japan and named as volcanic ash material. The Andisols are found to form from the deposition of volcanic material in recent geological times. These soils are not highly weathered mineral soils. The upper horizons are dark in colour. Previously these soils were classified as inceptisols. The typical characteristics of these soils are the high content of allophone which gives them a very low bulk density and fluffiness, especially, in B-horizon. These characteristics make them highly fertile and easy to cultivate. Since the Andisols are dominantly developed on volcanic ash, or materials

5

derived from it, they are mostly observed around the Ring of Fix in the Pacific, including Japan, Indonesia, New Zealand and Philippines. They are also found in 'Rift Valley' of Africa, Kenya, Western coast of USA and South America. In India, these soils are not in extensive but in very localized small areas in Andaman and Nicobar Islands. On steep slopes, the Andisols may have limitation of mechanized farming but in favourable climatic conditions are intensively cultivated and thickly populated. Andisols are generally stable and resist water erosion because of high infiltration rates. When dry, these soils are susceptible to wind erosion. Major limitation in these soils is their high P fixing capacity.

12. Gelisols (Gr. *gelid*, very cold): The Gelisols is the most recently introduced soil order of soils occurring in the extreme northern hemisphere. The Gelisols are the soils with gelic materials underlain by permafrost. Diagnostic horizons may or may not be present in Gelisols as thawing and freezing play an important role in their evolution. Permafrost influences their pedogenesis by acting as a barrier to the downward movement of the soil solution. Gelisols are commonly observed in areas of permafrost which include northern USA, Canada, Greenland, Russia, and other areas in the extreme northern hemisphere. These soils have not been reported in India but may occur in snow-covered Himalayas. The Gelisols are not cultivated because of climatic conditions. They may have natural vegetation.

Chapter 13

Major Soils of India

India, lies between the latitude of $08°04'$ and $37°06'$ N and longitude of $68°07'$and $97°25'$. It has a total geographical area of 328.79 Mha. The country exhibits great diversity in physiography influencing climate and vegetation. The climate and vegetation influenced the geological formations of different types of parent materials (rocks). The variation in dominating soil forming factors and processes acted upon different types of parent materials resulted in development of a large variety of soils in the country.

Physiographically, India has been divided into three broad regions:
a) *Peninsula-* a triangular Plateau in the Deccan and South of the Vindhyas.
b) *Mountain region of the Himalayas*, known as the *Extra-Peninsula*.
c) *Indo-Gangetic Plain* of Punjab and Bengal, separating the two above mentioned regions.

Peninsula region is occupied by the gneisses, schists and other rocks of diverse nature. The mountain region shows the development of marine sediments of all ages, especially, in north of the Himalayas. The vast Indo-Gangetic and other plains of Pleistocene origin are composed of alluvium of the great river systems flowing in this region. The alluvial soils of this region depend on the age of alluvia and degree of development.

Climatically, India has three distinct seasons:

a) Cool and mainly dry winters from November to February
b) Hot and mainly dry summers from March to June
c) Monsoon rainy season from mid June to September

Rainfall is received during June to September from the south-west monsoon, December to February from the north-eastern winds. The Western Ghats and the Eastern Himalayas ranges receive maximum rainfall because of their alignment across the summer monsoon winds. The Indo-Gangetic plains receive moderate rainfall while Rajasthan receives little rainfall as the Aravallies lie along the path of the moisture laden winds.

The country with a great variety of landforms, geological formations and climatic conditions, thus, exhibits a diverse variety of soils. Barring a few soil Orders (Andisols, Spodosols and Gelisols), India represents all the major soils of the world.

Major Soils of India

1. Alluvial soils: Alluvial soils are those soils that have developed on alluvium of recent origin derived from the decomposition of erosion products brought and laid down by various river systems. Coastal alluvium is however, laid down by the sea currents. These soils are most fertile occupying an estimated area of 113 Mha in the Indo-Gangetic plains, Brahmaputra Valley and coastal regions, extensively distributed in the states of Punjab, Haryana, Delhi, Uttar Pradesh, Uttaranchal, Bihar, West Bengal, Assam, and East and West Coasts (Fig. 13 .1).

Salient features

i) Variable in colour and texture depending upon the parent material, place of decomposition and calcareousness. They are coarser near the source and become finer near the proximity to the sea (delta area).

ii) Fluvial (stratified) in nature as reflected in their texture and irregular distribution of organic matter with depth.

iii) Mostly alkaline in areas where potential evaporation exceeds rainfall and neutral to acidic in areas where rainfall exceeds potential evaporation.

iv) Exhibit different profile development from least to well developed profile depending upon the prevailing climate, vegetation and age of alluvium.

v) Inherently rich in plant nutrients. In general, fairly sufficient in P and K, but deficient in N and low in organic matter contents.

vi) Prone to develop salt problem with indiscriminate use of canal water for irrigation.

Classification: According to the Genetic system of classification, these soils belong to the Order Azonal. In Taxonomy, these soils may be classified as Entisols, Inceptisols, Alfisols and Aridisols

2. Black (cotton) soils: These soils are very dark in colour and turn extremely hard on drying. They become sticky and plastic on wetting, and hence, are very difficult to cultivate and manage. These soils developed from weathered alluvium of Deccan basalt or basic parent material under arid, semi-arid and sub-humid climatic conditions occupying an estimated area of 55Mha in Maharashtra, Madhya Pradesh, Gujarat, Rajasthan, Chhattisgarh and some parts of Karnataka and Tamil Nadu. The weathering products of

the parent rocks (basalt and other metamorphic, containing lime and soda lime feldspars) are basic and rich in clay, which is dominantly smectitic type with high coefficient of expansion and contraction. Therefore, set up a steady churning process in the pedon. Churning causes vertical mixing in deep soils and leads to development of deep (> 50 cm) and wide (>1 cm) cracks.

Salient features:

i) Dark in colour due to clay-humus complexes and presence of ferrous magnetite mineral

ii) Inherently fertile but problem in workability and development of sub-soil sodicity in some areas

iii) Rich in smectitic clay (30-80 %) having high cation exchange capacity (30-60 cmol (p$^+$)/kg soil).

iv) Do not exhibit eluviation and illuviation processes because of the swelling and shrinking nature of the soil.

v) Create problems in construction, laying of water pipelines, tilting of electric/telecommunication poles being highly sticky and plastic.

Classification: As per the Genetic system, these soils belong to the Order Intrazonal and Azonal. According to Soil Taxonomy, these black soils are classified as Vertisols. The shallow soils are classified as Inceptisols and Entisols depending on the degree of profile development.

3. Red soils: Red soils are rich in sesquioxides developed from crystalline granite and metamorphic rocks like gneisses and schists of Archean period. These soils occupy about 85.7 Mha areas in the southern parts of the Peninsula comprising the states of Tamil Nadu, Karnataka, Goa, Maharashtra, Orissa and in North-Eastern States. These soils are found in semi-arid to warm humid tropical climatic conditions. Under such conditions, weathering is moderately intense and some weathering products are leached leaving behind the less mobile materials like silica, iron and alumina. The iron and aluminium under oxides conditions form sesquioxides imparting red colour to these soils.

In Andhra Pradesh, the Red and Black soils occur under similar climatic conditions but on different parent material and landforms. The red soils develop on igneous (acidic) rocks and occupy higher topographic positions whereas Black soils develop on basalt (basic) rock or on alluvium derived from basalt, and occupy lower positions on the landscape. The soils grade

from shallow, gravelly and light coloured in uplands to much fertile, deep, dark reddish brown in the plains and valleys.

Salient characteristics:

i)   Red to yellow in colour due to presence of ferric oxides (haematite or anhydrous FeO) and hydrated form (limonite).

ii) Highly variable in texture (loamy sand to clayey).

iii) Shallow in uplands to very deep and fertile in the plains and valleys.

iv) Well drained depending upon topographic position and texture.

v)   Neutral to acidic in nature depending upon the content of iron oxides.

vi) High amounts of iron and aluminium (30-40%).

vii) Cation exchange capacity and base saturation are relatively lower than that in the Black or Alluvial soils.

viii) Deficient in NPK and low in organic matter.

ix) Having kaolinite (1:1type) clay mineral.

Classification: According to the Genetic system: Red loam, Reddish and yellowish-brown soils and as per Soil Taxonomy: Alfisols, Ultisols, Entisols and Inceptisols.

4. Laterites and lateritic soils The laterites and lateritics soils are generally used in same sense. These are typically formed in tropical climate experiencing alternative wet and dry seasons. Soils in which the laterization is dominant soil forming process, i.e., eluviation of silica and enriched with oxides of iron and aluminium. Under high rainfall, silica is released and leached downwards and the sesquioxides are left behind in upper horizons of the soils. The end product of the process is termed laterite. These soils occur in about 18 Mha in the southern states along the west coast of Maharashtra, Orissa and some parts of West Bengal and north- eastern regions.

Salient characteristics:
i)   Low silica/sesquioxide ratio and almost complete absence of alkali and alkaline earth oxides.

ii) Formed at high levels are pale red, gritty, shallow and poor in plant nutrients and those formed at low levels are fine textured, darker coloured, richer in nutrients and organic matter.

110

iii) Well drained and porous with low pH.

iv) Predominantly kaolinitic clay, therefore, have low CEC.

v) Deficient in almost all nutrients but can be managed well.

Classification: Most of the lateritic soils have been classified Taxonomically as Ultisols and Alfisols.

5. Desert soils: The soils which support negligible vegetation except xerophytic plants, unless irrigated. These soils formed in cold or hot temperature regime occupying about 26.3 Mha in western part of Rajasthan, Gujarat, Haryana and Punjab and in cold arid of Leh and Ladakh region of Jammu and Kashmir. The soils of hot arid regions are comparable with those of alluvial soils but have an aridic moisture regime. The aeolian action moves and carries the sandy material and deposits in the direction of wind in the form of a thick mantle of sand at the surface. The sandy material under arid climatic conditions results in poor profile development.

Salient characteristics:

i) Sandy to loamy sand in texture with clay content of 3.5- 10%.

ii) Yellowish brown colour having either single grained or weak sub angular blocky structure.

iii) Inherently poor in fertility and water holding capacity.

iv) Slight to moderately alkaline in reaction (pH 7.9-9.0) because of their calcareous nature. The depth of accumulation of calcareous materials varies depending on the rainfall and topographic position.

v) Gypsiferrous in extremely arid areas such as Bikaner and Jaisalmer

Classification: According to the Genetic system: Pedocal Sierozems or Calcareous Sierozems. In Soil Taxonomy: Aridsols and Entisols.

6. Salt affected soils: The soils contain considerable amounts of soluble salts and/or sodium on the exchange complex. These soils mainly occur in arid and semi-arid climate (< 850 mm of rainfall) and occupy about 6.74 Mha areas. Due to high evaporative demand, the dissolved soluble salts move towards the soil surface by capillary action and accumulate at or near the surface, after the water is evaporated and it renders the soils as saline or alkali. These soils occur in almost all states except north-east region. Major

part of Indo-Gangetic Plan and part of coastal areas are saline. The major characteristics to identify the salt affected soils are:

Characteristics	Saline	Alkali (sodic)	Saline-Alkali
pH_s– pH of saturation paste	< 8.5	> 8.5	< 8.5
EC_e– Electrical conductivity of saturation paste (dS m^{-1})	> 4	< 4	> 4
Exchangeable sodium percentage (ESP)	< 15	> 15 (> 5*)	> 15 (> 5*)
Sodium adsorption ration (SAR)	< 13	> 13	> 13

 * In case of black soils (Vertisols)

Salient characteristics:

i)   Salts develop from weathering, groundwater, irrigation water and sea.

ii) Salinity develops due to chlorides and sulphates of Na^+, Ca^{2+} and Mg^{2+}.

iii) Soil solution concentrates in dry season and causes precipitation of carbonates ($CaCO_3$) which increases SAR, ESP and pH.

iv) Cultivated for salt tolerant crops like rice, wheat, barley, oats, cotton, sugarcane, etc., and grasses like Karnal grass, Bermuda grass.

v)   Leaching with good quality water along with adequate drainage network for removal of leached water is the practice for reclamation.

vi) Sodic soils have problem of drainage due to dispersion of clay and clogging of soil pores.

vii) Gypsum is applied for reclamation of sodic soils.

Classification: According to the Genetic system: Solonchaks (saline) and Solonetz (sodic). In Soil Taxonomy: Alfisols, Aridsols, Entisols and Vertisols.

7. Forest and hill soils: The soils developed under forest canopy. Climatic conditions and altitude control the kind of forest and their forest species, and topography control the type of soils and their degree of profile development. These soils occupy about 75 Mha dominantly in the states of Himachal Pradesh, Jammu and Kashmir, Uttarakhand, Sikkim, Madhya Pradesh, Kerala, north-east region and Andaman and Nicobar Islands. The major soils found in forest areas are: *Brown Forest and Podsolic* in northern Himalayas and *Red and lateritic* in the Deccan Plateau.

112

The Himalayan soils have developed on sand-limestone, conglomerates, granite, gneisses and schists under cold sub-humid climatic conditions, the Deccan Plateau soils are formed on igneous and metamorphic rocks (basalt, granite, gneisses) under sub-tropical climatic conditions, and hence differ in their properties.

Podsolic soils: The soils formed, in northern Himalayas region under coniferous vegetation, are termed as Podsols. The characteristics of Podsolic soils are:

☐ Moderately to strongly acidic (pH 4.5-6.0).

☐ High in organic matter content (3.0-3.5%) and low in base saturation (< 50%).

☐ Clay content varies from 20 -30%.

Brown black soils: Soil developed on sedimentary rocks and/or alluvium under sub-humid to humid climate and mixed vegetation (Non-calcic brown or brown Forest). The characteristics of brown black soils are:

☐ Neutral to slightly acidic (pH 6.0 -7.0). Soils having calcareous layer under sub-humid conditions may have a pH about 8.2.

☐ Moderate to high organic matter content (2-3%).

☐ Moderate cation exchange capacity (15-20 cmol (p^+) kg^{-1}) and exchange complex is almost saturated with bases (70-90%).

Classification: According to the Soil Taxonomy: Inceptisols and Mollisols on stable landforms and Entisols on eroded surfaces or steep slopes.

8. Peat and Marshy soils: These soils develop under humid tropical climate and occur in localized pockets of Kerala and eastern region of tidal swamps having large accumulation of organic matter with presence of pyrites (Fe_2S). Marshy soils are found in tidal swamps in West Bengal (Sunderbans), coastal areas of Orissa, Tamil Nadu and Goa with mangrove vegetation.

Salient characteristics:

i) Fine in texture and dark in colour with abundant organic matter content (20-40%)

ii) Generally submerged but sulphuric acid is formed when oxidised and becomes extremely acidic (pH < 4)

113

iii) Also called *acid sulphate soils* or *cat clays*, and saline peat soil of Kerala are called '*kari'* soils.

iv) Major clay minerals- kaolinite and smectite.

v) Highly problematic and very poor for plant growth.

vi) Rice can be grown successfully if water table is kept above pyrite layers.

Classification: In Soil Taxonomy, these soils are classified in the Orders of Inceptisols and Entisols.
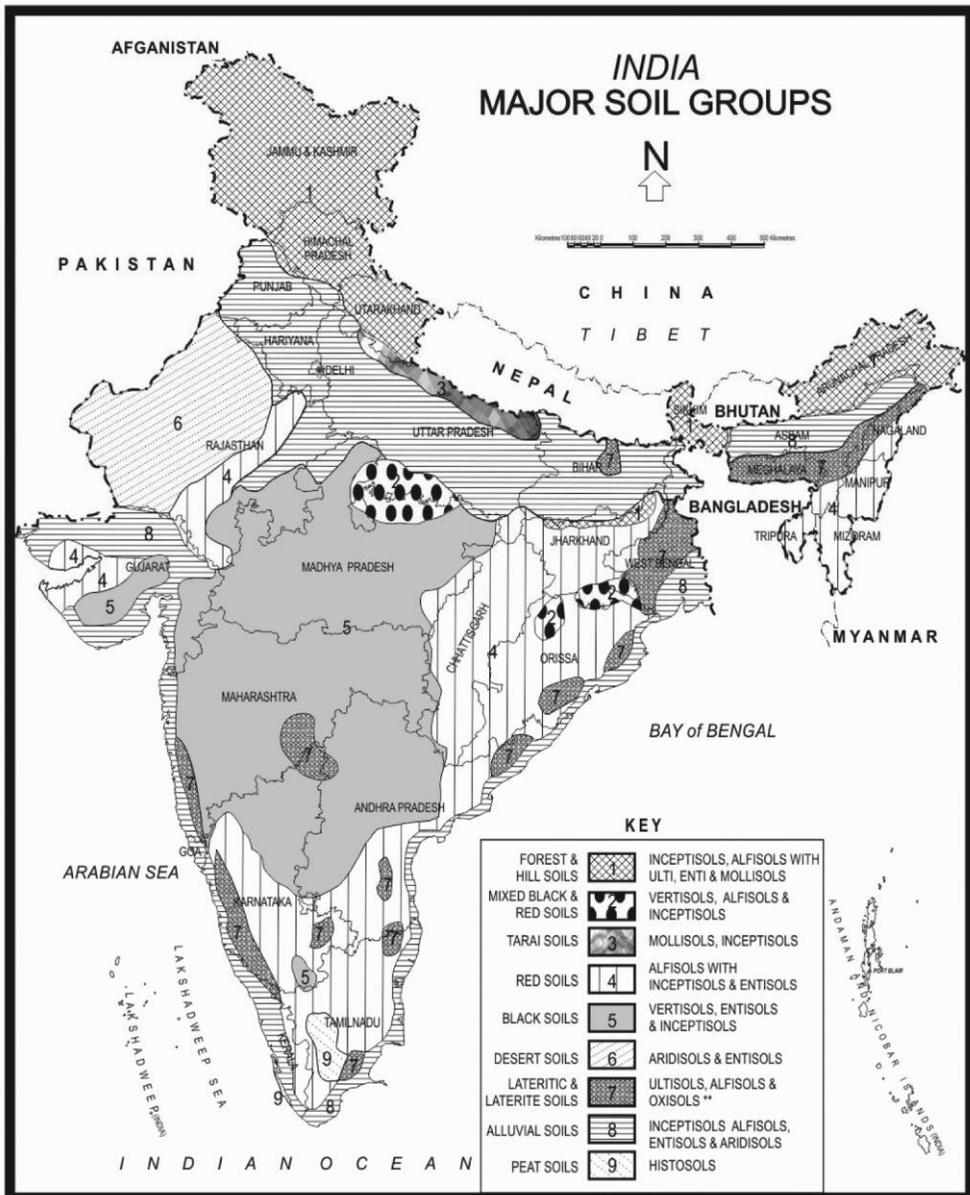
Fig. 13.1: Major soil groups of India

Chapter 14

Soil Water

Soil water is the liquid phase of soil which is composed of dissolved salts and gases, therefore, generally called *as soil solution or soil moisture*.

Retention of Water in Soils

Primarily two types of forces are responsible for retention of water in soils: the adsorptive forces and capillary forces. *Adsorptive forces* are due to adhesive (attraction between soil particles and water molecules) and cohesive force (attraction between water molecules). *Capillary force* is due to surface tension and pressure differences under curved menisci at solid-air-water interface.

1. *Adsorptive forces:* Adsorptive forces (cohesive and adhesive force) originate due to the following phenomena:

   i) *Electrostatic attraction:* Water molecules are retained on surfaces of clay particles due to electrostatic attraction between negative charges on clay particles and positive poles of water molecules.

   ii) *H-bonding:* The H-atom of water molecules, carrying a residual positive charge, gets attached to negatively charged O-atoms exposed on broken edges of clay particles, forming hydrogen bonds.

   iii) *Hydration of cation:* The cations adsorbed on clay particles attract dipole water molecules due to electrostatic attraction and get hydrated, thereby retaining water on clay particles.

   iv) *Osmotic potential:* The osmotic potential of water closer to the clay particles is lower than that the water in bulk solution due to relatively higher concentration of cations near the clay particles, as a result water moves from bulk solution towards clay surface and get retained in soil.

   v) *London-van der Waals forces:* Molecules can attract each other at moderate distances and repel each other at close range. The attractive forces are collectively called "London-van Waals forces. Though

they are weak attractive forces but can be significant when present in large numbers.
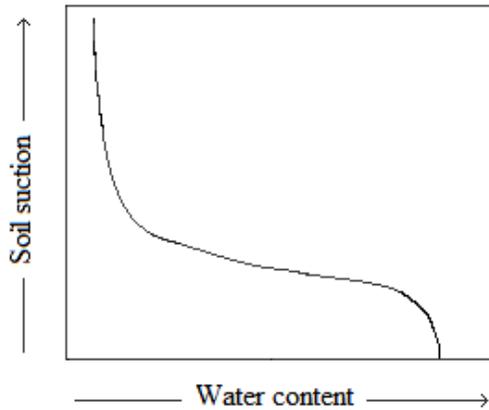
By adhesion, soil hold water molecules rigidly at their soil water interfaces. Once one layer of water molecules is attached to the soil solids, the additional water molecules get attached with that layer due to cohesive forces (h-bonding) between water molecules. In this way, the adsorbed water makes several molecular layers on colloidal surfaces. As the water films thicken, they become progressively heavier and the water then starts moving down in macropores under the influence of gravity.

2. *Capillary forces:* Water present in soil pores due to capillary forces which originate due to surface tension of water and its contact angle with the solid particles. This phenomenon is commonly evidenced at water-air interface. Capillary action is more important in coarse textures soil while adsorption is more important in fine textured soils. Further capillary water dominates in wet soils while adsorbed water becomes important in moist to dry soils. Clayey soils have greater proportion of fine pores and higher total pore space than sandy soils, as a result clay soils retain more water per unit volume of soil than sandy soil.

The retention and release of soil water depends upon its energy states. When all the pores are filled with water, its water potential (energy) increases to zero i.e., water in soil pores is not held strongly and free to move. This loosely held water moves downwards under the action of gravity forces (*gravitational water*).

As soil water decreases due to drainage and evaporation, the force (suction) with which water is held within the soil increases. As suction is increased further, the large sized pores which are unable to retain water against applied suction get emptied. With gradual increase in suction, progressively smaller pores will release water and at higher suction values, only very narrow pores retain water. An increase in soil water suction also results in decrease in thickness of water envelop to the soil particle surfaces. Thus, increase in suction is associated with decrease in soil wetness. The amount of water remaining in the soil at equilibrium is a function of the sizes and volume of water filled pores and the amount of water adsorbed to the particles i.e., matric suction.

The data on the amount of water held by the soil at various tensions provides information regarding the amount of water available to plants, the water that can be stored by the soil before percolation starts and the amount of water needed for irrigation. The relationship between the amount of soil water and the energy with which it is held (soil water potential) is a continuous function and the plot of relationship between the two for a given soil which is known

Fig. 14.1: Soil moisture characteristic curve

as the *soil moisture retention curve/ soil moisture release curve* or *soil moisture characteristic* (Fig. 14.1). Soil moisture retention curve is used to drive different quantities of water retained corresponding to the specific water potential values which are of practical importance to the irrigation and drainage management of soil. Water held at specific water potential values are called *soil moisture constants*. These constants are used to characterize a soil by a single number to compare the retention capacity of different soils.

Soil Moisture Constants

1. *Saturation:* The saturation water is also known as saturation percentage or maximum water holding capacity. When all the pores in the soil are completely filled with water, the soil is at saturation. In practice, complete saturation may not be possible as some air always remains trapped in soil pores. Thus, for practical purposes, a soil is said to be saturated with water when the soil water is at zero tension or suction (suction is negative of the soil water potential) and majority of its pores are filled with water.

   The maximum water holding capacity of a soil is desirable in pot culture experiments as it provides a simple means of determining useful moisture level to be maintained for good plant growth. With medium textured soils in pots, good growth is obtained at moisture level corresponding to 50-70% of the maximum water holding capacity.

118

2. *Field capacity:* When a saturated field soil is allowed to drain, soil moisture decreases with time. After 2 to 3 days, the moisture in the surface layer attains a steady state. At this stage, the water retained in the soil is known as at field capacity. Thus, field capacity is defined as *the amount of water retained in the soil after the downward movement from a pre-saturated soil has materially ceased or practically zero.* It is determined with the help of *pressure plate apparatus.* The matric potential corresponding to this moisture content is affected by soil texture, type of clay, organic matter, depth of wetting, the presence of impeding layers and evapo-transpiration. For these reasons, the concept of field capacity, being misleading, is generally abandoned by soil scientists. Generally, moisture percentage at 1/10 to 1/3 bar represents a measurable field capacity. Moisture percentage at 1/10 bar is more reasonable field capacity for coarse textured soils while 1/3 bar for medium and fine textured soils. The field capacity is about 4 % (by mass) in sandy soils, 45% in clayey soils and even up to 60% in some organic soils.

3. *Wilting point:* It refers to the soil moisture content at which plant roots cannot extract water at a rate sufficient to meet the transpiration needs. At this moisture content, plants lose cell turgidity and show symptoms of wilting. At this point, plant cannot regain turgidity even when placed in water saturated atmosphere. The matric potential corresponding to this moisture content is -15 bar (1 bar = 1000 cm of water column = 0.987 Atm) or pF of 4.18. Water retained by soil at -15 bar matric potential can be estimated with the help of pressure plate apparatus. The wilting point is affected by both the plant species and stage of the plant growth. At wilting point, there is a layer of about 5-6 molecules of water around the particles which is an exceedingly thin layer. So, soil structure has very little influence on moisture content at -15 bars and only texture plays the role. Concentration of salts in soil solution also has great influence on wilting point. Normally, the roots of a crop plants are extended to lower depths differing in moisture contents. Therefore, a plant can thrive in a soil which is dry at the surface but has relatively higher moisture in lower depths.

4. *Hygroscopic coefficient:* The hygroscopic coefficient of soils is "the amount of water held by the soil when it is in equilibrium with an atmosphere of 98% water vapour saturation or 98% relative humidity". The hygroscopic coefficient is the boundary between moist and dry soil

and arbitrarily set at -31 bars. The amount of water that a soil holds at the hygroscopic coefficient depends largely upon the amount and type of clay minerals, the nature of the exchangeable ions and salt concentration. Soils high in expanding type of clay and organic matter have a high hydroscopic coefficient.

5. *Oven dry soil:* Soil is considered as oven dry when it has reached equilibrium with the vapour pressure of an oven at 105°C. This corresponds to a pF of 7 or relative humidity of approximately zero. This condition is used as the basis for the calculation of soil moisture on gravimetric basis.

Soil moisture constants and their corresponding soil water potential are shown in Fig. 14.2.
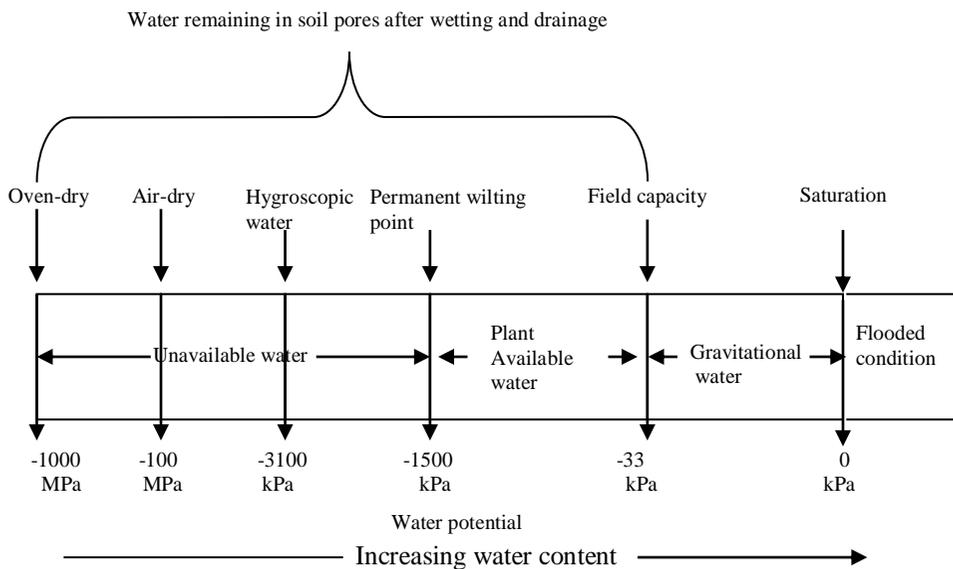
Fig. 14.2: Soil moisture constants and corresponding soil water potential

6. *Other soil moisture terms:*
   i) *Plant available water:* The plant available water signifies the water held by a soil between 1/3 and 15 bar suction i.e., between field capacity and the wilting point.

   ii) *Air dry soil:* The term air dry soil designates the moisture condition when soil is in equilibrium with the atmosphere. It corresponds to -31

120

to -1000 bar depending upon the degree of saturation and temperature of the atmosphere. It is not an equi-potential.

Factors Affecting Soil Moisture Retention

i) *Structure:* The amount of water retained at low suction (high matric potential) i.e. between 0 and 1 bar (100 kPa) strongly depends upon the capillary effect and pore size distribution which are highly affected by soil structure. Water retention at low suction is high in well aggregated than compacted soil due to uniform pore size distribution.

ii) *Texture:* The soil moisture retention curve is strongly influenced by the texture and specific area of the soil particles particularly at high suction due to adsorption of water by the soil particles. Soil water retention at particular matric potential increases as clay content increases. Therefore, suction will be significantly low in coarse textured soil as compared to fine textured soil at same volumetric water content. Therefore, soil texture influences the shape and range of the soil– moisture characteristic curve mainly in the high suction range.

iii) *Nature of clay minerals:* Soils having montmorillonite as the dominant clay mineral (black soil) retain largest amount of water followed by the soils dominant in illite mineral (alluvial soils) and kaolinite mineral (laterite soils which have smallest amount of water).

iv) *Organic matter:* The soil moisture retention in soil increases with the increase in organic matter. This may be due to formation of well aggregated structure of organic rich soils which results in higher amount of total pore space and uniform pore size distribution.

Classification of Soil Water

The water held in soil may be classified from physical as well as biological point of view.

1. *Physical classification:* On the bases of physical state (retention and energy), the soil water may be classified into three categories: hygroscopic, capillary and gravitational water.

Water applied to the soil is first adsorbed around the soil particles. The first two molecular layers of water on soil particles (mainly the soil colloids) which are held very strongly (suction ranging from 31 to 10,000 bar), is termed as *hygroscopic water*. This water is not available to the plants.

121

On further wetting the soil, the thickness of water layers around the soil particle increases. The water fills the capillary pores of the soil and the suction of the soil water further decreases. The water held in capillary pores with suction ranging from 0.3 to 31 bars is known as *capillary water*. *Not all the capillary water is available to plants*. Water held at suction 0.3 to 15 bars is available to plants.

With further increase in soil water, the larger sized pores start getting filled. The water in these larger sized pores is loosely held and has suction <0.3 bar and liable to move downwards under gravitational force, hence, it is known *as gravitational water or free water*. When all the pores in the soil are completely filled with water, the soil is said to be at *saturation*. In an unsaturated soil (pores are partially filled with water and partially empty), water is retained by the *forces of capillarity and adsorption*. The gravitational and capillary water held in the soil is illustrated as below.

Gravitational water   *Capillary water*

The pore spaces are filled with water in excess of their capillary capacity, and the excess or gravitational water drains downward.

Capillary water is held in the pore spaces against the force of gravity.

2. **Biological classification:** This classification is based on the availability of water to plants. Soil water is classified into three categories: free, available and unavailable water.
   a. *Free water:* It is the fraction of soil water that is present in macropores and moves freely into deeper soil layers under the influence of gravity. It is also known as drainage water or superfluous water. It includes all of gravitational water and a small part of capillary. This fraction of soil water is not available to plants, rather create problem of aeration, if stays longer.

122

b. *Available water:* It is the fraction of soil, water which is available to plants and includes a part of capillary water held between 1/3rd and 15 bar tension.

c. *Unavailable water:* The fraction of soil water retained at tensions higher than 15 bars tension. The water is so tenaciously held by the soil that plant roots are not able to extract this water. It includes part of capillary water and all of the hygroscopic water.

Methods of Measurement of Soil Moisture

There are direct and indirect methods of measuring soil water. In direct methods, water is removed from the soil sample by evaporation. The amount of water lost is then calculated. In indirect methods, the property of the soil which is controlled by soil water content is measured. Directly, soil moisture is measured by the traditional thermo-gravimetric method and indirectly by several techniques based on the determination of electrical resistance, slowing down of fast neutrons, gamma-ray attenuation, electrical capacitance and backscattering coefficient as a function of water content.

Depending upon the purpose of soil-moisture determination, soil water can be expressed either in terms of its amount or tension. The amount of water in soil can be expressed either on mass or volume basis but, commonly, it is expressed as mass of water per unit of mass of oven dried soil. For example, if 1 kg of moist soil (soil + water) loses 0.25 kg of water upon oven drying then the mass of oven dried soil will be 0.75 kg. The soil moisture percentage on mass basis is calculated as:

$$\frac{0.25}{0.75} \ 100 = 33\%.$$

On volume basis, the moisture content is expressed as the volume of water per unit volume of the soil. This measure gives a better picture of moisture available to roots in a given volume of soil.

1. *Thermo-gravimetric method:* In the thermo-gravimetric method is direct method, moist soil sample is weighed and then dried in an oven at 105°C to a constant weight, usually for 24 hours, in order to obtain the oven-dried weight of soil sample. The per cent soil moisture on mass basis is calculated by dividing the mass of water by the oven dried mass of soil sample and then multiplying by 100.

This method is simplest, cheapest and most accurate, and widely used standard method. All other methods are standardized with this method. Demerit of this method is that it is destructive and repeated measurements cannot be taken at particular site at a given time. The method is arbitrary in the sense that some clay still contain appreciable amount of adsorbed water even at 105 °C. Further, some organic matter may oxidize and decompose at this temperature and hence, the loss of weight on drying may not be entirely due to evaporation of water. It is also laborious and time consuming as a period of 24 hrs or more is necessary before the results are available.

2. *Electrical resistance method:* It is one of the non-destructive, indirect and *in situ* methods of measuring soil water content. The method is based on the fact that electrical resistance of a soil volume depends on its water content. In this method, two platinum electrodes are embedded in a porous block of gypsum, nylon or fibreglass. The block is placed in the moist soil at desired depth and allowed to equilibrate. These blocks when embedded in soil tend to equilibrate with the soil moisture suction rather than with moisture content directly. The electrical resistance of the porous block is then measured by an electrical resistance meter based on the principle of the Wheatstone bridge. The electrical resistance of the soil decreases with increase in water content. The soil water content is obtained using a calibration curve of electrical resistance against known soil water content for the same block. The equilibration of these blocks may be affected by the texture, structure, soluble salt content and soil hysteresis. For these reasons and temperature sensitivity, resistance blocks are not applicable in soils which are light in texture, saline or sodic in nature. When using gypsum blocks, there is problem in achieving a desired accuracy as dissolution of gypsum with time destroys the gypsum block. But the method is easy and less time consuming, non-destructive and measurements can be repeated as and when required.

3. *Nuclear radiations techniques:* The neutron scattering and gamma-ray attenuation are two nuclear techniques that can be used for non-destructive *in situ* measurement of soil water content, indirectly

   a) *Neutron scattering technique*: In the neutron scattering technique, the instrument used is called *Neutron Moisture Meter*. It consists of americium and beryllium or radium and beryllium as the neutron source (9.25×10^7 Becquerel) and boron trifluoride (BF_3) gas as a

detector. The instrument works on the principle that when fast moving neutrons are emitted radially into the soil, they undergo elastic collisions with hydrogen atoms having mass equal to the mass of neutron and get scattered. Their energy (kinetic) is reduced and speed is slowed down. (The neutrons will also colloid with atoms of other element such as Si, Al, etc., but the ability of hydrogen atom is greatest to slow down the neutrons because of same mass of neutron and H). The process is called *thermalisation* and the slowed neutrons are called *thermal neutrons*. The slowed neutrons are absorbed by BF_3 gas and counted with a scalar or rate meter or electronic microprocessor, which directly displays the moisture content.

The density cloud of thermal neutrons formed around the source/probe is proportional to the concentration of hydrogen in the soil. Since water is the main source of hydrogen in soil, the density of slow neutron is proportional to the volume-fraction of water present in the soil. The neutron moisture meter has to be calibrated for each soil. The probe which contains a source of fast neutron and a detector of slow neutron is lowered into an aluminium access tube inserted vertically into the soil to a desired depth. Aluminium access tube generally preferred as it is transparent to the neutron flux. Advantage of using neutron moisture meter is that it is an efficient and reliable technique for monitoring soil moisture in the field. It is rapid, less laborious, non-destructive and repeated measurements can be made at the same depth, and therefore, can handle large number of experiments. It is used for measuring moisture in deeper soil layers. The method is independent of temperature and pressure. The main disadvantages of the method are that it cannot be used for the measurement of soil moisture in surface soil since neutrons escape into the atmosphere which may be dangerous for the user. The instrument is costly also.

b) *Gamma-ray attenuation technique:* The gamma-ray attenuation technique of soil moisture content measurement depends on the fact that when a gamma-ray strikes to any substance, it loses part of its energy. The instrument used is called *Gamma-ray scanner or Gamma-ray apparatus*. It consists of two aluminium access tubes. In one of the tubes, radioactive isotopes ^{137}Cs (Caesium) or ^{241}Am (Americium) is used while other tube consists of thallium activated NaI crystal, which acts as a detector. When a narrow beam of

125

gamma-radiation is passed through the soil, the rays are attenuated depending upon the thickness of soil mass, the bulk density and water content of the soil, following the principles of Beer' Law. If the thickness and the bulk density of soil are known, the water content of the soil can be determined. The gamma-ray apparatus is most useful in laboratory studies where moisture content of very small depth increments of soil is to be determined non-destructively. It is very rapid method but practical difficulties limit its use in the field. It is costly and there is a radiation hazard also.

A number of isotopes are used for soil water movement studies. The isotope tritium (^{3}H) is largely used for water movement, ground water recharge and pollution studies. In hydrological studies stable isotopes- deuterium (^{2}H) and oxygen (^{18}O) are used.

4. Other methods: Time domain reflectometry and microwave remote sensing are also in use now-a-days for the determination of soil moisture.

Movement of Soil Water

Water is a highly dynamic component in soil system. It moves in all the three phases: solid, liquid and vapour phases. Under ordinary conditions, water movement in the soil does not occur in the form of solid phase (ice). Movement in solid phase is commonly occurring in the frozen soil where the formation of ice makes the soil swell and the movement occurs as an entire soil body as such.

In a saturated soil, water moves in liquid phase while in a partially dry or wet soil, it moves in both liquid and vapour phases. Liquid flow is of two types:

1. *Saturated flow:* The flow of water under saturated conditions in which most of the pores are filled with water and water is tension free. This occurs in the soil after heavy rains or during irrigation, and in the zone of groundwater.

2. *Unsaturated flow:* The flow of water under unsaturated condition of soil in which pores are partially filled with water and partially with air. The water is under tension. It is the flow of water held with water potential lower than -33 kPa. The driving force is primarily the matric potential gradient i.e. the difference in matric potential of the moist soil and the drier soil into which the water is moving.

Water movement in vapour phase occurs through the process of diffusion and mass flow:

a) *Diffusion:* Movement of water vapours as a result of vapour pressure differences (partial pressure).Vapour pressure increases with increase in moisture content and temperature and it decreases with increase in salt concentration.

b) *Mass flow:* When water vapor flow in a mass with the other gases of soil air due to the difference in total pressure gradient i.e. movement of soil air as such. Mass flow can be caused by change in atmospheric pressure, soil temperature and pressure change cause by infiltration (compression) and percolation (evacuation). Mass flow of water vapour represents only a small portion of the entire water vapour movement in the soil.

In liquid and vapour phases, water movement is governed by the principles of fluid flow (Poiseuille's law). In a flooded or saturated soil, water moves by gravity and the velocity of flow through soil increases with the height of water standing on the soil surface.

Poiseuille's Law

Poiseuille's Law states that "the flow of water (q) through a narrow tube is directly proportional to the fourth power of its radius and pressure difference, and inversely proportional to the viscosity and length of tube", and is given by the equation:

$$q = \frac{\pi \, r4}{8 \, \eta} \left(\frac{\Delta p}{L} \right)$$

where Δp is the pressure difference in dynes cm^{-2}, r is the radius of tube in cm, L is the length of tube in cm and η is the coefficient of viscosity of the liquid in dynes-sec cm^2 (poise). This relation is true only when the flow is steady and laminar and pressure is constant along the cross-section of the tube.

In soil, water movement occurs when there is a potential difference between two points in the soil system. It moves from higher potential to lower potential. In saturated water flow, water moves due to the difference in the gravitational and hydrostatic pressure potentials at different points in the soil.

Darcy's Law

Saturated water flow can be described by *Darcy's Law (*given by Henry Darcy, French Scientist) which states that the flow rate (Q), which is the volume V flowing through the soil column per unit time (t), is directly proportional to the cross-sectional area (A) and the hydraulic head drop, Δh (Potential difference), and inversely proportional to the length of the soil column L as depicted in the figure below:
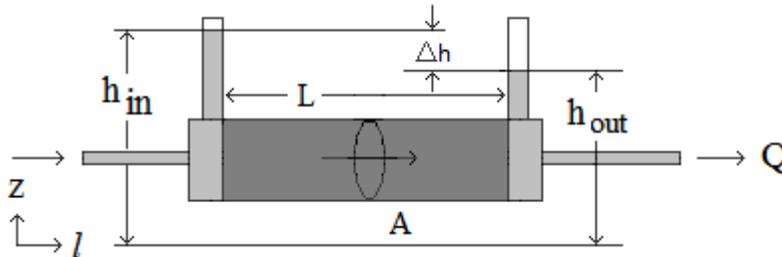
$$Q = V/t \; \alpha \; A \; \Delta h/L$$

The hydraulic head drop (Δh) is given by:

$$\Delta h = h_{in} - h_{out}$$

where h_{in} is hydraulic head at the inflow boundary and h_{out} is head at the outflow boundary. There will be no flow if $\Delta h = 0$ i.e., if there is no hydraulic head difference between inflow and outflow. The hydraulic head drop per unit distance in the direction of flow ($\Delta h/L$) is termed as hydraulic gradient (*i*) which acts as driving force for moving the water. The discharge rate per unit cross-sectional area, Q/A (i.e., volume of water *V* flowing through a unit cross-sectional area *A* per unit time *t*) is called specific discharge/flow velocity/flux density or simply water flux (v). Thus, the eq. 2 can be rewritten as:

$$v = Q/A = V/At \;\; \alpha \Delta h/L$$

$v = K \; \Delta h/L$, where v is also known as water flux or Darcy velocity, and *K* is hydraulic conductivity.

$$v = K \; i$$

This equation is known as Darcy's Law. Darcy's Law is valid when fluid is incompressible, medium is saturated, flow is in steady state and laminar, and temperature is constant. Under field conditions, the hydraulic head in most cases is such that the flow remains laminar.

Limitations of Darcy's law

The Darcy's law is valid in saturated water flow condition as long as flow is laminar and relationship between flux and hydraulic gradient is linear. This law is not valid at high flow velocities when the linearity of the flux versus hydraulic gradient relationship fails. Hence, Darcy's law is considered valid in all soils except in coarse sands and gravels where higher hydraulic gradients (more than unity) may result in non laminar flow conditions. For saturated soils, flux remains linear with hydraulic gradient or flow of water is laminar as long as Reynold's number (Rn) is smaller than one.

Hydraulic conductivity

Hydraulic conductivity is the property of soil with which the soil allows the water to conduct through it. Hydraulic conductivity depends upon the properties of soil (size and distribution of soils pores)and fluids (density and fluidity).

Therefore, soil hydraulic conductivity, K (LT^{-1}) is expressed as: K = k f, where k is *intrinsic permeability* (L^2) of the soil and depends upon the properties of soil only, and f is the *fluidity* (1/LT) of the permeating fluid (liquid/gas).

The fluidity is related directly to density and inversely to viscosity as follows:

$$f = \rho\, g\, /\eta$$

where ρ is density and η is viscosity of the fluid flowing through the soil.

Therefore, any change in fluidity caused by the change in temperature and soluble salts content results in change in saturated hydraulic conductivity.

Factors affecting the soil hydraulic conductivity: Any factor which influences the size and distribution of the soil pores affects the soil hydraulic conductivity:

a) *Soil texture:* The hydraulic conductivity is highest in sandy soils and decreases with decrease in coarseness of the soil. Therefore, it is several times more in sandy soils than clayey soils under saturated conditions.

b) *Soil structure:* Hydraulic conductivity is higher in highly porous or well aggregated soil than in compacted or dense soil. Hydraulic conductivity is highest in soil having granular structure than the soils having platy structure.

129

c) *Organic matter:* Organic matter improves the hydraulic conductivity of fine textured soils due to formation of large amount of water stable aggregates.

d) *Fluidity:* Saturated hydraulic conductivity is also dependent on fluidity which depends upon concentration and composition of salts dissolved in water and viscosity of water.

Water Infiltration

Infiltration is "the entry of water into the soil through the soil surface due to sorption and vertical flow of water through the soil profile". The rate at which water enters into the soil is known as *infiltration rate* i.e. volume of water entering into the soil per unit area per unit time. The infiltration determines the amount of runoff, rate of irrigation to be applied, and textural and structural conditions of soil surface and transmission characteristics of sub-surface soil layers.

Infiltration rate is measured using infiltrometer. Initially, the rate of infiltration is faster and subsequently reduces with time and attains a steady rate. The final steady rate is known as the *basic infiltration rate*. The total amount/depth of water that infiltrates the soil in a given time is called as *cumulative infiltration.*

In addition to texture, the infiltration capacity also depends on vegetation.

Texture	Infiltration capacity (mm/hr)	
	Vegetated soil	**Bare soil**
Loamy sand	50	25
Loam	25	13
Silt loam	15	8
Clay loam	5	3

The infiltration rate is classified as:

Class description	Infiltration rate (mm/hr)
Very rapid	>254
Rapid	127-254
Moderately rapid	63-127
Moderate	20-63
Moderately slow	5-20
Slow	1-5
Very slow	< 1

Factors Affecting Infiltration Rate

1. *Pore size:* Infiltration capacity usually increases as the size of pores increases.

2. *Initial moisture content:* Drier the soil more will be the infiltration rate.

3. *Surface condition:* The highest infiltration capacity is normally found in protected forest land > pasture > crop land > fallow.

4. *Time:* The infiltration capacity of a soil is highest at the beginning and then decreases until constant rate is obtained i.e. infiltration rate decreases with increase in time.

Infiltration rate with time is not similar in different soils. The change in infiltration rate with time is least in the sandy, gravelly or rocky soil. In clayey soils, the greatest changes occur as these soils crack on drying and thus, allow unlimited infiltration at the beginning. Once the cracks are filled with water, swelling of clay takes place and cracks are closed, therefore, infiltration practically ceases. In addition to texture, the infiltration rate increases under vegetation as compared to bare soil.

Water Percolation

Percolation is "the downward movement of water through the soil profile". It is the same as drainage. Percolation occurs predominantly in downward direction and infiltration can be considered as first stage of percolation. The downward movement of water below the maximum root zone depth is called *deep percolation*. It is unavoidable loss following irrigation which is more in coarser than in finer soils. Pressurized/micro irrigation systems (sprinkler and drip) are very helpful in checking deep percolation loss as water application rate in these systems may be adjusted as per the hydraulic properties of soil and water requirement of the crops.

Percolation is very important in soil development and land management. It removes the high salt content through leaching but removes valuable plant nutrients also. In coarser textured soils, the percolation capacity is greater as compare to the finer textured soils.

Inter-Flow

Inter-flow is "lateral seepage of water in relatively pervious soil above a less pervious soil layer". Such water reappears on the surface of the soil at a lower elevation. Interflow is a form of percolation and does not contribute

directly to the ground water. Due to the presence of an impermeable layer underneath, a large proportion of water accumulate on this layer and continues moving in a horizontal direction until it finds either more pervious subsoil to go into the groundwater or come to the soil surface at some location further down the slope. Interflow causes landslides in highly undulating areas of highly permeable surface soils and slowly permeable sub-soils.

Surface Runoff

"Water that runs off from soil without entering the soil to any appreciable extent is called *surface runoff*". Water in streams and rivers is also surface runoff.

Runoff from a field or a small watershed occurs when the rate of rainfall exceeds the infiltration capacity. Amount of runoff from a given area may be determined as:

Surface runoff = water gain - water loss - water storage

where *water gain* is precipitation, condensation and absorption from atmosphere; water *loss is* percolation, evaporation and transpiration; and *water storage* which includes interception storage (part of rain that remains in the vegetation until it evaporates), surface storage (rain stored in small depressions in the area) and soil storage (increase in soil moisture content in the soil profile).

Groundwater

Groundwater is "a continuous mass of water below the soil surface with zero water potential (free water)". The surface of the groundwater is called the *groundwater table*. It can be measured by drilling a hole in the soil and measuring the depth of water level in the hole from the surface. In some situations, two or more water table levels exist due to the presence of impervious layers at different depths in the soil. The upper groundwater is called *perched groundwater table*.

Chapter 15

Soil Temperature

Soil temperature strongly influences seed germination, growth and development of roots, and microbial activities. Soil temperature influences aeration, evaporation, and rate of chemical reactions in the soil. Understanding of soil thermal regimes is, therefore, important to manage soils to optimize soil temperature conditions in relation to plant growth.

Soil Thermal Properties

i) **Temperature and heat:** Heat is a form of energy which is measured by temperature. Heat energy refers to kinetic energy of the molecules of a substance due to their random motion or vibration. The unit of heat energy is *calorie* or *joule* and that of temperature is ^oC, ^oF or K. C*alorie* is defined as the amount of heat required to raise the temperature of one gram of pure water from 15^oC to16^oC.

ii) **Heat capacity:** It is the amount of heat present in a body. It may be expressed on 'per unit mass' (*specific heat capacity*) or 'per unit volume' (*volumetric heat capacity*) basis. Heat capacity is expressed in terms of gram calories, i.e. calories per gram (cal/g) for specific heat capacity and calories per cubic centimetre (cal/cm^3) for volumetric heat capacity. One gram calorie is the amount of heat required to raise the temperature of one gram of water from 15 to $16 ^oC$.

iii) **Specific heat:** *The specific heat* is the quantity of heat required to raise the temperature of one gram of the substance by $1 ^oC$. The unit of specific heat is cal g^{-1}. Specific heat of water is 1 cal g^{-1} and of many soil forming minerals is nearly 0.2 cal g^{-1}. Practically, all substances have specific heat smaller than that of water.

iv) **Thermal conductivity:** It is the property of a substance to conduct heat. It is "the quantity of heat transmitted through a unit length of a substance per unit cross-section per unit temperature gradient per unit time and expressed in cal cm/sec-cm^2-^oC or cal/sec-cm-^oC". Thermal conductivity of soil depends on texture, structure, moisture content, organic matter content, compaction and mineralogical composition of soil.

With increase in moisture content, the thermal conductivity of soil increases as moisture increases the area through which heat can flow. Similarly with increase in bulk density due to compaction increases the thermal conductivity due to increase in the area of contact between individual soil particles. Thermal conductivity is higher in sandy soils than clayey soils and least in organic soil.

v) ***Thermal diffusivity:*** It is a measure of the ability of a substance to conduct thermal energy relative to its ability to store thermal energy. It is "the ratio of thermal conductivity to heat capacity on a volume basis". It is a measure of the rate of change of temperature with time and expressed as m^2/sec in SI units.

vi) ***Albedo****:* It is "the fraction of the incoming radiation that is reflected from the earth's surface". It dependents on the surface condition, colour and the angle at which the sun rays strike the earth surface. Albedo is higher at the dawn and dusk, and in winter than in summer. Higher absorption of solar energy leads to lower albedo. Moist soils are relatively darker than drier soils therefore, have lower albedo. Similarly, rough surface has lower albedo than smooth.

vii) ***Thermal regime of soil:*** It usually includes heat flux (movement) in soil, the thermal properties of soil (heat capacity, specific heat, thermal conductivity and thermal diffusivity) and heat exchange between soil and air.

Sources of Soil Heat

Primary source of soil heat is the solar radiation. Some amount of heat is coming from the earth interior, radioactive substances and chemical and biological processes occurring within the soil.

Thermal radiation is the transfer of heat energy across space without a carrier medium. It is measured as heat energy per unit area per unit time (cal $cm^{-2}min^{-1}$). One cal cm^{-2} is also known as one *langley*. Therefore, one cal cm^{-2} min^{-1} is equal to one langley per minute. The rate at which the solar radiation is received at the top of earth's atmosphere is known as the *solar constant*, and has been estimated to be equal to 2.0 langleys per minute. Most of this radiation is absorbed in atmosphere and by plants, and also scattered. Only a small part of the radiation is reaching to soil.

Factors Affecting Soil Temperature

Both the environmental and soil factors affect the soil temperature.

1. *Environmental factors:*

    i) *Solar Radiation*: Radiation received at the soil surface depends on:
        a. The angle at which the solar radiation strike the soil surface. This angle is determined by latitude, altitude and extent of exposer of soil surface to solar radiation, sun's position with respect to earth's surface, and steepness and direction of slope.

        b. The insulation by water vapour, clouds, dust, smoke, fog and vegetation or other mulching materials.

    ii) *Exposer and Latitude*: The incident angle of solar radiation depends upon the latitude, direction of exposure and degree of slope of soil surface. The radiation received per unit area decreases with the increase in the angle of incident radiation with respect to the perpendicular. This amount is directly proportional to the cosine of angle between perpendicular to the surface of earth's surface and the direction of incoming solar radiation, i.e. proportional to Cos θ. The amount of radiation received per unit area decreases in proportional to the increase in area covered by it. The radiation reaching earth's surface perpendicularly covers relatively small area compared to the one received at an angle, therefore, earth's surface receives more radiation per unit area, and hence is warmer. The diurnal temperature varies with the position of the sun with respect to earth's surface.

    Southern (south facing) slopes receive more solar radiation than northern (north facing) slopes, therefore, the soil temperature is much higher than the northern slopes. It results in snow covers on northern slopes for much longer periods than on southern slopes in Himalayas. Northern slopes, therefore, remain moist for a longer period of time and support thicker vegetation and forest than the southern slopes which become dry very fast due to longer exposure to the sun.

    iii) *Insulation:* Soil can be insulated against solar radiation due to water vapours, dust, clouds, fog, gases present in the atmosphere as well as snow, vegetation and mulch at soil surface. Insulated soils are cooler in summer than bare soils but warmer in winter. Similarly, insulated soils are cooler during day and warmer during night than bare soil.

The impact of different insulating materials on soil temperature is explained below:

a) *Water vapour:* The water vapours, clouds, fog, dust and different gas *molecules* present in atmosphere reflect, absorb and/or scatter the incoming radiation, thereby decreasing the net radiation reaching the ground, and obstruct the long-wave radiation from escaping the soil surface. That is why, cloudy days are cooler and cloudy nights are warmer than the clear days and nights.

b) *Vegetation:* Vegetation through reflection of incident radiation decreases the soil temperature. Vegetation canopy decreases penetration of the radiant energy, increases the amount of latent heat of vaporization through transpiration and uses energy for photosynthesis. Vegetation acts as an insulating layer, lowering diurnal soil temperature fluctuations and keeping soil warmer during winters and cooler during summers as compared to bare soils.

c) *Mulches:* Mulches affect soil temperature through reflection of incident radiation depending upon *albedo* value of the mulch material, trapping solar radiation and reducing evaporation from soil surface. Light coloured mulches (straw, dust) increase reflection of incident radiation as compared to dark coloured mulches (FYM, black polythene sheet). Transparent mulch traps solar radiation and transmits heat to the soil due to the green-house effect and increases soil temperature. Mulches lower diurnal temperature fluctuations in soil, and keeping soil cooler during the day and warmer during the night as well as warmer during winter and cooler during summer as compared to un-mulched bare soils.

iv) *Evaporation and Condensation:* Evaporation is an endothermic process, consumes 540 cal of heat to change 1g of water to gaseous state. This loss of heat energy from soil makes soil cool. Thawing of ice also absorbs heat, therefore causing cooling effect in soil. Condensation is an exothermic process (opposite of evaporation) evolving heat when vapors condense and keeps the soil warmer. Similarly, freezing of water in soil generates heat.

v) *Rainfall:* The temperature of rainwater is lower than the soil itself, therefore, exert a cooling action. The rain water which percolates through the soil results in rapid cooling in subsoil.

2. Soil factors:

i) *Moisture content:* Soil moisture influences temperature of soils through specific heat and thermal conductivity of soil.

ii) *Specific heat:* Soils of high specific heat exhibit slow temperature change. Therefore, wetter soils require more heat to raise its temperature. Heavy soils with high moisture content, therefore, remain cool but light soils holding less moisture warm up quickly.

iii) *Thermal conductivity:* A loose soils have very low thermal conductivity because of small contact area between the particles and conductivity of the air is very low.

iv) *Thermal diffusivity:* The increase in thermal diffusivity with increase in moisture content is slow than increase in thermal conductivity. Thermal diffusivity is highest at about 1 bar suction, and decreases with further increase in moisture content as volumetric heat capacity in this moisture range increases faster than the thermal conductivity.

v) *Soil Albedo:* Soil colour and soil moisture content substantially impact soil temperature by changing soil albedo. Drier the soil, the smoother its surface and brighter its colour, the higher is its albedo and cooler is the soil.

vi) *Texture:* Thermal conductivity of soils decreases with decrease in size of the soil particles, therefore, sandy soils having large sized particles have higher thermal conductivity than clayey soils having smaller sized particles. Peat soils (high OM containing soil) have least thermal conductivity.

vii) *Structure:* Soils with good natural structure have higher conductivity than tilled soils. Platy and blocky structures of soils provide higher conductivity than granular structure.

viii) *Bulk density:* Soils which are compacted, have larger contact between the soil particles and hence have a greater thermal conductivity than the loose soil. Loosen of soil through tillage makes the surface soil poor in conduction of heat to lower layers.

137

ix) **Soil colour:** Light coloured soils absorb less and reflect more energy than dark coloured soils.

x) **Biological activity:** Soils higher in organic matter can warm up more than biologically inactive soil as biological activities evolve heat.

xi) **Soluble salts:** Soluble salts affect soil temperature indirectly through their influence on processes like evaporation, and condensation, and biological activities. Higher salt concentration lowers evaporation and suppresses biological activities in soil.

Heat Flow in Soil

The heat flow in soil occurs mainly through conduction. The flow of heat by convection and radiation is of little importance.

i) **Conduction:** In conduction, heat flows by transfer of momentum of individual faster moving molecules at the hot end to their slower moving neighbouring molecules at the cooler end by collision.

ii) **Convection:** Heat flow by convection occurs due to differences in density of water as a result of temperature gradients in soil profile and vaporization of water molecules from the hotter end of a partially saturated soil pore and their condensation at the cooler end where it releases latent heat. This process occurs only in fluids.

iii) **Radiation:** Radiation is the process by which heat is transmitted from one place to other without any carrier medium. The radiative transfer of heat in soil occurs in empty pores as electromagnetic waves.

The heat flow in a soil through conduction is described by Fourier's law, which states that "the amount of heat transmitted per unit time in a unit area of a block of soil is directly proportional to the ratio of temperature difference between the hot and cool ends of the block and its thickness".

Measurement of Soil Temperature

Both contact and non-contact types of thermometric methods are available. In contact type, the thermometers are used in which thermal expansion of a solid (bimetallic strip thermometers), liquid mercury or alcohol (in glass) or gas (constant pressure or constant volume thermometers) is measured. Some common contact type thermometers are based on the changes in electrical properties of the material with change in temperature e.g. thermistors and thermocouple thermometers. In most commonly used contact methods,

138

changes in temperature are recorded using mercury (in glass) thermometers, thermocouple thermometers and thermistors. Non-contact type methods include infrared thermometers optical pyrometers, total intensity radiometers and remote sensing. All thermometers must be carefully calibrated and installed at the point of measurement.

Effect of Soil Temperature on Plant Growth

There are direct and indirect effects of soil temperature on plant growth.

1. ***Direct effects*:** Seeds of most crops require optimum temperature to germinate (10-35ºC) in a reasonable time. The site of temperature perception, i.e. shoot meristem, lies below the soil surface for an appreciable period in cereal crops. Once germinated, a minimum temperature is required to initiate the growth of plants. The requirement of the minimum and maximum temperatures for different crops is different and varies with crop growth stages.

   Very low or very high temperatures cause stunted roots and reduce their branching. High soil temperature causes decaying of roots of low temperature requiring crops. Temperature for the growth of roots of most crops is 20-25ºC usually lower than their shoot growth where the microorganism activity is optimum between 25-35ºC.

   Based on the impact of temperature on plant growth, the three temperature ranges have been defined as a) *optimum range-* plants thrive and produce best, b) g*rowth range-* plants can grow but yield may not be optimum and c) s*urvival limit-* plants may not grow and produce anything.

2. ***Indirect effects:***
   i) *Soil formation and development:* Temperature directly influences all reactions taking place in the soil leading to soil formation and their development.

   ii) *Soil moisture:* Soil temperature influences the free energy of water which increases with rise in temperature. Temperature also effects vapour pressure and viscosity in soil. The movement of water in vapour phase is caused by difference in vapor pressure which is more prominent in sandy soils. The water from subsurface moves upwards in vapour phase and condenses in the root-zone at night and become available to plants.

139

iii) *Soil structure:* The temperature influences biological activities, decomposition of organic matter, wetting and drying, and freezing and thawing processes which are responsible for genesis of soil structure and stabilization of the aggregates.

iv) *Microbial activity and availability of nutrients:* Microbial activities are strongly influenced by soil temperature. The microbes decompose organic matter and make the nutrient available to plants. Microbial activity is highly restricted below 10°C and becomes practically zero below 5°C. *Soil solarisation* is a process in which soil temperatures above 50°C are maintained for few days to control pests and diseases, especially fungal diseases of vegetable and fruit crops. Nitrification is highest at around 30°C. Maximum release of only retard K release but also decrease K uptake by the plant roots.

Management of Soil Temperature

Under field conditions, the following practices may used for altering the soil temperature.

i) *Mulching:* Mulch reduces the extremes in soil temperature and conserves soil moisture. Soil temperature is raised under polyethylene mulch during the day as it is transparent to the incoming solar radiations.

ii) *Vegetation:* Vegetation reduces soil temperature fluctuation by intercepting incoming and outgoing radiation from soil. Vegetation lowers the air temperature above it canopy than at soil surface on a clear night.

iii) *Tillage:* Tillage operation alters soil temperature by changing the moisture rent ion in the soil. The changes in soil temperature on ridges formed during tillage operation are rapid as compared to the furrows. Tilled soils are warmer during the day because of low thermal conductivity than untilled soil.

iv) *Soil compaction:* Close packing of soil particles increases the thermal conductivity of soils resulting in smaller changes in its temperature.

v) *Irrigation and drainage:* As water has high specific heat and heat of vaporization, it resists changes in soil temperature. Irrigation reduces soil temperature fluctuations and causes cooling of soil in summer season. The soil temperature may be raised by providing drainage in waterlogged areas and the temperature of dry soils may be stabilized irrigation.

140

Chapter 16

Soil Air

The soil air is one of the important plant growth factors like nutrients and water. It is the gaseous phase of soil, also known as *soil atmosphere,* present in moisture free pore spaces. The composition of soil air is highly dynamic depending on the balance between the rate of production and consumption of gases, as well as the rate of gaseous exchange between soil air and the atmospheric air. The first process tends to widen the difference in gas composition between soil air and the atmosphere while the second process tries to minimize this difference.

Composition

The composition of soil air refers to the relative concentration of its different constituents. The atmospheric air, by volume, is composed of approximately 79.0% of N_2 and inert gases, 21.0% of O_2 and 0.03% of CO_2. The composition of soil air is not constant but highly variable. Several factors influence the soil air composition such as moisture, temperature, organic matter content, pH and depth of soil; time of the year; activities of soil microorganisms and plant roots; solubility of O_2 and CO_2 in water; rate of gaseous exchange between soil pores and atmosphere. Unlike atmospheric air, soil air is discontinuous; therefore, it is different at different locations within a given soil.

In the surface, the soil air has slightly lesser concentration of O_2 due to its regular consumption in respiration by plant roots and microorganisms, and chemical reactions; higher concentration of CO_2 due to regular production in respiration by plant roots and microorganisms, oxidation of soil organic matter; almost similar N_2 and higher humidity than atmospheric air because of stable structure and presence of sufficient macropores, (Table 16.1). Under anaerobic condition, the concentration of O_2 may be as low as zero but soil air may contain methane, hydrogen sulfide, and ammonia as these gases are formed in the process of decomposition of organic matter under reduced or waterlogged conditions. The concentration of CO_2 is highly variable and may increase to as high as 20%. This increase in CO_2 in

invariably accompanied by reduction in O_2 concentration but not necessarily in the same proportion.

Humidity in soil air may approach 100% at most of the times except in surface soil, particularly during prolonged dry spells while in atmosphere it generally varies between 30-60%.

Table 16.1: Average composition of air in well aerated surface soil and atmospheric air

Component	Soil air (%)	Atmospheric air (%)
Nitrogen	79.2	79.0
Oxygen	20.6	21.0
Carbon dioxide	0.3	0.03
Relative humidity (Water vapour)	95-100	Highly variable (20-90)

Other gases- traces

Factors Influencing Composition of Soil Air

i) *Physical properties of soil:* The soil physical properties influencing the composition of soil air are texture, structure, moisture content, macro pores, degree of compaction and the depth of soil. Just after irrigation or heavy rains, all the soil pores are filled by water. As water evaporates or drains from the soil, the air enters into the pores (macro-pores). The macropores primarily controls the gaseous exchange which is affected by texture, structure, bulk density and organic matter content of the soil. Due to large volume of macropores, aeration is more in sandy soil as compared to clayey soil. Clayey soils have higher concentration of CO_2 than sandy soils due to the presence of large volume of micropores restricting aeration. Subsoil generally has less O_2 than surface soil because of restricted diffusion due to higher moisture and lesser volume of macropores in subsoil. The CO_2 content is usually more in flooded and puddled soils due to restricted aeration.

ii) *Tillage:* Exchange of gases affects the gaseous composition which is rapid in soils which are tilled as compared to untilled soils. In shallow tilled soils, evolution of CO_2 is higher in the surface soil.

iii) *Soil organic matter:* Decomposition of the added organic materials by microbes decreases the concentration of O_2 and increases the concentration of CO_2.

142

iv) ***Cropping:*** Cropping tends to reduce O_2 and increase CO_2 content of the soil air due to respiration by plant roots. The amount of CO_2 is usually much higher near their roots of plants than further away.

v) ***Season:*** The changes in soil temperature and moisture with season affect the composition of soil air. There is lower concentration of O_2 and higher concentration of CO_2 in wet soils during monsoon season to dry soil in summer due to increased decomposition of organic matter and slow gaseous exchange but it not always true as increased microbial activities during warm season increases the evolution of CO_2 in soil.

Importance of Soil Air

Soil air with its constituents plays a vital role in modifying the physical, chemical and biological properties of soil thereby govern the availability water and nutrients, and ultimately the plant growth. The importance of individual constituent is summarized as follow:

☐ The O_2 is required for the respiration of microbes and plant roots which increases with increase in population and growth of the plants. Though, it is not easy to establish the optimum requirement of soil O_2 by the various plant species but for the normal growth of plants, the concentration of O_2 in soil air should exceed 10%. An excess of O_2 in the soil is also undesirable because the organic matter would be oxidized too rapidly and the soil would be dried quickly. Deficiency of O_2 is considered more harmful to plants than the excess of CO_2 within the reasonable limits ($< 20\%$ CO_2).

☐ The nutrients are dissolved with the help of CO_2 and become available to plants.

☐ The N_2 is converted into the available form of nitrogen for plants by symbiotic and non-symbiotic bacteria.

☐ Desiccation of soil is prevented by water vapour present in soil air. Water vapours helps in the movement of water within the soil, particularly, in sandy soils.

For optimum plant growth and yield, soil aeration must be adequate. *Adequate aeration* is defined as "a soil condition where the oxygen diffusion rate (ODR) is at least 30×10^{-8} g cm^{-2} min^{-1} and O_2 concentration of the soil air is at least 10% in the root zone".

Soil Aeration

It is "the process of the gaseous exchange between soil and atmosphere". Only two major gases, i.e. O_2 and CO_2 are associated with aeration. Through soil aeration, the consumed O_2 is replenished and toxicity of CO_2 evolved during respiration of plant roots and microorganisms is prevented (Fig.16.1).
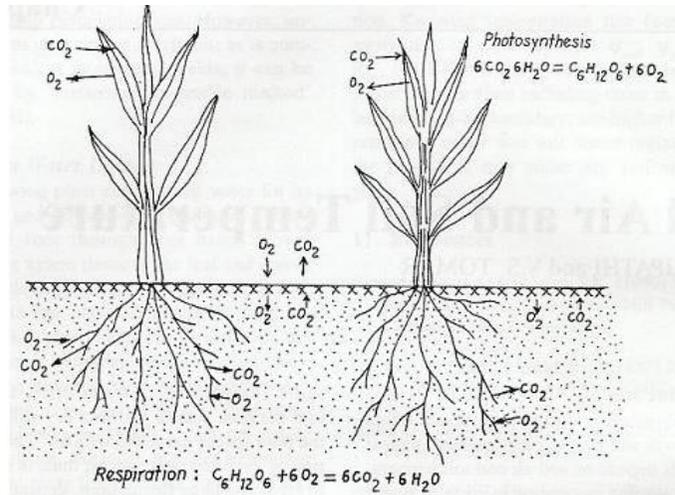
Fig. 16.1: Consumption of O_2 and production of CO_2 during respiration by plant roots and soil microbes

Processes of Gaseous Exchange

1. ***Mass flow***: The mass flow (also called *convective flow*) of air occurs in response to total pressure gradients of gas. The whole mass of air moves from a place of higher pressure to that of lower pressure due to the total pressure gradient from atmospheric air to soil air or vice-versa, and. from one location of soil to another. The difference in total pressure between soil air and atmospheric air may results from several phenomena such as changes in the barometric pressure in the atmosphere, wind blowing across the soil surface, water infiltration due to heavy rainfall or irrigation, temperature gradient near the soil surface, changes in soil water content through drainage and evapo-transpiration, fluctuating water table, tillage, etc. Some of these mechanisms are discussed below:

   i) *Soil temperature:* Charle's Law states that "the air pressure is directly proportional to the air temperature at a constant volume". Therefore, the pressure gradient develops due to the temperature gradient between two points which causes the movement of air. This

144

movement of air may be within the soil layers and/or between soil and atmosphere due to temperature differences. This type of movement is restricted to surface layer because of very less variation in soil temperature below 30 cm depth. The contribution of change in temperature to the total gas exchange is very small, i.e. < 0.1% because the coefficient of expansion of air is very small, i.e. 1/273 per °C.

ii) *Pressure:* Boyle's Law states that "the volume of air is inversely proportional to the pressure at a constant temperature". With an increase in atmospheric pressure, the volume of soil air decreases making the air move from atmosphere to soil. With a decrease in the atmospheric pressure, the volume of soil air in surface soil, particularly in coarse textured, increases causing soil air to move to the atmosphere. The contribution of change in barometric pressure is also very small, i.e. <1.0%

iii) *Wind:* High wind velocity creates pressure and suction which causes the exchange of gases between soil air and atmosphere air but the effect is limited only to surface soil. The contribution of wind velocity to mass flow of air is not very significant, and seldom exceeds 0.1 % as wind velocity at the soil surface is negligibly small to cause air pressure differences.

iv) *Rainfall and irrigation:* Rainfall and irrigation play an important role in mass flow of soil air. Rainfall and irrigation displace the soil air rapidly during infiltration causing an increase in O_2 concentration in lower depths. Then, with the loss of water from the soil by evapotranspiration and deep drainage, the air enters into the soil. The contribution of rain to total air exchange depends on the frequency and intensity of rain, and is estimated to be around ≤10%.

2. **Diffusion:** It is the main process of renewal of soil air. *Diffusion* of soil air refers to the movement of gases through diffusion in response to their partial pressure gradient, i.e. concentration gradient of individual gases not due to the total pressure gradient. As per the kinetic theory of gases, the molecules of gases are in a state of random motion in all directions. When two gases are put together, they readily get mixed up. This is known as *diffusion*. Net movement of gases by diffusion occurs when the partial pressures of individual gases in the two neighbouring systems are different, but the total pressure of gases in two systems is the same. The

atmospheric air contains a higher amount of O_2 and lower amount of CO_2 than soil air, therefore, the partial pressure of O_2 is higher in the atmospheric air than in the soil air, and the partial pressure of CO_2 is higher in the soil air than in the atmospheric air even though the total pressure in the atmosphere and soil may be same. This difference in partial pressure causes the movement of O_2 from atmosphere into the soil and CO_2 from soil to the atmosphere. With increase in temperature, the diffusion process also increases.

Characterization of Soil Aeration Status

It is important to characterise soil aeration status before any soil air management practices are adopted. Several indices are available for use depending on the objective and accuracy of measurement. These are:

i) *Composition of soil air:* The amount of different gases present in soil air, particularly O_2 and CO_2 are determined using gas analyzer, gas chromatographic or chemical methods.

ii) *Air-filled porosity and Aeration Porosity:* The volume fraction of pore space occupied with air is called air-filled porosity. It can be determined by subtracting volumetric water content from the total volume of pore space.

It is important that air-filled porosity is defined at some fixed water content in order to compare two soils. Some scientists used field capacity as this water content, and called the air capacity at field capacity as *field air-capacity*. Another such value is the aeration porosity. *Aeration porosity* which is "the volume of pore space filled with air when soil is under a tension of a 50 cm of water". Only pores of sizes > 0.06 mm in diameter are filled with air at a tension of 50 cm. The critical value of aeration porosity below which the crop plants are adversely affected is considered to be 10%.

iii) *Air-permeability:* It is the readiness with which soil transmits gases when there is a pressure gradient. It is determined by the amount, size and continuity of air-filled pores within the soil. *Air permeameter* is commonly used to determine air permeability in both field and laboratory conditions. This method provides a better idea of renewal of soil gases than the actual availability of oxygen to plant roots.

iv) Carbon dioxide released: The aeration status may be studied by measuring the release of CO_2 released from a definite area of the soil surface due to microbial and root activities in the soil.

v) Redox potential: Oxidation-reduction potential or redox potential (E_h) is an important chemical characteristics of soil related to soil aeration which indicates the tendency of soil to reduce or oxidize chemicals, usually measured in milli-volts. In a well aerated soil, the oxidized states of elements- iron as ferric (Fe^{3+}), nitrate (NO_3^-), and sulphate (SO_4^{2-}) dominate where as in poorly aerated soils, the reduced forms of these elements such as ferrous iron (Fe^{2+}), oxides of nitrogen (NO_x) and sulphide (S^{2-}) dominate.

A standard electrode and a platinum electrode are inserted in the soil solution for the measurement of E_h of a soil. The values of E_h can be interpreted up to a certain extent in terms of the ratios of certain oxidizing and reducing organic and inorganic materials present in the soil system. The value of E_h is positive and may be as high as +0.5 volt under strong oxidizing conditions. It is low and even negative when elements are present in reduced forms. The E_h values have the advantages of providing a measure of intensity of reduction under reduced conditions. It is, therefore, useful in characterizing the soil aeration in the range below which the diffusion of oxygen is zero, for example, the rice fields where soils remain saturated or submerged under water.

The E_h values of certain elements at which their oxidized and reduced forms occur are given in the Table 16.2.

Table 16.2: The oxidized and reduced forms of certain elements and their redox potential (E_h) at which the exchange in their forms occur.

State of element		E_h at which exchange in form occurs (V)
Oxidised	**Reduced**	
O_2	H_2O	0.38 — 0.32
NO_3^-	N_2	0.28 — 0.22
Mn^{4+}	Mn^{2+}	0.28 — 0.22
Fe^{3+}	Fe^{2+}	0.18 — 0.15
SO_4^{2-}	S^{2-}	-0.12 — 0.18
CO_2	CH_4	-0.20 — 0.28

vi) Oxygen diffusion rate (ODR): This is the best method of measuring soil aeration. The ODR is "the rate at which O_2 can replenish when it is used

by respiring plant roots or by microorganisms" which is measured using *ODR meter*. The ODR meter consisted of a small platinum electrode and a standard calomel electrode which are inserted into the soil to a desired depth. The output electric current is related to the rate of oxygen flux at the electrode surface as:

$$i \times 10^{-6} = nFA\varphi$$

where I = Electric current in microamperes

n = No. of electron required for reduction of one molecule of oxygen i.e. 4

F = Faraday's constant

A = Surface area (cm^2) of platinum electrode

φ = flux or ODR to the electrode surface in number of molecules of oxygen per second per cm^2.

The ODR is calculated as:

$$\text{ODR} = \frac{i \times 60 \times 32 \times 10^{-6}}{4 \times 96500 \times A} = \frac{0.497 \times 10^{-8} \times i}{A} \text{ g cm}^{-2}\text{min}^{-1}$$

Critical limits of ODR for growth of most plant roots is 20×10^{-8} g cm^{-2} min^{-1}. The ODR requirements of some crops are given in Table 16.3.

Table 16.3: Critical oxygen diffusion rate (ODR) for different crops

Crop	ODR (10^{-8} g cm^{-2} min^{-1})
Peas	39.5
Maize	30.0
Soybean	28.4
Wheat	26.3
Toria	22.9

The ODR decreases with depth of soil and the decrease is sharp for soils in which the concentration of oxygen is lower at the soil surface. It also decreases as the moisture content increases.

Effects of Soil Aeration

i) The growth of plant roots is reduced. Prolonged water logging retards the growth of the plants. In some cases, roots may develop abnormally such as de-shaping of carrot and sugar beet.

ii) Plants are unable to take nutrients and water.

iii) Plant roots become susceptible to diseases causing increase in the disease incidence.

iv) Nitrogen fixation by *Rhizobium* is affected.

v) Decomposition of organic matter by micro-organisms is adversely affected. Decomposition of soil organic matter by anaerobic bacteria librates toxic substances which are harmful to plant growth such as methane, sulphides and other organic acids.

vi) Some toxic compounds of iron and manganese are formed under anaerobic conditions, specifically in acidic soils.

Management of Soil Aeration

Under field conditions, the soil aeration may be optimized by following methods:

i) *Soil structure:* The soil structure may be improved by adding organic materials (farmyard manure, green manuring, incorporation of crop residues, and growing of legume crops). Improved soil structure results in an increase in the volume of air-filled pores. Massive structure permits diffusion of O_2 and CO_2 only if soil is dry. The fine pores of massive or compacted soils retain water for longer time after a wetting and inhibit diffusion.

ii) *Drainage:* Providing surface and/or subsurface drainage may help in maintaining aerobic condition in poorly drained soils. Drainage drainage systems are essential for proper aeration in soils where there is a continuous seepage from canals, presence of perched or high water tables, heavy rains or irrigation. The drainage reduces the moisture content and increase the effective air capacity of soil.

iii) *Temperature:* The rate diffusion of gases in soil increases with increase in temperature but the increased temperature also increases the evolution of CO_2 in soil. Therefore, the net result on the partial pressure of O_2 in a soil may be either positive or negative. In such conditions, mulching is a useful practice which protects the soil surface from raindrops impact and maintains its tilth which favours aeration but mulch keeps the soil moist and restricts the soil aeration. Therefore, individual situation determines the favourable or unfavourable effect of mulching on diffusion rate. However, mulching largely reduces diffusion of O_2 into the soil.

iv) Cultivation: In poorly drained heavy textured soils, shallow cultivation and inter-culture operations help in exchange of gases. Soil crust may obstruct the gaseous exchange, therefore, mechanical breaking of the soil crust help in improving soil aeration. The use of deep rooting crops, sub-soiling and vertical mulching are very useful practices for improving the aeration in subsoil.

v) Plant adaptations: Roots of most plants are though adapted to aerobic conditions but some species increase the air space in roots or internal aeration through leaves and cortex cells, and grow well in oxygen-deficient soils. Crops tolerant to poor aeration may be grown in poorly drained soils. Rice flourishes well in waterlogged conditions whereas soybean may tolerate temporarily waterlogged conditions better than crops like pigeon pea, maize and other deep rooted crops.

vi) Regulation of root respiration: Soil aeration may also be controlled by regulating soil respiration by reducing fertilizer doses, plant population and incorporation of crop residues. Low O_2 requiring crops or crops with shallow root system may be preferred only surface soil has some aeration.

Chapter 17

Soil reaction refers to degree of acidity or alkalinity of a soil. It indicates the chemical environment of soil and affects soil properties (chemical, biological and indirectly physical), nutrient availability and activity of micro-organisms, and mobility of pollutants by affecting their biochemical breakdown, solubility and adsorption to soil colloids.

Soil reaction is denoted by the pH of a soil water suspension. The term 'pH' was first coined and used by Danish Chemist, Sorensen in 1909. The term is derived from the French word '*pouvoir hydrogen*' or '*hydrogen power*'. It measures the H^+ activity and is expressed conveniently in logarithmic term as 'the negative logarithm of the H^+ activity in an aqueous solution in moles L^{-1}. The practical significance of logarithm scale is that each unit change in pH means a ten-fold change in the amount of acidity or basicity. It is given by the expression:

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

where H^+ activity (moles L^{-1}) is the product of H^+ concentration and activity coefficient. For very dilute solutions H^+ concentration and H^+ activity are considered similar.

Water is both a weak acid and a weak base. It dissociates into H^+ and OH^-. The product of H^+ and OH^- is the dissociation constant of water (K_w) and is given by expression:

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

Thus, the pH of aqueous solution ranges from 0-14, with 7 being neutral. Solution with pH <7.0 are acidic and those with >7.0 are basic or alkaline. Pure water has a pH value of 7.0. Adding an acid to water will increase $[H^+]$ with corresponding decrease in $[OH^-]$ because K_w is constant, i.e. 10^{-14}. For example, a solution of 0.01M HCl will have $[H^-]$ 10^{-1} moles L^{-1} and thus $[OH^-]$ will be 10^{-13} moles L^{-1}.

Types of Soil Reaction

On the basis of pH, the soil reactions are of three types i.e. acidic, alkaline and neutral.

a) Acidic: The soil reaction is generally acidic (pH <6.5) in regions where precipitation is high and climate is warm. The high precipitation leaches appreciable amounts of exchangeable bases from surface soil and the exchange complex is dominated by H^+.

b) Alkaline: The soil reaction is mostly alkaline (pH >7.5) due to comparatively high degree of base saturation in arid and semi arid regions having low rainfall. When salts of strong bases such as sodium carbonate go into soil solution and hydrolyse, they give rise to alkalinity:

$$Na_2CO_3 \longrightarrow 2Na^+ + CO_3^{-2}$$
$$2Na^+ + CO_3^{-2} + 2HOH \longrightarrow 2Na^+ + 2OH^- + H_2CO_3$$
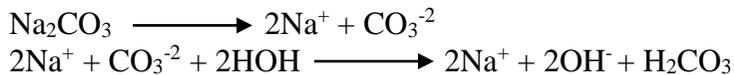
As sodium hydroxide dissociates to a greater extent than the carbonic acid, OH^- ions dominate and give rise to alkalinity and soil pH may be as high as 9 or 10.

c) Neutral: The neutral soil reactions occur in regions where H^+ ions just balance OH^- ions of the soil solution. Soils having pH in the range of 6.5-7.5 are considered as normal soils.

For mineral soils, pH extends from 3.5 to 10.5, however, in peat soils, pH may sometimes be as low as 3.0 and in some alkali soils, it may be as high as 11.0.

Factors Affecting Soil Reaction

There are various factors which affect the soil reaction. These are:

1. *Nature of soil colloids:* The colloidal particles (clay and humus) greatly influence the soil reaction. Clays possessing high cation exchange capacity (CEC) have tendency to adsorb and release more H^+ ions like montmorillonite as compared to clays having low CEC like kaolinite. Therefore, pH of the soil with montmorillonite is less than kaolinite.

2. *Per cent base saturation and kind of adsorbed bases:* The per cent base saturation decreases with high rainfall (humid region) due to leaching of bases. If percentage base saturation is <80, the soil becomes acidic and if lies 80-90, the soil is neutral, and when >90 as in arid and semi-arid regions (low rainfall), the soil reaction is alkaline. Sodium dominated soils have much higher pH than those dominated by calcium and magnesium.

3. *Concentration of soil solution:* The concentration of the soil solution varies with the soil moisture and affects the soil pH. The dilution and concentration affect the soil solution in opposite ways. Dilution causes dissociation and increases the number of H^+ ions but at the same time it lowers the concentration of H^+. On the other hand, increased concentration causes less dissociation but increases the number of H^+ ions per unit volume. It is observed that pH of the soil solution increases on dilution and vice-versa, but the change is very small. Thus, the soil pH tends to drop as the soil gets progressively dry. Soils having pH above 8.5 with high sodium show increase in pH on dilution because of hydrolysis and formation of sodium hydroxide. Since soil reaction varies with the salt concentration, it is preferred to measure pH in soil suspension in 0.01M $CaCl_2$ or 1N KCl solution to avoid fluctuation in pH measurements.

4. *Presence of Al^{3+} ions:* Presence of more Al^{3+} ions makes the soil acidic and vice-versa.

5. *Decomposition of organic matter:* Decomposition of organic matter by microorganisms result in formation of organic acids, CO_2, water and carbonic acid. Carbonic acid, in turn, reacts with Ca and Mg carbonates in the soil to form more soluble bicarbonates. The leaching of soluble bicarbonates makes the soil more acidic.

6. *Climate:* In general, soils formed in regions of high rainfall are acidic while those formed in low rainfall regions are alkaline.

7. *Soil management:* The cultural operations, in general, tend to increase the soil acidity. Acid soils become more acidic and alkaline become less alkaline. Cultivation reduces basic cations due to their leaching and uptake by crops. Besides, the use of acid forming fertilizers, such as ammonium sulphate or urea in soils creates soil acidity as Ca^{2+} and other basic cations are replaced by NH_4^+, leading to the formation of calcium sulphate, which is leachable. In addition, addition of manures and N_2 fixation by legumes cause acidity.

8. *Flooding:* Flooding tends to increase the pH of acid soils and decrease the pH of alkaline soils. Most soils reach at pH of about 6.5 to 7.5 within one month after flooding irrespective of their original pH values, and retain this pH until they get dried.

Acid sulphate soils formed naturally in waterlogged coastal area containing iron sulphide mineral (FeS_2) when drained become highly acidic. Due to drainage both S and Fe are oxidized and produce large quantities of sulphuric acid which brings down the pH to 4 or less.

Soil pH and Nutrient Availability

There is strong relationship between soil pH, and the availability of nutrients to plants (Fig. 19.1), as well as the activities of soil-organisms.

In strongly acidic soils (pH <5.5), the availability of the primary (N,P,K) and secondary nutrients (Ca, Mg, S) and molybdenum (Mo) is reduced. On the other hand, availability of most micro-nutrients (Fe, Mn, Zn, Cu and Co) is increased, even to the extent of toxicity to plants and microorganisms.

Fig. 19.1: Effect of soil pH on nutrient availability

Indirect effect of soil reaction occurs through the activity of microorganisms. Most microorganisms function best within a pH range of 6.0 to 7.5. If the soil reaction is changed beyond this range, the activities of microorganisms reduce substantially and availability of some of the essential elements like nitrogen is considerably decreased as the processes such as nitrification, nitrogen fixation, denitrification, etc. are carried out by different microorganisms. Among microorganisms, bacteria, in general, prefer neutral to slightly alkaline reaction (6.5-7.5), fungi grow in acidic conditions (4.5-6.5) and actinomycetes prefer slightly alkaline environment.

Though, it is difficult to generalize the relation between pH and nutrient availability but the pH range of 5.5 to 7.0 may provide the plant nutrients in most satisfactory levels. This may not be valid for all soils, *e.g.,* certain micronutrient deficiencies are common in some sandy soils at pH values 6.0 to 6.5.

The availability of different nutrients with pH is described as:

1) **Nitrogen:** The availability of N (NO_3^-) depends on the activity of nitrifying bacteria which are most active between pH 6.5-7.5. Their activities are adversely affected if the pH falls below 5.5 or rises above 9.0.

2) **Phosphorus:** The availability of phosphorus is highest between soil pH 6.5 - 7.5. In strongly acidic soil, soluble Fe and Al are present in abundance which combines with phosphorus to form iron and aluminium phosphates making phosphorus unavailable. This is called *phosphorus fixation*. The fixation of phosphorus also takes place when the soil pH is high. At high pH, phosphate combines with calcium and magnesium to form insoluble calcium or magnesium phosphate. The $H_2PO_4^-$ dominates in highly acidic soil (pH 4.0 -5.0). The concentration of HPO_4^{2-} starts increasing with increasing pH. At pH 9 and above, the PO_4^{3-} are available to plants. The $H_2PO_4^-$ and HPO_4^{2-} ions are considered to be more available than PO_4^{3-} ions.

3) **Potassium:** The availability of potassium is not influenced by the soil pH.

4) **Calcium and magnesium:** Acid soils are poor in calcium and magnesium. In soils having pH 7.0-8.5, availability of Ca and Mg is high. At pH above 8.5, the availability of Ca and Mg decreases.

5) **Sulphur:** The availability of sulphur is not affected by the soil pH. However, it is more soluble in acidic conditions and lost as leaching.

6) **Iron and manganese:** The Fe and Mn are readily available in acidic soils. At low pH, the solubility of these micro nutrients increases. At pH below 5.5, the solubility of these nutrients increases, consequently increasing their concentration to toxic levels. Between the pH range of 5.5 to 7.0, Fe and Mn are present in soluble ferrous (Fe^{2+}) and manganous (Mn^{2+}) forms. In alkaline conditions, Fe and Mn are generally present in ferric (Fe^{3+}) and manganic (Mn^{3+}) states. Thus, in soils having pH 7.5 and above, iron and manganese become unavailable.

7) **Boron, copper, molybdenum and zinc:** The availability of boron, copper and zinc reduces in alkaline soils and that of molybdenum in acid soils.

Buffering Capacity of Soils

It refers to the resistance to the change in pH of a soil solution. The hydrogen and aluminium ions along with the adsorbed cations largely control buffering capacity of soil. The clay and humus (colloidal complex) act as a powerful buffer in the soil and does not allow rapid changes in soil reaction. Clay soils rich in organic matter have more buffering capacity than sandy soils.

Buffering capacity of the soil also varies with its cation exchange capacity (CEC). The greater the CEC of the soil, greater will be its buffering capacity as there is equilibrium between reserve acidity (due to adsorbed hydrogen and aluminium ions) and active acidity (due to hydrogen ions of soil solution). When H^+ ions in the soil solution are neutralized by basic substances, more H^+ are released from soil exchange complex into soil solution to resist a rapid change in pH. The degree of buffering is highest between pH 4.5 and 6.0 and decreases below pH 4.5 and above pH 6.0.

At low pH, Al^+ and hydroxyl aluminium ions react and block exchange sites on silicate clays and humus, which reduces the CEC. On liming, the CEC increases and more of Ca^{2+}, Mg^{2+}, etc. are absorbed. Carbonates, bicarbonates and phosphates also act as buffering agents. The organic acids, which are formed continually as a result of microbial activities, are weak acids and serve as excellent buffering agents.

Importance of Soil Buffering Capacity

Changes in soil reaction (pH) have a direct influence on availability of plant nutrients as some nutrients are deficient at a given pH but others may be available in excess to toxic levels at the same pH. Buffering capacity of soil tends to maintain stability in soil pH, preventing sudden changes and fluctuations that might be detrimental to plants and soil micro-organisms. For example, well buffered soils resist the acidifying effect of acid rain. Knowledge of soil buffering capacity helps to estimate the required amount of amendments such as lime or sulphur to bring about the desired change in soil pH.

Factors Affecting the Buffering Capacity of Soil

The buffering capacity of soil is affected by texture of the soil, type and amount of clay minerals, and amount of organic matter present in the soil. Fine textured soils (clay soils) have greater buffering capacity than coarse textured soils (sandy soils). It is due to higher cation exchange capacity of

fine textured soils than coarse textured soils as fine textured soils have high clay content whereas coarse textured soils have low clay content. A soil high in organic matter has high buffer capacity due to its high exchange capacity and it requires large amounts of amendments for a change in its pH.

Chapter 18

Soil Colloids

The soil colloids are the most active fraction of the soil and largely determine the physical and chemical properties of a soil. Colloids are particles < 0.001 mm in size, and the clay fraction includes particles < 0.002 mm in size. Therefore, all clay minerals are not strictly colloidal. Colloidal particles float in a *dispersion medium* and do not tend to settle, therefore, colloids are referred to as dispersed systems. *Inorganic colloids* (clay minerals, hydrous oxides) usually make up the bulk of soil colloids. *Organic colloids* include highly decomposed organic matter generally called *humus*. Organic colloids are more reactive chemically and generally have a greater influence on soil properties per unit weight than the inorganic colloids. Humus is amorphous. Clay minerals are usually crystalline (although some are amorphous) and usually have a characteristic chemical and physical configuration. Both inorganic and organic colloids are intimately mixed with other soil solids. Thus, the bulk of the soil solids are essentially inert and the majority of the soil's physical and chemical character is a result of the colloids present.

General Properties of Soil Colloids

1. *Surface area:* The soil colloids have large surface area per unit mass because of their small size. The external surface area of 1g of colloidal clay is at least 1000 times that of 1g of coarse sand. Some alumino-silicate clays have large internal surfaces as well. The surface area of the soil colloids ranges from 10 m^2/g (for clays with external surfaces, e.g., kaolinite) to more than 800 m^2/g (for clays with external and internal surfaces both, e.g., montmorillonite).

2. *Surface charges:* Soil colloids having both external and internal surfaces, carry negative and/or positive charges. In most of the soil colloids, negative charges predominate. Although some colloids in very acid soils have net positive charge. The presence and intensity of charge on soil colloids play an important role in attraction and repulsion of the particles towards each other and consequently influencing both physical and chemical properties of the soil. Negative electric charges on clay minerals originate due to:

i) *Ionizable hydrogen ions (pH dependent):* The -Al-OH portion of the clay ionizes the H and leaves an un-neutralized negative charge on the oxygen (-Al-O⁻). The extent of ionization depends on the pH of the soil, and increases with the pH of the soil.

ii) *Isomorphous substitution:* The substitution of one ion for another, of similar size and often with lower positive valence, causes the charge on the clay minerals. Clay minerals have dominance of Si^{4+} in tetrahedral sheets and Al^{3+} in octahedral sheets. During the clay crystallization, generally Si^{4+} ions are replaced by Al^{3+}, and Al^{3+} are replaced by Fe^{2+}, Mg^{2+}, or Zn^{2+}. As most of the substitutions are by the ions with lower charge (less positive valence) than the ions being replaced, therefore, substitution results in an excess of negative charge at that site in the structure.

3. *Adsorption of cations:* The cations such as H^+, Al^{3+}, $Ca^{2+,}$ and Mg^{2+}, etc., are attracted to the colloidal surfaces as soil colloids possess negative charge. The adsorption of these cations to the negatively charged soil colloids gives rise to ionic diffuse double layer.

4. *Adsorption of water:* Water is a polar molecule, therefore, in addition to the adsorbed cations, a large number of water molecules are also associated with the soil colloidal particles. Some water molecules are attracted to the adsorbed cations and cations get hydrated. Some water molecules are held in the internal surfaces of the colloidal particles and results in the swelling of colloidal particles.

5. *Cohesion:* Cohesion is the phenomenon of attraction of colloidal particles that are of similar nature. For example, attraction between water molecules, sticking together of clay particles, etc.

6. *Adhesion:* Adhesion is the phenomenon of attraction of colloidal particles to other substances. For example: sticking of colloidal particles on the surface of sand particles, and to the farm implements.

7. *Swelling and shrinkage:* Some clays such as montmorillonite/smectite swell when wet and shrink when dry. After a prolonged dry spell, soils high in smectites, *e.g.,* Vertisols, are often characterized by wide and deep cracks. During rain or when irrigation is applied, initially these soils due to wide cracks allow the water to infiltrate rapidly, but later on due to swelling of clay minerals, these soils become more impervious than the

soils dominated by kaolinite, chlorite, or fine-grained mica (Illite). Vermiculite is intermediate in its swelling and shrinkage characteristics.

8. *Flocculation and dispersion:* Flocculation is the process, where the individual particles of clay are coagulated to form *floccule*. The degree and permanence of flocculation depend upon the nature of the ions present. For example, calcium and hydrogen tend to increase flocculation. Dispersion is a process in which the individual particles are kept separate from one another. This is accomplished by potassium and sodium. Thus, depending upon the cations present in a soil, it may be either in a flocculated (aggregated) or in a dispersed (massive) state. Sodium saturated clays have a thick electric diffuse double layer surrounding the ion, that means the clays remain is suspension. Calcium suppresses the double layer and cause flocculation, while tri- and tetravalent ions are more efficient in causing flocculation.

Types of Soil Colloids

On the basis of the nature, soil colloids are classified into two types.

a) *Inorganic soil colloids:* The alumino-silicate clay minerals (layered crystal); hydrous oxides of Fe, Al (sesquioxides), allophane and associated amorphous silicates, and clay sized primary minerals are termed as inorganic soil colloids. The alumino-silicate clay colloids are dominant in temperate regions while hydrous oxides of Fe and Al occur in soils of tropical and sub-tropical regions.

b) *Organic colloids:* Humus is organic colloid which is dominant in soils of temperate region.

Alumino-Silicate (layered) Clays

These are the most important silicate clays, known as *phyllosilicates* because of their leaf-like or plate like structure. These clays are composed of two types of horizontal sheets, one is dominated by silicon and other by aluminium and/or magnesium. The silica dominated sheet is composed of one silicon atom surrounded by *four oxygen* atoms, called *silica tetrahedron* having four sided configuration. Numerous tetrahedral units linked together horizontally form the *tetrahedral sheet* (Fig. 20.1).
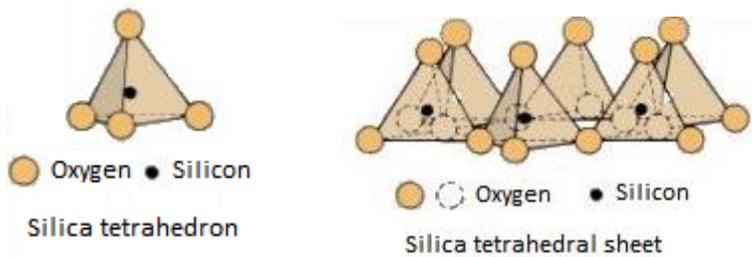
Fig. 20.1: Silica tetrahedron and silica tetrahedral sheet

The aluminium and/or magnesium sheet is composed of aluminium (or magnesium) ion surrounded by *six oxygen* atoms or hydroxyl groups, called aluminium (or magnesium) octahedron having eight sided configuration. Numerous octahedral units linked together horizontally form the octahedral sheet (Fig.20.2). Aluminium dominated sheet is known as *dioctahedral* sheet whereas the sheet dominated by the magnesium is known as *trioctahedral* sheet. The sheets are designated as dioctahedral and trioctahedral because two aluminium ions in a diocthedral sheet satisfy the same negative charge surrounding oxygen and hydroxyl as three magnesium ions in a trioctahedral sheet
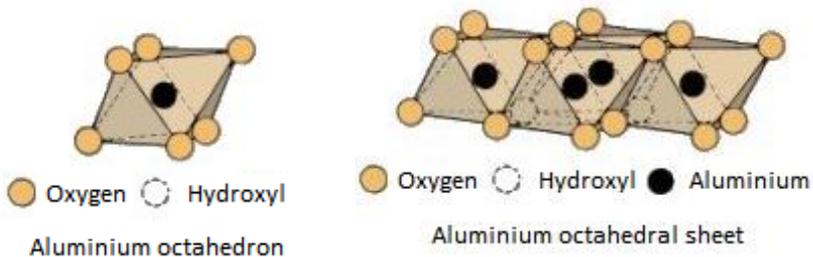
Fig. 20.2: Aluminium octahedron and Alumiun octahedral sheet

The tetrahedral and octahedral sheets are the fundamental structural units of silicate clays which are bound together within the crystals by the shared oxygen atoms into different layers. The arrangement of sheets and chemical composition in these layers vary from one to another type of clay and are responsible for their physical and chemical properties.

Types of Clay Minerals

On the basis of arrangement of tetrahedral and octahedral sheets in the crystal units, silicate clay minerals/clays are classified into three types: 1:1, 2:1 and 2:1:1 or 2:2 type clay minerals.

161

a. **1:1 Type clay minerals:** The 1:1 type clay minerals consist of one tetrahedral (silica) sheet combined with one octahedral (aluminium) sheet in their crystal lattice (Fig 20.3), *e.g.,* kaolinite and hallosite.

The kaolinite is the most important 1:1 type clay mineral in soils. The tetrahedral and octahedral sheets in a layer of a kaolinite crystal are held together tightly by oxygen atoms, which are mutually shared by the silicon and aluminium ions in their respective sheets. These layers are held together by hydrogen bonding, therefore, the structure is compact and no

Fig. 20.3: One silica tetrahedral sheet combined with one aluminium octahedral sheet in their crystal lattice

expansion generally occurs between layers when the soil with kaolinite clay minerals is wetted. Cations and water do not enter between the structural layers of a 1:1 type mineral. The specific surface area of kaolinite is mainly due to its external surface and there is little isomorphous substitution in the 1:1 type clay minerals, therefore, these clay minerals have low capacity to adsorb cations, *i.e.,* low CEC. Kaolinite crystals usually are hexagonal in shape and large in size ranging from 0.10 to 5 μm. The kaolinite clays show less plasticity, cohesion, shrinkage and swelling. Strong bonding between their structural layers does not allow the kaolinite to break down into extremely thin plates.

b. **2:1 Type clay minerals:** These minerals consist of an octahedral sheet sandwiched between two tetrahedral sheets (Fig 20.3). These clay minerals are grouped into two types:

  i) *Expanding type:* smectite (montmorillonite, beidellite, nontronite and saponite) and vermiculite (limited expansion)
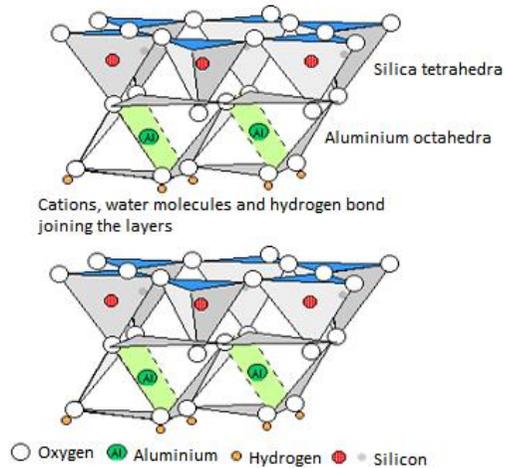
  ii) *Non-expanding type:* fine grained micas (illite)

162

Expanding type smectite group is characterized by interlayer expansion. These minerals swell on wetting as water enters in the interlayer space forcing the layers apart. Montmorillonite is the most prominent mineral of expanding type clays in soils. Other expanding type clay minerals are: beidellite, nontronite and saponite.

The plate like structure of montmorillonite is made of expanding type 2:1 clay mineral layers. These layers are loosely bound with each other as there is little attraction between oxygen atoms in the bottom tetrahedral sheet of one unit and those in the top tetrahedral sheet of another. This loose bonding between two layers permits a ready and variable space between layers which is occupied by water and exchangeable cations. The internal surface area exceeds the external surface area. The substitution of aluminium by magnesium in octahedral sheet and silicon by aluminium in tetrahedral sheet give rise to negative charge. The montmorillonite minerals show high CEC, and swelling and shrinkage properties. Due to swelling and shrinkage properties of these minerals, wide and deep cracks are formed in smectite dominated soils (Vertisols) under dry condition and it becomes difficult to till such soils.

In non-expanding type mica (Illite) one fourth of tetrahedral sites are occupied by Al^{3+} ions and this substitution causes an excess of one negative charge per formula unit in 2:1 layer. The excess negative charge is balanced by K^+ ions that occupy inter layer sites between the two adjacent 2:1 layers. Since the units layers do not part on addition of water, the K^+ ions between the unit layers are not available for exchange, they are fixed. Only K^+ ions on the external surface can be exchanged for other cations.

c. *2:2 or 2:1:1 Type clay minerals*: These minerals are structurally related to the three sheet minerals such as smectite but the charge compensation between smectite type unit layers is accomplished by a positively charged interlayer octahedral hydroxide sheet (containing Mg, Al, Fe). Example: Chlorite. Chlorites in soils of the Indo-Gangetic Plains are rich in iron.

Organic Colloids (humus)

Humus is the end product of the decomposition of organic matter and important constituent of soils. It forms the largest fraction of soil organic

matter and plays dominant role in improving the soil productivity. Humus is complex substance formed by decomposition of plant and animals residues by soil micro-organisms. It is fairly resistant to further decay, and thus forms stable organic component of the soil (not as stable as clay). It is polymeric substance, dark coloured, and nearly insoluble in water but soluble in NaOH or KOH solution. Because of their wide range of molecular sizes and properties, the humic substances are grouped into fractions:

i) *Fulvic acid:* Most soluble fraction being soluble in water, acids and alkalis, and has yellow to brownish yellow colour.

ii) *Humic acid:* This fraction is soluble only in alkali and not soluble in water and acids. It is dark brown to black coloured.

iii) *Humin:* Most insoluble fraction of the humus which is not soluble in both acids and alkalis. This fraction is strongly bound with the soil matrix and difficult to extract.

Humus has negatively charged carboxylic and phenolic sites and entirely pH dependent CEC, which is low at low pH but exceeds silicate clays above pH 6. Humus saturated with H^+ on its exchange sites, can extract nutrient ions (Ca,Mg, K) from minerals by dissolving them, and then hold the nutrients in exchangeable positions for plant uptake.

Ion Exchange Phenomena in Soils

Ion exchange is defined as a reversible process by which cations and anions are exchanged between soil colloids and soil solution, and between solid phases in close contact with each other. For exchange of cations, the process is called *cation exchange* while for anions it is called *anion exchange*. Ion exchange in soils is very important for the availability of nutrients to plants and their retention in soil.

Adsorption of Ions

Adhesion is a phenomenon by which an accumulation of an ion species occurs on a solid due to ion exchange or other reactions. It differs from *absorption*, in which a fluid permeates into a liquid or solid. The *sorption* refers both adsorption and absorption while *desorption* is the reverse of adsorption. The composition of soil solution keeps on changing due to rainfall or irrigation, uptake of ions by plants, leaching, and application of fertilizers, chemical amendments, sewage sludge and industrial effluents. This leads to exchange of ions from soil colloids to soil solution and *vice versa*. The process involved is ion exchange.

The soil colloids are of amphoteric nature, therefore, have the power to hold both cations and anions. The electric charge on the soil particles is neutralized by an equivalent amount of oppositely charged ions called exchangeable ions, which are held to the surface mainly by coulomb forces and van der Waals forces. The exchangeable cations in most of the soils are Ca^{2+}, Mg^{2+}, H^+, K^+, Na^+ and NH_4^+ of which Ca^{2+} is the dominant cation. In strongly acidic soils, $Al(OH)_2^+$ and in alkali soils Na^+ may act as a dominant exchangeable ion.. The most common anions are SO_4^{2-}, Cl^-, HCO_3^-, etc. The adsorbed anions are commonly present in small quantities than the cations because the negative charges, generally, predominate on the soil colloids.

Cation Exchange Capacity (CEC)

The CEC is the capacity of soil to adsorb and exchange cations per unit weight of dry soil. Higher CEC of soil means more cations are retained by the soil. The CEC of soil is normally expressed as meq/100 g of soil or cmol (p^+)/kg soil where (p^+) denotes proton. Similarly, the anion exchange capacity of soil is expressed as meq/100 g of soil or cmol (e^-) kg^{-1}, (e^-) denotes electron. The CEC of clay minerals ranges from 10-150 meq/100 g, and that of organic matter from 200-400 meq/100g. Therefore, type and amount of clay and organic matter determine CEC of soils. Sandy soils have low CEC due to small amount of clay and organic matter.

The exchanging power of cations varies with size, degree of hydration, valiancy, concentration, and CEC of soil. The exchanging power of cations follows the order: $H^+ \simeq Al^{3+} > Ca^{2+} > Mg^{2+} > K^+ \simeq NH_4^+ > Na^+$.

Importance of CEC

The CEC plays an important role in soil fertility as cation exchange sites hold Ca^{2+}, Mg^{2+}, K^+, Na^+ and NH_4^+ and reduce their leaching losses. Amount of lime required for reclamation of acid soils and gypsum for the reclamation of sodic soils depends upon CEC of the soils. Adsorption of heavy metals on exchange sites prevents them to pollute the groundwater.

Percent Base Saturation

It is the percentage of total CEC occupied by the *basic cations*, i.e., other than H^+ and Al^{3+}. The nature and amount of exchangeable bases in a soil have a great influence on its general properties. Soils with a high calcium base saturation (arid and semi-arid regions) are the most appropriate in terms of physical conditions. These soils have granular structure, adequate aeration

and good drainage. There may be soils which are fully base saturated but high in sodium, such as alkali soils. These soils are deflocculated, sticky, and difficult to work, and have poor drainage and aeration. A soil is considered fertile if the base saturation percentage is > 80.

Factors Affecting CEC of soil

The cation exchange capacity of soil is affected by texture, nature of clay minerals, organic matter content and pH of soil.

i) *Soil texture:* The CEC increases with increase in fineness of the soil particles. With increase in clay content, the specific surface area increases and ultimately the net charge and CEC increase.

ii) *Organic matter:* In general, the CEC increases with increase in organic matter content. The pH dependent charges in the organic matter cause variation in CEC. When pH of the soil solution increases, the CEC will also increase.

iii) *Nature of clay:* The soil dominated with 2:1 type clay minerals (montmorillonite) have higher CEC than those dominated with 1:1 type of clay mineral (kaolinite) because of higher specific surface area.

iv) *Soil reaction:* The CEC increases with increase in soil pH. As the pH increases, the pH dependent charge increases. In humus, most of the CEC is pH dependent.

Anion Exchange Capacity

The adsorption and exchange of anions vary with the type of clay mineral, pH, and nature of anion. The AEC of kaolinite is greater than montmorillonite followed by illite. It increases with the increase in acidity. The affinity of adsorption of some anions in the soils follows the order of $PO_4^{3-} > SO_4^{2-} > Cl^- > NO_3^-$. Therefore, under normal pH, nitrate, chloride and sulphate ions are easily leached down due to their less affinity to adsorption at exchange sites.

Importance of Anion Exchange

The adsorption of phosphate ions by clay particles from the soil solution results in phosphorus fixation and reduces its availability to plants. The process is shown as:

$$OH\text{–}clay + H_2PO_4^- \rightleftharpoons H_2PO_4\text{–}clay + OH^-$$

166
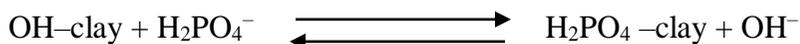
Phosphate ions again become available through reverse reaction when replaced by the OH$^-$ ions released by the substances like lime applied to soil to correct soil acidity. However, the whole of phosphate absorbed by the clay is not exchangeable at pH 7.0 and above, and substantial amount of phosphate remains fixed with clay minerals. The phosphate not only gets fixed with clay minerals but also forms insoluble complexes with oxides of iron and aluminium and gets fixed:

$$Al(OH)_3 + H_2PO_4^- \rightleftharpoons Al(OH)_2.H_2PO_4 + OH^-$$
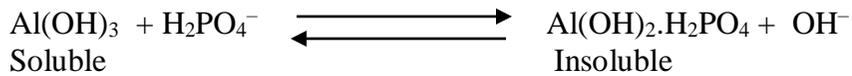
Soluble   Insoluble

Under slightly acidic conditions, the reverse reaction takes place and soluble phosphate is released, but under strongly acidic conditions phosphate ions are irreversibly fixed and are not available to the plants.

Chapter 19

Soil organic matter comprises of partially and completely decomposed plant and animal residues, and other organic compounds synthesized by the soil microbes. The end product of the decomposition of organic matter is *humus* which is brown or dark brown in colour. The soil organic matter is a reservoir of plant nutrients and very important in soil fertility management. The organic matter content of a typically well drained mineral soil is low (1-6% by weight) in the surface layer which deceases with depth in the soil profile.

Sources of Soil Organic Matter

The primary sources of soil organic matter are residues (branches, leaves and roots) of trees, shrubs, grasses, crops and soil microorganisms while secondary sources include waste products of animals (dung) and remains of animals after their death.

Soil Organic Matter Composition

Organic matter includes all *organic components* of a soil:
- Fresh residues (<10%)
- Decomposing organic matter- active fraction (30-50%)
- Stable organic matter- humus (30-50%)
- Living organisms (<5%)

Factors Affecting the Organic Matter

1. *Climate:* The climate (temperature and rainfall) has dominant effect on the amount of organic matter found in soils. Decomposition of organic matter increases with temperature, therefore, the soils of cold regions have more organic matter as compared to the soils of warm regions. High rainfall areas have sufficient vegetation; therefore, the soils of humid regions are generally rich in organic matter. Low rainfall areas, due to limited moisture, have limited vegetation, therefore, soils of arid and semi arid regions are low in organic matter.

2. *Natural vegetation:* The soils formed under coniferous forest have higher organic matter than the soils formed under deciduous forests.

3. *Texture:* The soils with higher clay content (loamy, clayey) have generally higher organic matter than the coarse textured soils (sandy).

4. *Soil reaction:* Most of the microorganisms grow best at pH range 6-7.5 and their activities are severely inhibited at below pH 4.5 and above pH 8.5, thus affecting the decomposition of organic material.

5. *Drainage:* Poorly drained soils have higher organic matter than well drained soils due to high moisture and anaerobic conditions slowing down the decomposition of organic matter.

6. *Tillage:* Resource conservation tillage practices leave higher proportion of crop residues on or near the soil surface, helping to maintain high organic matter compared to conventional tillage practices. Therefore, zero-tillage or minimum tillage is advocated for maintaining the level of soil organic matter.

7. *Crop rotations and residues:* Crop rotation of cereals with legumes results in higher soil organic matter. A rotation of corn, oat and clover results in higher soil organic matter than continuous corn crop. Crop residues as mulching also help to enhance the soil organic matter.

Functions of Organic Matter

Organic matter serves many purposes in the soil and influence soil physical, chemical and biological properties.

- Soil organic matter plays an important role in maintaining soil physical conditions. It improves the soil structure which increases water infiltration, percolation, aeration and water retention.

- The organic matter reduces the surface runoff and soil erosion.

- Mulching of soil with organic materials like crop residues, optimizes the soil temperature by keeping the soil cooler during summer and warmer in winter.

- The organic matter serves as a source of energy for the growth of micro-organisms which plays a vital role in improving the soil productivity.

- Organic matter serves as reservoir of nutrients for plant growth.

- Decomposition of organic matter releases organic acids which reduces the alkalinity in soils.

169

- Fresh organic matter supplies food for earthworms, ants and rodents, and make soil P readily available in acid soils

- Acts as a buffering agent which checks rapid changes in soil pH.

Decomposition of Soil Organic Matter

When organic materials (plant and animal residues) are incorporated in the soil, they are at once attacked by the variety of soil micro-organisms, worms and insects for decomposing into new substances and finally into most resistant substance to decomposition called *humus.* The whole of the organic material does not decompose at once, some of the constituents decompose very readily (sugars, starches and simple proteins), some less readily (hemicelluloses, celluloses), and others very slowly (fats, waxes, resins, lignins). When organic material is added to soils, decomposition takes place as follows:

1. ***Sugars and water-soluble nitrogenous compounds*** of the bulk of the organic material first undergo enzymatic oxidation as they offer a very readily available source of carbon, nitrogen and energy for the microorganisms. The enzymatic oxidation takes place with carbon dioxide, water and heat energy as the major products. e.g.,

$$C_6H_{12}O_6 + 2O_2 \longrightarrow 2CH_3.COOH + 2CO_2 + 2H_2O$$

(Sugar) (Acetic acid)

2. ***Decomposition of insoluble substances*:**
   Breakdown of protein: Proteins are complex organic substances containing nitrogen, sulphur and phosphorus in addition to carbon, hydrogen and oxygen. During the decomposition of plant residues, the proteins are first hydrolyzed to intermediate products, *e.g.,* polypeptides. Polypeptides are then converted to amino acids and amides to ammonia, known as *ammonification*.

   Breakdown of cellulose: Cellulose is the most abundant carbohydrate present in plant residues. The micro-organisms break up cellulose into cellobiose and glucose. Glucose is further attacked by organisms and converted into organic acids.

   Cellulose $\longrightarrow$ Cellobiose $\longrightarrow$ Glucose $\longrightarrow$ Organic acids $\longrightarrow$ $CO_2 + H_2O$

Breakdown of hemicellulose: Hemicellulose decomposes faster than cellulose. Hemicelluloses are first hydrolysed to sugars and uronic acids. The sugars are further attacked by the microorganisms. The uronic acids are broken down to pentose and carbon dioxide.

Breakdown of starch: Chemically, it is glucose polymer. Starch is first hydrolysed to maltose by the action of enzymes which further converts to glucose by another enzyme (maltase). Glucose is soluble in water and utilized for metabolic activities.

Decomposition of fats: Fats first decompose into glycerol and fatty acids by micro-organisms. Glycerol is further oxidized to organic acids which along with other fatty acids are oxidized to carbon dioxide and water.

Fats $\longrightarrow$ Glycerol +Fatty acids (lipase)

Glycerol $\longrightarrow$ Carbon dioxide + water (oxidation)
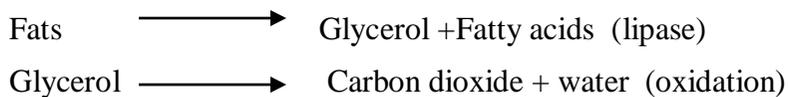
Decomposition of lignin: Lignin decomposes slowly. Complete oxidation of lignin gives rise to carbon dioxide and water. Lignin is constituent of cell wall to impart strength to the plant.

Clay Humus Complex

Humus and clay together form soil colloidal complex. The clay is crystalline while humus is amorphous (having no definite shape or form) in nature. Clay mainly supplies basic nutrients while humus supplies both basic and acidic nutrient ions. Depending upon the nature of cations binding the clay and humus together, two types of colloidal complex are formed. One is held by calcium ions which is more stable colloidal complex and responsible for the favourable soil physical conditions, mainly soil structure. Other type of colloidal complex is formed by iron as binding agent.

Humus

Humus is defined as a brown to black complex amorphous and colloidal organic substance which is not recognized under a light microscope. Humus is separated from the non-humic substances such as carbohydrates (a major fraction of soil carbon), fats, waxes, alkanes, peptides, amino acids, proteins, lipids, and organic acids because distinct chemical formulae can be written for these non-humic substances. Most small molecules of non-humic substances are rapidly degraded by microorganisms within the soil.

In contrast soil humus is slow to decompose under natural soil conditions. When in combination with soil minerals, soil humus can persist in the soil for several hundred years. Humus assumes an important role as a fertility component of all soils, far in excess of the per cent contribution it makes to the total soil mass.

Humic substances (major component of organic matter) can be subdivided into three major fractions:

i) *Fulvic acids:* Soluble in water, acid and alkali.

ii) *Humic acids :* Soluble in alkali

iii) *Humin:* Insoluble in water, acid and alkali.

Chapter 20

Soil Organisms and Their Significance

Presence of millions of living organisms makes the soil a living entity. These organisms and plant roots develop in soil pores, and help in development of soil and transformation of unavailable nutrients (generally dead tissues) into available forms. There are two main groups of organisms in the soil, *i.e., soil flora* (belonging to plants) and *soil fauna* (belonging to animals).

Classification of Soil Organisms

Soil organisms are classified based on size, their ecological functions, temperature requirement for their growth, mode of nutrition and their requirement for molecular oxygen.

i) **Size:** As per their sizes, these organisms are classified as macro (> 2 mm in size), meso (0.2 to 2 mm) and micro-organisms (< 0.2 mm, can be seen only using microscope).

ii) *Ecological functions:* On the basis of ecological functions performed by the organisms, they are classified as:

   a) Herbivores   - survive on living plants

   b) Detritivores/saprophytes - live on dead plant debris

   c) Predators   - prey on animals

   d) Fungivores   - eat fungi

   e) Bacterivores   - eat bacteria

   f) Parasites   - live off but do not consume other organisms.

iii) *Temperature requirement:* Based on the optimum temperature requirement for their growth, the organisms are classified as:

   a) *Psychrophiles* : $<10^0$C

   b) *Mesophiles*   : 20-35^{0}C. Highly dominant and numerous in soils

   c) *Thermophiles* : $> 45^0$C. Commonly found in compost pits.

iv) *Mode of nutrition:* On the basis of mode of nutrition, soil organisms are classified into two categories:

   a) *Heterotrophs:* Relying on oxidation of organic compounds for their C and energy needs.

173

b) *Autotrophs:* Deriving their C mainly from CO_2 and their energy from photosynthesis. The autotrophs are further classified as *chemoautotrophs* which get energy from the oxidation of simple inorganic compounds and *photoautotrophs* which get energy from sunlight.

v) ***Requirement of oxygen***: On the basis of requirement of molecular oxygen, soil organisms are classified as:

a) Obligate aerobes: Organisms that need O_2 for respiration and cannot survive without O_2.

b) Facultative anaerobes: Organisms which are aerobic but adapt to grow under anaerobic condition using oxidized substances like NO_3, SO_4, CO_2, etc. Denitrifying bacteria are example of such organisms having significant role in agriculture.

c) Obligate anaerobes: Organisms which grow in the absence of O_2.

Macroorganisms in Soil

The macroorganisms in the soil include earthworms, millipedes, centipedes, termites, ticks, mites, springtails, lice, beetles, snails, etc. The population of macroorganisms in soil is fewer than the microorganisms, non-uniformly distributed and highly mobile in soil. They have important roles in soil as:

i) Help in the decomposition of organic material in soil by mixing or fragmentation as they eat the organic material, and also convert the ingested soil along with organic material into worm casts called mull humus.

ii) Form burrows and tunnels which increase soil aeration, drainage and turning of surface soil which further increase the rate of decomposition of organic matter.

iii) Macro-organisms like termites, mites, etc. feed on soil organisms including plant pathogens.

Macro-organisms which play an important role in soil fertility are:

Earthworms: The total biomass of earthworms in soils ranges from 110 - 1100 kg/ha (furrow slice). Their population decrease with cultivation, tillage and application of pesticides. Dry, waterlogged, clayey, sandy or gravely soils having low organic matter are not suitable for the growth and activity of earthworms. Earthworm cast is a rich source of plant nutrients, particularly

N, P and Ca. and contains more bacteria and organic matter. Dead tissues of earthworms decompose faster due to high protein content. Generally, earthworms ingest material 5-36 times of their body weight per day and cast as high as 2600 t/ha/year in tropical conditions.

Earthworms mix the organic matter with mineral matter which increases the stabilization of clay bound carbon. Earthworms also increase the soil porosity, water holding capacity, infiltration rate, water stable aggregates, availability of plant nutrients, and microbial population. Earthworms are being used for hastening the decomposition of farm waste for preparing compost known as *vermicompost*. The species used for vermicompost are: *Eisenia foetida*, *Eudrilus eugeniae*, etc.

Termites: Termites influence the soil properties through following activities:

i) Physical modification of soil profiles by constructing mounds and sheeting;

ii) Changes in soil texture through movement of clay fraction from subsoil for construction of mounds, etc.;

iii) Changes in nature and distribution of organic matter and plant nutrients through litter brought into nests and digested by termites and decomposed by the microbes in the soil;

iv) Changes soil drainage and moisture regime by constructing subsurface galleries.

In intensively cultivated soils, the population of termites is low. However, forest and pasture lands have mound forming termites. Termites have cellulose decomposing microbes in their guts and therefore, their excreta have lower organic matter content than that of earthworms.

Plant roots: The plants provide a large quantity of organic residue to the soil through roots and litter fall. Roots consume oxygen, water and nutrients while releasing CO_2 and exudates (mixture of organic acids, sugars and other soluble plant compounds that escape from roots).

The plant roots which play important role in soil formation, its fertility and productivity, can also be considered as one of the soil macro-organisms. Being primary source of organic matter in soil, plants and their roots supply food and energy to saprophytic soil organisms and maintain the soil biological activities. Plant roots exert physical pressure on soil particles and form channels and capillaries, causing cracks in soil. By producing different

chemicals as root exudates, roots also influence the chemical and biological environment of the soil around them (rhizosphere).

The roots produce:
a) exudates- chemical compounds leaking from the roots
b) secretions- chemical compounds released through plant metabolic processes
c) mucilages- complex compound produced by the roots or bacterial degradation
d) mucigels- gelatinous layers composed of mucilages and soil particles. These compounds at the soil- root interfaces have a special kind of place for the proliferation of microbes.

Vertebrates: The vertebrates (mice, squirrels, etc.) are example of soil macrofauna. They mix soil through their burrowing activity. Arthropods are fauna with a jointed exoskeleton and can belong to the macro or meso group. They are a diverse group of bizarrely shaped spiders, mites, pseudoscorpions, and insects. Many arthropods prey on disease-causing pests. Others help to shape soil structure and thus can improve root development, water infiltration, drainage, and aeration. Some arthropods are the front line in decomposition of organic matter. They shred plant residues, mix them with soil, and stimulate decomposition within their intestines. They are especially important in forests, rangelands, no-till cropland, and in other areas where the soil is minimally disturbed and covered all year.

Microorganisms in Soil

Bacteria: *Bacteria are the smallest and most numerous of the organisms in soil.* Bacteria can be either autotrophic or heterotrophic and both aerobic and anaerobic. They are single celled organism and their size is approximately 1 μm in diameter and up to 10 μm in length. In spite of their small size, bacterial biomass could be as high as 3500 kg/ha in the surface soil. Bacteria are the most diverse group of soil organisms. A gram of soil may contain 20,000 different species. The number of bacteria is highly variable depending upon soil type, nature of crop cover, and climatic conditions. Generally soils with low organic matter and sandy soils have low population of bacteria.

Bacteria due to their huge population and very rapid rate of multiplication play a very significant role in carrying out various biochemical reactions controlling availability of plant nutrients. They play important role in

processes of N_2 fixation, decomposition of organic matter and mineralization of nutrients such as N (nitrification) and S to forms available to plants, phosphate solubilisation, synthesis of humus, denitrification, and ammonification, etc., leading to transformation of various macro and micro-nutrients in soil. Free living bacteria belonging to the genus *Azotabacter*, *Azotomonas* reduce the atmospheric nitrogen into ammonical form enriching the soil with plant available nitrogen, and another group of bacteria belonging to the genus *Rhizobium* fix the atmospheric nitrogen in symbiosis with the legumes forming root nodules.

Azospirillum, a spiral bacterium can also fix nitrogen in association with plants in rhizosphere entering into roots without forming nodules and the process is called *associative nitrogen fixation*.

The soil bacteria (*Bacillus, Pseudomonas*, and *Micrococcus*) which transform the nitrate to oxides of nitrogen and gaseous nitrogen resulting in loss of fertilizer nitrogen are called denitrifying bacteria. These bacteria are essentially aerobic.

The microbiological oxidation of ammonium to nitrate is one of the most important transformation taking places in soil because plants predominantly take nitrogen in form of NO_3^- ion. Such transformation is carried out by a group of bacteria called *nitrifying bacteria*. It is a two step process. In first step, ammonium is transformed into nitrite by bacteria belonging to genus *Nitrosomonas*, and in the second step *Nitrobacter* bacteria convert nitrite into nitrate. Again, these bacteria are aerobic in nature.

Any cultural practice which improves aeration results in enhancing nitrification. The optimum pH for these bacteria is between 6.5 and 7.5. Therefore, under acidic conditions nitrification is slow and is nearly negligible below pH 5.0.

Actinomycetes: Actinomycetes belong to soil microflora (heterotrophic, aerobic). They are single-celled, filamentous and often profusely branched organisms. Therefore have characteristics of both bacteria (cell size and mode of multiplication) and fungi (branching). They are next to bacteria in number and widely distributed in soils. They are more common in neutral to slightly alkaline and dry soils, and undisturbed pastures and grasslands. They are aerobic organisms, so their population is less in lowlands. The species commonly found in soil belong to genera *Streptomyces*, *Micromonospora*, *Thermoactinomyces*, etc. Many actinomycetes produce antibiotic compounds

177

that kill other microorganisms (e.g. streptomycin is produced by growing soil actinomycetes in pure culture). The earthy smell of the soil just after the first rainfall is due to the production of *geosmins* by actinomycetes. They are slow growing organisms, hence they cannot compete with bacteria and fungi for available nutrients and thus grow on substances that are relatively more resistant to attack of bacteria and fungi. They are of great importance in the decomposition of soil organic matter and the mineralization of nutrients, especially in alkaline soils. They are reported to produce a number of coloured pigments contributing dark coloured to soil humus. Their population is much higher in compost pits as they can tolerate high temperatures. Some of them are pathogens causing plant disease such as potato scab, etc.

Fungi: Fungi belong to soil microflora (aerobic) and are filamentous organisms with much larger cell width than actinomycetes. They are heterotrophs devoid of chlorophyll and are primarily responsible for organic matter decomposition. Though their number is less than that of bacteria but their biomass is more than bacteria being larger in size. Soil fungi can grow in wide range of soil pH but their population is more under acidic conditions because of severe competition with bacteria at neutral pH. As heterotrophs, fungi depend on living (as parasites) or dead organic materials for both their C and energy. Saprophytic fungi perform a very important function in the decomposition of organic matter, particularly plant residues.

Some fungi form a symbiotic association with roots of higher plants facilitating uptake of plant nutrients particularly of those which are less mobile. This association is known as *'mycorrhizal association'*.

The beneficial effect of the fungi on nutrient uptake has been attributed to following factors:
i)   Increased absorption of available nutrients from soil as the fungus changes root morphology which results in the larger root surface available for nutrient absorption. Fungal filaments also act as absorption surface.
ii) Increasing the nutrients availability by solubilising insoluble nutrients like P which thus become available to plant,
iii) Increasing the nutrient mobility due to faster intracellular nutrient mobility and mobilizing nutrients from the soil mass.

Algae: Algae belong to soil microflora. They are autotrophic (i.e. have chlorophyll and are capable of performing photosynthesis) and eukaryotic organisms. They are unicellular, filamentous or form colonies from single cell. Algae are most active and abundant in wet soils. In dry soil, the water film that surrounds soil particles becomes too thin for them to move freely. Because they need light for photosynthesis, algae are most common at or very near the soil surface. Some algae make symbiotic associations with fungi forming *lichens* (composite organisms consisting of a symbiotic association of a fungus with algae, a photosynthetic partner, that are important in colonizing bare rocks and other low organic matter environments (deserts). The algae are classified on the basis of colour/pigment. The most common groups of algae present in soil are blue green (*Cyanobacteria*), yellow-green and grass green.

The blue green algae are most important from agricultural point of view because they fix atmospheric nitrogen and contribute towards the nitrogen pool of soils, especially in rice cultures of tropics. Blue green algae have been reported to fix about 20 kg N ha^{-1} year^{-1}. Submerged soil conditions in rice field provide an ideal environment for the growth of algae. A nitrogen fixing algae, *Ananbaena azollae*, forms a symbiotic association with a fresh water fern, azolla and fixes nitrogen.

In addition to production of a substantial amount of organic matter in some fertile soils, certain algae excrete polysaccharides that have very favourable effects on soil aggregation.

Protozoa: Protozoa belong to soil microfauna and are single celled organisms larger in size than most soil microorganisms. All protozoa are heterotrophic, feed on bacteria and usually obtain their food through some form of ingestion followed by intracellular digestion. In fertile soils, the number of protozoa may be up to 1 million per gram. Protozoa play an important role in mineralizing nutrients, making them available for use by plants and other soil organisms.

Nematodes: Among the microfauna, the nematodes are next in abundance to protozoa. Because of their narrow long bodies, they are also called thread worms. They may be either saprozoic feeding on decaying organic matter or parasitic on living plants. Due to less number in soils, they are not of much significance in organic matter decomposition. Parasitic nematodes cause plant disease and thus gain significance in some localized pockets due to high population. They are controlled by chemical fumigants.

Virus: Viruses are *ultramicroscopic organisms smaller than bacteria* which cannot be seen by ordinary light microscope. They parasitise animals, plants and microorganisms. Sometime a soil may act as a sink for viruses causing human diseases. Soil viruses do not take part in nutrient transformations due to their parasitic nature but they may affect nutrient cycles indirectly by parasitizing bacteria responsible for these cycles such as nitrifying bacteria, nitrogen fixing bacteria, cellulose hydrolyzing bacteria, etc.

FUNDAMENTALS OF
SOIL SCIENCE

V.K. PHOGAT
(Emeritus Professor)

RITA DAHIYA
(Professor, Soil Physics)

VISHAL GOYAL
(Assistant Soil Chemist)

**DEPARTMENT OF SOIL SCIENCE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR– 125004**

LABORATORY MANUAL
FOR
COURSE

FUNDAMENTALS OF
SOIL SCIENCE

V.K. PHOGAT
(Emeritus Professor)

RITA DAHIYA
(Professor, Soil Physics)

VISHAL GOYAL
(Assistant Soil Chemist)

DEPARTMENT OF SOIL SCIENCE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR– 125004

2020

FOREWORD

Maintaining the soil quality is essential for agricultural sustainability to fulfil the increasing demand for food, fibre and fuel. Use of modern intensive input driven technologies in agriculture has increased the crop production but it has been observed that long term intensive agriculture led to the deterioration of soil quality and environment. Therefore, there is a need to understand the basic components and properties of soils which determine the inherent capability of soils for optimum plant growth. The systematic knowledge about soil properties plays a key role in deciding the effective and environmental friendly management practices for enhancing the soil productivity.

The course curriculum for B.Sc. (Hons.) Agriculture has been revised as per the recommendation of 5th Deans' Committee of ICAR for under–graduate programme. Keeping this in view, a greater emphasis has been given on practical aspects on fundamental courses of Soil Science. In addition, outbreak of Covid–19 pandemic all over the world in the year 2020 also necessitates developing a self–explanatory practical manual for the undergraduate students.

I appreciate the sincere efforts made by Dr. V. K. Phogat, Emeritus Professor, Dr. (Mrs.) Rita Dahiya, Professor (Soil Physics) and Dr. Vishal Goyal, Assistant Soil Chemist, Department of Soil Science for preparation of this excellent practical manual entitled, "Laboratory Manual for Course on Fundamentals of Soil Science" which would be of immense use to the students, teachers and researchers for conducting various laboratory and field practicals in the Soil Science and allied fields.

DR. S. K. SEHRAWAT
Dean, College of Agriculture, Hisar
CCSHAU, Hisar

PREFACE

The sustainable agricultural production is pre–requisite to ensure the food security of growing population of the country. The agricultural production primarily depends upon the soil quality and productivity. The maintenance of soil productivity requires proper understanding of the soil properties and processes taking place in soil and their effects on plant growth. This manual describes the practical methods to analyze the soils to get inside the soil properties to assess their quality for potential use for optimum plant growth.

The aim of the manual is to enhance the ability of the under graduate students, majoring in Soil Science including Agronomy and Agricultural Engineering to fulfil bachelor's degree programs. The experimental methods are described in details to satisfy the interests of students for their effective learning and self–preparation for higher studies.

The manual contains 16 exercises to describe the methods for studying the soil profile, commonly used tools for collection of composite soil samples, soil forming rocks and minerals, the important properties of soils such as particle density, bulk density, moisture, hydraulic conductivity, infiltration rate, texture and water flow in soils. The manual also illustrates the standard methods for determination of soil chemical properties such as soil reaction, electrical conductivity, soil organic matter content, etc. Each experiment is explained in a simple and lucid language with suitable illustrations and tables for better understanding of the subject matter. The topics on soil colour and soil map would give insight the students to understand the soils of different colours and genesis of different types of soils of Haryana. The authors feel that manual will be very beneficial to the students, teachers, research workers and other field functionaries working in the area of agriculture.

V.K. PHOGAT | RITA DAHIYA | VISHAL GOYAL

CONTENTS

Exercise-I

EXAMINATION OF SOIL PROFILE IN THE FIELD

The most apparent part of any soil is its surface through which matter and energy are transported between soil and the atmosphere. But soil surface does not describe the character of the soil as a whole. To characterize soil as a whole, it is necessary to examine the soil in depth which can be done by digging a trench (soil profile).

Soil profile: Soil profile is a vertical section of the soil from its surface to the parent material (Fig. 1.1). In deep soils, it may be considered up to a depth of 1.8 m while in shallow soils, it is up to the bed rock/parent material or up to water table.

Soil horizons: A sequence of more or less distinct layers of soil almost parallel to the surface of soil varying in physical properties, chemical composition and biological characteristics from adjoining layers due to soil forming processes are called soil *horizons*.

Master horizons: Maximum five master soil horizons may be observed in a soil profile which are designated using the capital letters O, A, E, B and C. Any particular profile may exhibit only part of horizons. In addition, it may exhibit more detailed sub-horizons as indicated in the (Fig. 1.1). The sequence of horizons and their characteristics within a profile are:

Oi   Loose, easily recognizable, organic debris
Oe   Partially decomposed organic materials
Oa   Fully decomposed organic materials

A   Surface mineral horizon; darker and higher in organic matter. If plowed, will be designated Ap

E   Eluviated horizon; light colored zone of maximum leaching of clay, iron, aluminum, and soluble organic matter. Often mixed into Ap

EB Transition from E to B; more like E than B

BE Transition from E to B; more like B than E

B   Subsurface zone of maximum accumulation of clay, iron, etc. Common features include development of blocky and/or prismatic structure, clay coatings on larger particles, red and yellow colors from accumulation of iron oxides

BC Transition from B to C; more like B than C

C   Weathered parent material such as saprolite, oxidized sediments, unconsolidated bedrock, etc.
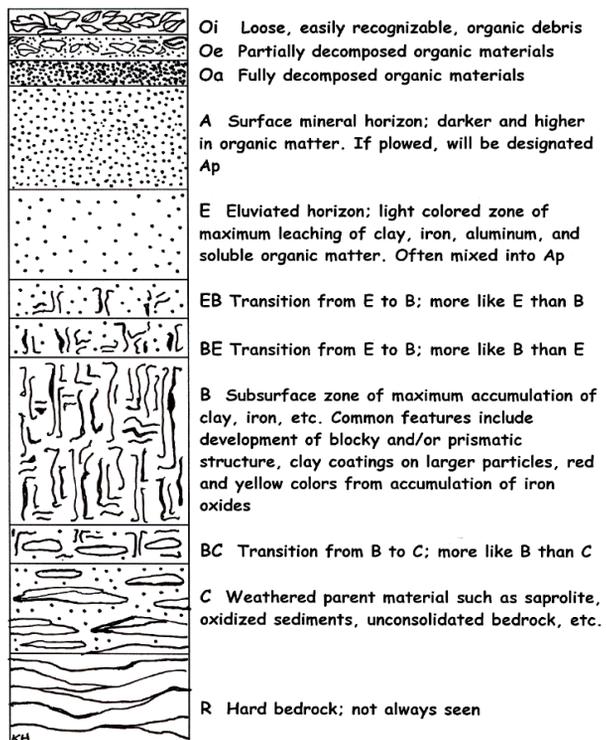
R   Hard bedrock; not always seen

Fig.1.1: Hypothetical soil profile showing horizons and sub-horizons

O-horizon: The upper most *organic horizon* formed above the mineral soil from the waste resulting from dead plants and animals. This horizon is typically occurred in soils developed under forests and absent in crop and grassland regions. O-horizon is

further divided into O_i, O_e and O_a depending upon the degree of decomposition of organic material i.e. slightly, moderately and highly decomposed, respectively.

A-horizon: A-horizon is the topmost mineral horizon mixed with partially decomposed (humified) organic matter which lies at or near the soil surface. Due to high organic matter, this horizon is normally darker in colour than the lower horizons. A-horizon is the zone of major biological activities, maximum leaching and most fertile zone of soil but also vulnerable to erosion by water and wind. It is also called as a zone of *eluviation.*

E-horizon: The E-horizon lies below A-horizon. Certain colloidal materials (silicate clays, oxides and carbonates) are removed continuously from this horizon by leaching leaving a higher amount of resistant minerals, such as quartz, in the coarser fraction i.e. sand and silt sizes. This horizon is also known as a zone of *eluviations,* usually found in forest areas and commonly lighter in colour than the A-horizon. The E-horizon which is absent in soils developed under crop and grassland regions, the colloidal materials are removed constantly from the A horizon by leaching. E-horizon is further divided into E and EB. The EB horizon is transition to B, more like to E than B-horizon.

B-horizon: The B-horizon lies immediately below the A-horizon/E-horizon characterized by less organic matter than A-horizon. It is the zone of *illuviation* in which maximum accumulation of colloidal materials leached from the above lying horizons occurs. This horizon is often thicker and denser than the A-horizon. The B-horizon is further divided in to BE, B and BC. The BE is transition to E, more like B than E- horizon and BC is transition to C, more like B than C-horizon.

The A, E and B horizons together are called the **'solum'** (true soil). The solum is distinguished from the parent material lying immediately below.

C-horizon: The unconsolidated material underlying the solum or B-horizon is called C-horizon which may or may not be the same as the parent material. This horizon is less weathered than solum and consequently has not been subjected to horizon differentiation.

R layer: The R layer is underlying consolidated bedrock.

If the soil is formed from the bedrock *in situ*, the C horizon consists of a weathered and fragmented rock material. In other cases, the C-horizon may consist of alluvial, aeolian or glacial deposits. In a young soil, the B-horizon is absent but in a developed matured soil, A- and B- horizons are more prominent and at times the C- horizon may

disappear. In a recent alluvium, hardly any profile differentiation is apparent. The horizons- O, A, E, B and C are collectively termed as *'regolith'*.

The sequence of horizons with different properties is the record of events happened to that soil since it begins to form. The specific properties and sequence of horizons that a soil acquires in the process of its development are determined by the nature of parent material from which it developed and the influence of climate, vegetation and topography which acted over a period of time to transform the parent material into soil.

In this exercise, field visits may be arranged for the students to examine the exposed profile by the side of a Hill and an agricultural land. The profile characteristics and evidence of soil forming processes may be explained at the exposed sites. During these visits, students may observe the boundaries of solum, regolith, bedrock, etc. While observing soil profile, the different horizons present may be pointed out. Properties such as texture, structure, colour, permeability, thickness, reaction, mottling, free lime, etc., are to be determined. After studying these properties, it is established whether the soil is erosive, aerated, suitable for irrigation and best adaptive for certain crops.

A complete data sheet from an inspection of the profile exposed in the field or from laboratory studies of the collected sample is prepared. In studying soil horizons and filling the data sheet, following standard terms for different soil properties are used:

Texture	Structure	Permeability	Colour	Mottling	Free lime
sand	Spherical	Slow	Black	Present	Present
loamy sand	Blocky	Moderate	Bray	Absent	Absent
sandy loam	Prismatic	Rapid	Brown		
loam	Platy		Red		
silt loam	Single grained		Yellow		
silt					
sandy clay loam					
clay loam					
silty clay loam					
sandy clay					
silty Clay					
clay					

Record of the climate, native vegetation, parent material, soil type, time and topography helps in understanding the processes of soil development and soil classification.

Data Sheet

Soil Profile No. _____

Horizon	Thickness (cm)	Texture	Structure	Permeability	Colour	Mottling	pH	Free lime

Nature of soil forming factor resulting in the formation of the soil at the site are:

Climate : _____
Native vegetation : _____
Parent material : _____
Time : _____
Topography : _____

Soil Classification

Soil type :
Great soil group :
Geographical distribution :

●●●●●

Exercise-II

SOIL SAMPLING TOOLS, SAMPLE COLLECTION, PROCESSING AND STORAGE

Soil sampling is the collection of sample of soil taking into account its variability, handling and processing, and finally sub-sampling for actual analytical determination. The sampling procedure is determined by the purpose for which sample is taken.

Sampling tools: Various soil sampling tools (Fig. 2.1) may be used for taking samples for the analysis of soil properties in different types of soils. For example, for sampling for aggregate size analysis, spade can be used while core sampler is required for undisturbed bulk density, porosity or water holding capacity determinations.

Fig. 2.1: Different sampling tools-auger (tube, screw, post-hole), soil cores, spade and *khurpi*. (www.ams-sampler.com)

A tube auger, spade and *khurpi* may be used quite conveniently in soils which are soft and moist where a screw type auger is more useful in hard or dry soil. Tube auger is also handy for sampling from lower depths. For sampling in excessively wet areas like rice fields, the post-hole auger is appropriate. For using a spade or *khurpi* for sampling, a V-shaped cut is first made up to 15 cm depth and a uniform 2 cm thick slice from surface to 15 cm depth is then taken out.

Sampling tools should be free from any other materials to avoid contamination of the samples. Plastic sheet may be used for mixing the sample of soil.

Collection of soil sample: The soil sample collected should be representative of the area sampled. If a field appears uniform in all respects, it may be treated as a single sampling unit. Variation in slope, texture, colour, crop(s) growth and management levels are taken into account for soil sampling. Separate composite samples need to be collected from areas differing in these characteristics. Recently fertilized plots and areas near bunds, channels, trees, farm ways, wells, buildings, compost piles etc. must be avoided during sampling. When crops are grown in rows, samples can be taken in

between the rows. The litter or any stone present on the surface be removed before taking the sample.

Most commonly used sampling methods are:

Random sampling: Sampling in a random fashion is convenient, less time consuming and economical but usually done in a leveled area where chances of variation are negligible.

Zig-Zag sampling: This sampling method is most satisfactory for longitudinal and oddly shaped fields. More complete coverage is obtained when the sampling is started from the different parts of the field. The method is, however, expensive, time consuming and elaborate.

Latin-square sampling: Taking samples in a Latin-square fashion is the most satisfactory for square area. The area is divided in many rows and columns, and only one sample is taken from every row and every column in a random fashion. Thus, samples are taken in a modified random fashion but the method requires proper planning than the other two methods. The samples are collected into suitable containers and transported to the laboratory.

Depth of sampling: Rooting depth of plants is very important for deciding the sampling depth. For field crops (cereals, vegetables and others seasonal crops) a sampling depth of 0-15 cm is suitable. For deep-rooted crops or in dry land farming conditions, samples from different depths may be taken while for horticultural crops, sampling is done at depths of 0-15, 15-30, 30-60, 60-90, 90-120, 12-150 and 150-180 cm. In saline-alkali soils, salt crust present on the surface should be sampled separately and sampling depth be recorded.

Under intensive cultivation, soil sampling should be done every year. If one crop per year is grown, sampling once in three years is sufficient.

Preparation of composite sample: For making composite sample, mix the soil samples collected from 5-6 different locations from the field by hand on a polythene sheet or thick paper. Reduce the bulk sample to about 500 g by quartering process. In this process, entire soil mass is spread, divided into four quarters, two opposite samples are discarded and the remaining two are remixed. This process is repeated till about 500 g soil is left.

Sample information: A label with the details of the sample be put inside the sample bag and another label with similar information should be put on the bag. The location,

field number, name of farmer and information about slope, drainage, previous cropping history, irrigation, fertilizer and manure used must be recorded.

Processing of soil samples for analysis: Processing of soil samples involves drying, grinding and sieving. Dry the soil sample in shade at room temperature. Grind the sample using wooden pestle and mortar and sieve through 2 mm stainless steel sieve. Stones and gravels will remain on the sieve, if present in the soil sample. Before disposing this material, record their weigh.

For specific type of soil analysis (organic carbon, chemical analysis), the sample is further grinded and passed through 0.5 mm sieve. The whole quantity of sieved sample is properly mixed before a sample is taken for analysis.

Aluminum or plastic sieve with nylon netting should be used for the analysis of micronutrients like zinc, iron, copper and manganese instead of brass sieve.

The estimation of nitrate, ammonia, bacterial count and soil moisture must be carried out on soils obtained straight from the field with any air-drying

Storage of soil samples: Processed samples should be store in well labeled clean cloth bags (13 cm × 25 cm in size) or use glass or plastic bottles (1 kg) for a longer duration.

Precautions in collection, processing and storage of soil samples: Avoid bags used previously for storing fertilizers or any chemical and keep the sample away from chemicals, fertilizers or manures for avoiding contamination.

●●●●●

Exercise-III

SOIL FORMING ROCKS AND MINERALS

Mineral is a naturally occurring inorganic crystalline solid having an orderly internal arrangement of elements/atoms (characteristic geometric form), a definite chemical composition and physical properties. The mineral may be composed of an element or various elements but most minerals consist of two or more elements. Examples: quartz (SiO_2), magnetite (Fe_3O_4), calcite ($CaCO_3$), hematite (Fe_2O_3), gypsum ($CaSO_4.2H_2O$), etc. Minerals consisting of only one of the naturally occurring elements may be a metal, such as copper, iron, aluminium or a non-metal such as silicon, carbon and sulphur.

Salient characteristics of minerals used for identification: General characteristics of mineral include:

a) *Colour:* Reflection of certain colour which is exhibited by ordinary light. For example: Quartz– colorless, calcite– white, orthoclase– pink, magnetite– black iron pyrite– yellow.

b) *Luster:* Shining of an individual mineral- metallic or non-metallic. For example: Rock crystal– vitreous, talc– resinous, zeolite– pearly, gypsum– earthy, apatite– waxy and asbestos– silky luster.

c) *Light transmission*: Transparent, opaque or translucent. If the outline of the object appears distinct and clear through a mineral, it is called transparent (mica, calcite rock salt crystal) and if it does not appear clear and distinct and indistinct, it is called translucent (flint, milk quartz). If no light passes through a mineral, it is called opaque (iron pyrite, copper pyrite, magnetite).

d) *Hardness:* Hardness is the resistance offered by a mineral to scratching on the bases of Mohr's scale it ranges 1 to 10 i.e. 1. Talc (Softest), 2. Gypsum, 3. Calcite, 4. Fluorite, 5. Appetite, 6. Feldspar, 7. Quartz, 8. Topaz, 9. Corundum and 10. Diamond (hardest).

e) *Streak:* Colour of the line drawn by rubbing the mineral against a coarse hard plane surface which may be different from the colour of mineral. Normally white minerals have got white streak, e.g. rock salt crystal. Orthoclase is pink in colour but steak is white, iron pyrite is yellow but streak is green, hematite is black but its streak is cherry red and Magnetite is black and its streak is also black.

f) *Specific gravity:* It is defined as 'ratio of the weight of mineral to the weight of equal volume of water' providing information regarding heaviness of a mineral.

g) Tenacity: Brittle (breaks into small pieces), flexible (easily bent) or malleable (flattened) against an external force on the mineral.

h) Cleavage: Tendency of some minerals to break along planes of weakness in the chemical bonds. If parallel to crystal faces, it yields more or less smooth surfaces. Cleavage may be perfect (diamond) or imperfect.

i) Fracture: It is the non-planar breakage of minerals providing even, uneven, or conchoidal surface.

j) **Form and structure:** If a definite form is developed, it is called crystalline, otherwise massive or amorphous. Crystalline form has six basic systems: i) monometric (cubic, isometric, regular), ii) dimetric (octahedron, tetragonal), iii) tritmetric (orthorhombic), iv) monoclinic, v) triclinic and vi) hexagonal. The arrangement of crystals gives rise to several types of structures, e.g. granular, lamellar, columnar, reticulated, stellated or drusy.

k) **Chemical nature:** The minerals are found in form of oxides, carbonates, silicates, sulphates, etc., as explained later in this section.

Classification of soil forming minerals: The minerals may be classified on the basis of their mode of formation, abundance (amount of mineral in the rock), specific gravity and chemical composition. The minerals are categorized as primary and secondary minerals based on their mode of formation. (Images of minerals and rocks are taken from 'Soils4teachers.org/mineralogy')

Primary minerals: Form an original component of igneous rocks. Anhydrous in nature and most prominent in coarser fractions (sand and silt) of the soil			
Examples			
Quartz	Feldspars	Hornblende	Mica
Simple in chemical composition (SiO_2), highly resistant to weathering and next to feldspars in abundance	Structure less dense than quartz, most abundant and source of Na, K, Ca and many trace elements	Ferro-magnesium mineral, easily weatherable and main source of Fe and Mg	K bearing mineral, plate like structure, and source of Fe and Mg

Secondary minerals: Formed as a result of weathering and recombination of primary minerals. Hydrous in nature and dominate in the clay fraction of soil.			
Examples			
Clay minerals	Hematite (Fe_2O_3)	Goethite ($Fe_2O_3.H_2O$)	Gibbsite ($Al_2O_3.3H_2O$)
Layered silicates, sheet type, contain large amount of Mg, Fe and K and negative charge on the surface	Red-blackish red, metallic luster, occur as coating on sand particles, cementing agent and swells on wetting	Hydrated ferric oxide, yellow to brown, colouring and cementing agent and present as iron concretions	Most common Al mineral, white, and found in highly weathered soils-laterites
Calcite ($CaCO_3$)	Dolomite $Ca.Mg (CO_3)_2$	Siderite ($FeCO_3$)	Iron pyrite (FeS_2)
White and decomposes easily	Resistant than calcite and major source of Mg	Important mineral in water-logged soils	Golden colour (Fool's gold)
Gypsum $CaSO_4.2H_2O$	Apatite $Ca_3(PO_4)_2$	Sulphur S	Copper Cu
Common mineral in desert soils, slightly soluble, source of Ca and S and amendment to reclaim sodic soils	Rock phosphate and primary source of phosphorus	Native element	Native element

Classification of soil forming minerals based on chemical composition: The minerals are grouped into several categories depending upon their chemical composition such as:

i) *Oxides and hydroxides:*- quartz (SiO_2), hematite (Fe_2O_3), gibbsite (Al_2O_3).

ii) *Carbonates***:**- calcite ($CaCO_3$), dolomite Ca, Mg $(CO_3)_2$.

iii)*Sulphides* :- iron pyrite (FeS_2), chalcocite (Cu_2S).

iv) *Sulphates:*- gypsum ($CaSO_4.2H_2O$).

v) *Phosphates:*- fluorapatite ($Ca_5(PO_4)_3F$), chlorapatite ($Ca_5(PO_4)_3Cl$).

vi) *Silicates:*- quartz*,* feldspars, mica

vii) *Native elements:*- sulphur, copper.

The images of some of the minerals varying in chemical composition have already shown in images of primary and secondary minerals.

Rocks: Rocks are the hard mass consisted of one or more minerals that have been cohesively brought together by rock-forming processes and constituting the earth's crust. For example, limestone rock is composed of the single mineral calcite while the granite rock is composed of several minerals, like quartz, mica and orthoclase.

Classification of rocks: Rocks are of three types based on their origin: igneous, sedimentary and metamorphic constituting 95, 4.9 and 0.1% by weight of the lithosphere, respectively.

Igneous rocks (Fire rocks): Igneous rocks formed by cooling and crystallization of molten mass (magma) on or beneath the earth surface. These rocks are non-laminar, massive and crystalline structure, source of parent materials for other rocks and ultimately for the soils and consisted of mainly primary minerals (92%) like feldspars (58%), amphiboles & pyroxenes (16%), quartz (13%), micas (4%), etc. and therefore, also called as *primary rocks*. These rocks are of two types: Extrusive or volcanic and intrusive or plutonic.

1. *Extrusive or volcanic rocks:* The rocks which are formed by cooling of magma on the earth surface e.g. basalt. These rocks are fine grained and may be highly porous. The rocks which contain gas cavities or vesicles are called as *vesicular* rocks. If these cavities are embedded by some minerals (quartz, calcite, zeolite) are called amygdaloidal rocks.

2. *Intrusive or plutonic rocks:* The rocks formed by cooling of magma beneath the earth surface e.g. granite. They are coarse grained, compacted and occurring at greater depth in the earth's crust. Some of these rocks consolidated in vertical cracks of pre-existing rocks and formed wall like mass and called *dykes* and other that consolidated in horizontal cracks or planes are called *sills*.

Examples of some of the volcanic and plutonic rocks and their characteristics

Volcanic or extrusive rocks		Plutonic or intrusive rocks	
Basalt	Pumic	Granite	Gabbro (Basic)
Dark, basic rock (silica=45-55%) mainly composed of feldspars and ferromagnesian minerals	Highly porous, light weight (specific gravity <1) and comparable to granite in composition	Light colored acidic rock (silica = 65-75%) mainly composed of quartz minerals.	Diorite (Neutral)

Sedimentary rocks (Aqueous, Clastic, Stratified rocks): The rocks which are formed from the sediments (weathered products) of igneous rocks. The sediments of igneous rocks are transported and deposited in lakes and seas by blowing wind, flowing water, glaciers and gravity where it is cemented to form sedimentary/ secondary rocks. The cementing materials to compact the sediments are silica, oxides of iron, lime. These rocks are also stratified rocks as the sediments are usually deposited in layers, classic rocks (clasts or fragment) and aqueous rocks as water is the main agent in their formation.

Examples of some of the common sedimentary rocks:

Sand stone	Shale	Lime stone	Conglomerate
Mainly composed of quartz with cementing agents- $CaCO_3$, iron oxides and clays, light to red coloured, usually granular and porous structure	Mainly composed of clay minerals, quartz and cementing agents as in sand stone, light to dark coloured and has thinly laminated structure	Composed of calcite with some iron oxides, clays, phosphate and organic matter, light grey to yellow, fine grained and compact structure	Highly variable in composition, shape, structure, colour & texture, mainly composed of quartz,feldspars along with the sediments of varying sizes

Based on mode of formation, the sedimentary rocks are classified as:

#	Type	Description	Example
1	Arenaceous or sandy	Formed due to deposition of coarse particles (quartz and feldspars) carried by the water. Depending upon the nature of cementing materials, some rocks are hard but most of the rocks are loose and undergo weathering easily, e.g. sandstone & conglomerate.	Sand stone
2	Argillaceous	Formed from small sized particles consisting of hydrated silicate of alumina (clays), calcareous materials, and other silicates. Deposition of clay mainly consisting of silicate of alumina is called as *Kaolin (China clay).*	Shale
3	Calcareous	Usually consisted of carbonate of Ca and/or Mg, formed by deposition and cementation of sediments, chemical precipitation or organic agency but mainly composed of debris from plants and animals when formed by the organic agency. When formed by chemical precipitation, the calcareous materials get deposited in form of sheets. Initially, the precipitate is soft but soon after it becomes hard.	Limestone
4	Carbonaceous	These are formed from decomposing vegetation under anaerobic condition in lower layers of earth, mainly consists of carbon. During decomposition, major proportion of the carbonaceous matter is retained and slowly converted into coal.	Lignite
5	Siliceous	These are of organic origin formed from silica-secreting minute plants and animals deposited either in salts or fresh water. These are mainly consist of microscopic SiO_2, dense, hard, and fine grained e.g. radiolarians, diatoms, or some types of sponges.	Chert

6	Precipitated	These are mainly deposits formed either by cooling, evaporation or direct chemical precipitation on or beneath the surface. Examples: *Oxides-* hematite, bauxite, quartz; *carbonates-* limestone; *sulphates-* gypsum; *phosphates-*phosphorite; and *chlorides-* rock salt	 Gypsum

Metamorphic rocks: The physical and/or chemical changes in igneous and sedimentary rocks by the action of internal heat and/or pressure leads to the formation of metamorphic rocks. The constituent minerals of the rock are changed into more stable minerals having better structural arrangement. The structure and mineral composition of these rocks depend on the composition of the original rocks and the kind of metamorphism. The rocks formed by the action of heat- *thermal metamorphic,* by the action of pressure- *dynamo metamorphic* and by the combined action of heat and pressure are called as *dynamo-thermal metamorphic rocks*.

Based on the structure and composition, these rocks can be grouped as *foliated* and *non-foliated* metamorphic rocks. Bands of alternative dark and light coloured minerals are characteristics of the foliated metamorphic rocks, e.g. gneiss and slate. The non-foliated metamorphic rocks consist of minerals which are more or less equi-dimensional in their shape, e.g., marble and quartzite.

Some of the important metamorphic rocks with their characteristics are:

Gneiss	Marbles	Slate	Schist	Quartzite
 Thermal metamorphism of granite (igneous), Foliated and light and dark bands.	 Thermal metamorphism of limestone/dolomite (sedimentary), non-foliated and white, red, green or black	 Dynamo metamorphism of shale (sedimentary), foliated and grey to black in colour	 Dynamo metamorphism of Basalt + Shales (igneous + sedimentary), foliated and light to dark	 Dynamo-thermal metamorphism of sand stone (sedimentary), non-foliated, light to red

Exercise-IV

PARTICLE DENSITY OF SOIL

The particle density of soil refers to the density of solid particles collectively. It is the ratio of the total mass of solid particles to their total volume excluding pore spaces between the particles. In simple terms, it is the mass per unit volume of soil solid and commonly expressed as g cm^{-3} and Mg m^{-3}. A knowledge of particle density is required for calculation of volume-mass relationships of the soil, viz. porosity, bulk density and void ratio. The particle density is also required for calculating the settling velocity of different sized particles in machnical analysis. The calculations involving particle movement by wind and water also require knowledge of particle density.

In spite of considerable range in the density of the individual soil minerals, the value of particle density (D_p) for most of the cultivated mineral soils ranges between 2.6 to 2.7 Mg m^{-3} with an average of 2.65 Mg m^{-3}. The presence of large amounts of organic matter may decrease the value of D_p.

Methods of determination

Particle density of a given soil is calculated by knowing the mass of its solids and their volume. The mass of solids is determined by weighing a sample of oven dried soil and volume is calculated by immersion method i.e. from the mass and density of water displaced by the soil solids. The pycnometer method is widely used.

Pycnometer method: A pycnometer or specific-gravity bottle (Fig. 4.1) is a glass flask fitted with a ground-glass stopper piercing lengthwise by a capillary opening.

Principle: A known quantity of dry soil upon immersion into a known volume of water, expels air and displaces the volume of water equal to its own volume. The volume of soil solid particles is thus calculated from the mass of water (M_w) displaced by the immersed soil particles. For calculating M_w, the mass of water filled pycnometer (M_{Pw}), mass of dry soil (M_s) and mass of pycnometer containing soil and filled with water (M_{psw}) is recorded, separately.

Fig. 4.1 : Pycnometer

Mathematically: $M_w = M_{pw} + M_s - M_{psw}$

But $M_w = V_s \times D_w$ where V_s = Volume of soil solids and D_w = Density of water.

As $V_s = \dfrac{M_s}{D_p}$, therefore, $D_p = \dfrac{M_s \times D_w}{M_w}$

Assuming the density of water to be 1.0 Mg m^{-3}, $D_p = \dfrac{M_s}{(M_{pw} + M_s - M_{psw})}$ Mg m^{-3}

Apparatus: A pycnometer (specific gravity bottle), pipette (20 ml capacity), plate or water bath, analytical balance, oven, thermometer and filter paper.

Procedure: Fill the clean and dry pycnometer with freshly boiled and cooled distilled water. Record the temperature of the water. Insert the stopper and thoroughly dry the outerside of the pycnometer with filter paper. Weigh the pycnometer and its contents. Empty it, dry it and add carefully 10 g of oven-dried 2 mm sieved soil. Using the pipette, fill the pycnometer to about half with distilled water, washing into it with a stream of water for removing any soil particle sticking to the inner side of the neck. Remove the entrapped air by gentle boiling the contents for several minutes.(If soil is heavy clay, leave it overnight so that all pores become water saturated). Leave the pycnomter to cool its contents to room temperature. After cooling, fill the pycnometer with freshly boiled and cooled distilled water. Insert the stopper, thoroughly dry and clean the outer side of the pycnometer with a filter paper and take its weigh.

Observations and calculations

Mass of the soil taken $\qquad = M_s$ g

Mass of the water filled pycnometer $\quad = M_{pw}$ g

Mass of pycnometer + Water + Soil $\quad = M_{psw}$ g

Particle density $\qquad\qquad\qquad\quad = \dfrac{M_s}{(M_{pw} + M_s - M_{psw})}$ g cm^{-3} or Mg m^{-3}

●●●●●

SOIL BULK DENSITY AND POROSITY

Soil bulk density: The soil bulk density is defined as the ratio of the mass of the oven dried soil to its bulk volume including the volume of soil particles and pore space. It is expressed as $g\ cm^{-3}$ and $Mg\ m^{-3}$. It is widely used for converting water content by mass to its volume, calculating porosity and void ratio when the particle density is known, and for estimating the mass of volume of a soil too large to weigh conveniently, such as the mass of a furrow slice. The bulk density of soil varies depending upon the mineral composition, organic matter content, soil structure and compaction. In swelling soils, it varies with water content and should be recorded along with water content during sampling. Bulk density of soils largely depends upon the management practices. Soils develop dense plough sole if they are not tilled at appropriate soil moisture content and restrict root penetration.

In general, soil bulk density increases with increase in depth because of decrease in organic matter content, and the compaction resulting from the pressure of upper soil layers and the use of heavy implements and machinery for various tillage operations. The bulk density of a sandy soil may be as high as $1.8\ Mg\ m^{-3}$ whereas of an aggregated loam or clay soils may be as low as $1.1\ Mg\ m^{-3}$. For good plant growth, the bulk density should be $1.4\ Mg\ m^{-3}$ for clays and $1.6\ Mg\ m^{-3}$ for sands. Normally, soil bulk density ranges from 1.2 to $1.8\ Mg\ m^{-3}$.

Methods of determination

Different methods are used for determination of bulk density depending upon the collection of soil sample and measurement of soil volume. For example, soil core, clod and excavation methods. Some other methods are also available where different principles are employed, e.g. radiation method. Most common methods are: weighing bottle, core and clod method.

1. Weighing bottle method

Principle: The oven-dried soil is packed in a weighing bottle of a known volume by placing the soil in the bottle in small amounts (5-6 g) and tapping 15-20 times on a table from a height of about 2-3 cm. This tapping is assumed to produce the same packing as occurring naturally in the field. Bulk density is calculated from oven dried mass of the soil packed and the volume of the weighing bottle.

Apparatus: A weighing-bottle, burette (50 ml) and balance

Procedure: Take the weight of a 50 ml bottle. Fill it with oven dried soil by tapping and take its weigh again. Determine the exact volume of the bottle using burette after the sample is removed.

Observations and calculations

Mass of the empty bottle	$= M_1$ g
Mass of bottle filled with soil	$= M_2$ g
Mass of soil	$= (M_2-M_1)$ g
Volume of water filling the bottle	$= V$ cm^{-3}
Bulk density	$= \dfrac{(M_2-M_1)}{V}$ g cm^{-3} or Mg m^{-3}

2. Clod method

Principle: A few small stable soil clods (3-4 cm in diameter) are oven-dried, weighed and coated with rubber solution (water repellent substance) just enough to check water entry into the clods. These clods are placed in a graduated cylinder filled with water and the volume of water displaced is recorded. From the oven-dried weight of the soil clods and the volume of water displaced (volume of clods), the bulk density is calculated.

Apparatus and reagents: Rubber sheets, benzene, wide mouthed container, toluene, electric stirrer, a thin wire mesh, 250 ml graduated cylinder, weighing balance, oven and soil clod of at least 3 cm diameter.

Procedure:

Preparation of rubber solution: Take 50 g of rubber sheet and cut it into small pieces and soak in toluene (rubber: toluene::1:5 by weight) overnight in a tight container Add 400-500 ml of benzene and stir thoroughly with an electric stirrer till the swollen pieces of rubber are shattered and a homogeneous solution is obtained. Dilute this solution with benzene or toluene to achieve concentration of 1:30 by weight. Benzene is preferred over as it dries rapidly when applied over the soil clod.

Coating of soil clods: Take oven-dried pre-weighted soil clod. Wrap them in a thin wire mesh and dip in the rubber solution kept in a wide mouthed container. Remove it momentarily and repeat the process 3-4 times.

Measurement of the volume displaced: Put 150 ml of water in a 250 ml graduated cylinder. Put the rubber coated soil clods into cylinder. Note the volume of water displaced by the clods which will be equal to the volume of soil clods.

Observations and calculations:

Mass of oven-dried clods	$= M$ g
Volume of water in the cylinder	$= V_1$ cm^3
Volume of water after adding clods in the cylinder	$= V^2$ cm^3
Volume of the clods	$= (V_2-V_1)$ cm^3
Bulk density of the clods	$= \dfrac{(V_2-V_1)}{M}$ g cm^{-3} or Mg m^{-3}

3. Core method: Core method is used to determine the bulk density of undisturbed soil samples taken from the field.

Principle: A cylindrical metal sampler or core of known volume is inserted into the soil to the desired depth and removed carefully to safeguard the known volume of sample as it existed *in situ*. The core sample is then dried at 105 ºC and it weight is taken. Bulk density is calculated from the oven dried mass divided by volume of the sample (core). Core method cannot be used in gravely soils.

Apparatus: A core sampler, a tray, sharp knife, moisture boxes and oven.

Procedure: Insert the core sampler into either a vertical or horizontal soil surface far enough to fill the sampler. Remove the sampler and its contents carefully. Trim the soil extending beyond the sampler with a sharp knife. The volume of soil sample is the same as that of the volume of the core. Shift the moist soil to a tray and weigh it. Take a portion of the sample in a moisture box, weigh and dry in an oven and weigh it again.

Observations and calculations

Mass of the wet bulk soil sample	$= M_1$ g
Mass of the moisture box	$= M_2$ g
Mass of moisture box and moist soil	$= M_3$ g
Mass of moisture box and oven dried soil	$= M_4$ g
Mass of moist soil	$= (M_3-M_2)$ g
Mass of oven-dried soil	$= (M_4-M_2)$ g
Oven dried mass of bulk soil sample	$= \dfrac{(M_4-M_2)}{(M_3-M_2)} \times M_1$ g or say M_5 g

Volume of soil core $= V$ cm^3 or $= \pi r^2 h$ cm^3 where r is the radius and h is the height of the core.

Bulk density	$= \dfrac{M_5}{V}$ g cm^{-3} or Mg m^{-3}.

Precautions: Core sampling should be avoided in soils which are too wet or too dry. The friction along the sides of the sampler and vibrations due to hammering in too wet soils may cause viscous flow of the soil and compression of the sample. Compression may occur even in dry soil if it is very loose. In dry soil, hammering the sampler often shatters the sample and makes it loose.

Soil porosity: The porosity of a soil represents the volume which is occupied by air and water. It is defined as the ratio of the volume of pores to the total volume of soil and expressed in percentage. It is generally varies between 30-60 per cent. Soil porosity is affected by soil texture, structure, tillage, cropping practices, soil depth and compaction. It gives an idea only about the total storage capacity for fluids or gases and not of the pore size distribution. In soil mechanics, instead of porosity, the term 'void ratio' is used and refers- the ratio of volume of soil pores to the volume of soil solid and its value usually ranges between 0.3 to 2.0.

Methods of determination

Total porosity can be measured from the volume of non-polar liquid such as paraffin adsorbed by a dry clod under vacuum. Alternately, porosity can be calculated from the values of bulk density and particle density of a soil.

Theory: The soil bulk density $(D_b) = \dfrac{M_s}{V_t}$ or $V_t = \dfrac{M_s}{D_b}$ where M_s is the mass of over dried soil and V_t is the total volume of soil mass.

Similarly, the soil particle density $(D_p) = \dfrac{M_s}{V_s}$ or $V_s = \dfrac{M_s}{D_p}$ where V_s is the volume of the solid particles. Therefore, the volume fraction not occupied by the solid particles or the volume occupied by pore $(V_p) = \dfrac{V_t - V_s}{V_t} = 1 - \left(\dfrac{V_s}{V_t}\right)$ or $= 1 - \left(\dfrac{D_b}{D_p}\right)$.

Procedure: Calculate the total porosity from the values of particle density and bulk density determined for a given soil sample as per procedures explained in the exercise IV and in earlier section in this exercise, respectively, using the above mentioned relationship, and express in percentage.

●●●●●

Exercise-VI

The soil moisture content is a measure of amount of water per unit mass or volume of soil. The moisture content is required to calculate the water storage capacity of soils, plant available water, moisture depletion patterns, etc. It is also required to study movement of water and chemicals in soils, and for scheduling of irrigation and calculating the depth of irrigation water to be applied.

The moisture content is frequently expressed as per cent either on dry mass or volume basis, i.e. $\theta_g = \dfrac{M_w}{M_s} \times 100$, or $\theta_v = \dfrac{V_w}{V_t} \times 100$

where θ_g and θ_v is the percentage of water on mass and volume basis; M_w and V_w is the mass and volume of water in the sample; and M_s and V_t is the mass of oven dried soil and bulk volume of soil sample, respectively.

The moisture percentage is generally expressed on mass basis unless stated otherwise. The θ_g can be converted into θ_v, if the soil bulk density (D_b) is known or assumed.

$$\theta_v = \frac{V_w}{V_t} \times 100 \text{ or} = \frac{M_w}{V_t} \times 100$$

$$D_b = \frac{M_s}{V_t} \text{ or } V_t = \frac{M_s}{D_b}$$

$$\theta_v = \frac{M_w}{\left(\frac{M_s}{D_b}\right)} \times 100 = \left(\frac{M_w}{M_s}\right) \times D_b \times 100 \text{ or} = \theta_g \times D_b$$

The degree of soil wetness is not a permanent characteristic of a soil. It depends upon the weather conditions, depth of groundwater, physical properties of soil, characteristics of plant cover, etc.

Methods of determination: The methods of determination of soil moisture are either direct or indirect. In direct methods, the amount of moisture present in a soil is directly determined (gravimetric method) while in indirect methods, a soil property or some reaction products relating to soil water content is determined. In these methods, a calibration curve indicating the relation of the soil properties and soil water content is first established and then used for the estimation of moisture content, for example, neutron scattering and dielectric methods. Here only gravimetric method is discussed.

Gravimetric method: This is the most widely used direct method and also used for the calibration of other indirect methods. This method is simple, routine, reliable and inexpensive but destructive, laborious and time consuming.

Principle: Moist soil samples (disturbed or undisturbed) are weighed, dried in an oven at 105°C and reweighed. From these weights, the moisture content on dry mass basis is calculated which can also be expressed on a volume basis by multiplying it with the bulk density of the soil.

Apparatus: Tool for sampling, moisture box, oven and a desiccator with an active desiccant (calcium chloride).

Procedure: Collect moist soil sample in a moisture box and weigh it immediately. Place the box with lid off in an oven (105°C) and dry the soil to a constant weight. Take out the sample from the oven, replace the lid, and place the box in the desiccator until it is cool. Weigh it. Determine the mass of the empty moisture box.

Observations and calculations:

Mass of moisture box $\qquad = M_1$ g

Mass of moisture box with moist soil $\qquad = M_2$ g

Mass of moisture box with oven dried soil $\qquad = M_3$ g

Mass of moisture in the soil $\qquad = (M_2 - M_3)$ g

Mass of the oven dried soil $\qquad = (M_3 - M_1)$ g

Per cent moisture content (dry mass basis) $(\theta_g)\qquad = \left(\dfrac{M_2 - M_3}{M_3 - M_1}\right)\times100$

Per cent moisture content (volume basis) $(\theta_v)\qquad = \theta_g\times D_b$ where D_b is soil bulk density

●●●●●

Exercise-VII

SATURATED HYDRAULIC CONDUCTIVITY OF SOIL

The saturated hydraulic conductivity (K_s) is a measure of readiness with which a saturated soil transmits water through it. It has its importance in studies related to irrigation, drainage and evaporation. The K_s is usually assumed to be a constant soil physical property for any given position in the field at any given time. Both, the viscosity and density of water affect the K_s, therefore, varies with different qualities of waters. When K_s is adjusted to account for viscosity and density of the water, it is called intrinsic permeability which is same for all waters/fluids. Thus, intrinsic permeability is the factor used exclusively for soil. However, the word permeability is still used to represent the quality of state of a porous medium relating to readiness with which it conducts fluids. The saturated hydraulic conductivity (K_s) is related to intrinsic permeability (k) as:

$K_s = k \times f$ where f is fluidity of the fluid and is given as:

$$f = \frac{dg}{\eta}, \text{ therefore, } K_s = \frac{kdg}{\eta}$$

where, d is density (Mg m^{-3}), η is the viscosity (kg m^{-1} s^{-1}) of the fluid and g is the acceleration due to gravity (m s^{-2}).

Ratings of hydraulic conductivity

Class	Rating (cm hr^{-1})	Class	Rating (cm hr^{-1})
Very slow	< 0.125	Moderately rapid	6.25- 2.5
Slow	0.125-0.50	Rapid	12.5-25.0
Moderately slow	0.50-2.0	Very rapid	> 25.0
Moderate	2.0-6.25		

Methods of determination

The K_s may be determined by several methods in the laboratories and in the fields but constant water head method is most widely used method in laboratories. Principally, the K_s of soil is calculated from Darcy's law by measuring the soil water flux and hydraulic gradient.

Constant water head

Principle: When a constant head of water is maintained (Fig. 7.1) on one end of a saturated column of soil of length, L cm, the volume of water, Q cm^3, percolating

through the other end per unit cross-sectional area, A cm^2, of the soil column per unit time, t minute, is directly proportional to the hydraulic gradient $\left(\frac{\Delta H}{L}\right)$ over the length of the soil. Thus,

$$\frac{Q}{At} = -K_S \frac{\Delta H}{L} \qquad (1)$$

As per Darcy's law the proportionality constant K_s, in equation 1 is the saturated hydraulic conductivity of the soil. The symbol H stands for the total head, which is the sum of hydraulic head (h) and the gravity head (z) at any point in the soil column. The difference of H at the inflow and the outflow of soil column (ΔH) divided by the length of the column (L) gives the hydraulic or the total head gradient.
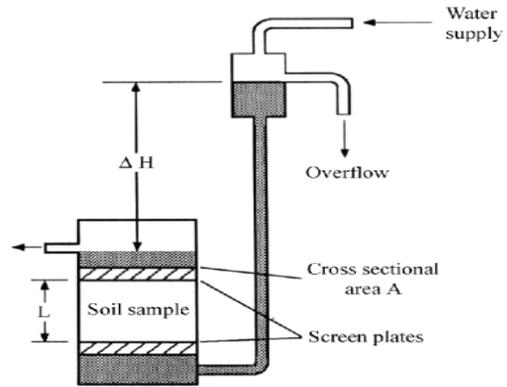

Fig. 7.1: Constant water head

Apparatus: Brass permeameters (7 cm i.d. and 10 cm in length) with the perforated bottoms (wall effect in smaller diameter permeameters causes more error); stand; water reservoir with an arrangement for maintaining a constant head over the soil column; graduated cylinders; stop watch and measuring scale.

Procedure: Put a filter paper on the perforated bottom the permeameter. Put 200 g of air-dried soil (2 mm sieved) into the permeameter and tap the permeameter 15-20 times on a wooden slab from a height of 2-3 cm for proper packing. Put a filter paper on the top of the soil and place the permeameter in a tray filled with water, keeping the water level slightly above the bottom of the sample. Allow it to soak till fully wet at the surface. Now raise the water level in the tray to coincide with the top of the soil in the permeameter for complete saturation. Fix the permeameter on the stand and start the siphon to maintain a constant head (2-3 cm) on the top of the soil. Note down the time when the water head on soil sample becomes constant and a steady flow is obtained. Collect the percolating water in a graduated cylinder and measure the volume at pre-calculated time intervals. Record consecutive readings till the flux become constant. Measure the water head on the soil and the length of soil column with the measuring rod.

Observations and calculations

Diameter of the permeameter	= d cm
Cross-sectional area of the permeameter	= A cm^2
Water head on the soil	= h cm
Length of soil column	= L cm
Time for which percolate collected	= T (min)
Volume of percolate collected	= Q cm^3
Hydraulic gradient	$= \dfrac{(L+h)}{L}$
Saturated hydraulic conductivity	$= \dfrac{QL}{At\,(L+h)}$ cm min^{-1}

●●●●●

Exercise-VIII

INFILTRATION RATE OF SOIL

Infiltration is the rate of water entry into the soil when water covers the surface at a shallow depth and downward flow into and through the soil is non-divergent. Quantitatively, infiltration rate is defined as the volume of water entering into the soil per unit area per unit time. It has the dimensions of velocity and usually expressed as mm hr^{-1} or cm hr^{-1}. In dry soils, water infiltrates rapidly which is the initial infiltration rate. As more and more water replaces the air in the pores, water from the soil surface infiltrates more slowly and eventually reaches a steady state. This is called the basic infiltration rate. The maximum possible infiltration rate is called the infiltration capacity of the soil or infiltrability. Infiltration rate is important in determining the proportion of the amount of rainfall or irrigation water that enters the soil and that flows over the soil surface as run off. Various factors such as soil texture, structure, total porosity, hydraulic conductivity, initial moisture content, organic matter, soil cover, tillage, cropping practices, rainfall intensity, impeding layer, etc., influence the rate of water entry into the soil.

Percolation is the downward movement of water through the soil under the influence of gravity. It is the same as drainage. Infiltration can be considered as the first phase of percolation and both are mutually related. Percolation occurs when water is under pressure or when tension is smaller than about half of an atmosphere because in soils that are drier than this, the water is held so tightly that it cannot flow under the influence of gravity. Percolation is important in soil development and land management. It removes the soluble salts that would otherwise accumulate at the surface. On the other hand, percolation removes valuable plant nutrients, especially, nitrate. Percolation capacity is largely governed by texture and structure of the soil.

Infiltration rate

Principle: When water is ponded on the soil surface in plots of a few square meter area at the test site or inside concentric metallic rings driven into the soil, the rate of recession (fall) of the water level, or the rate of water withdrawn from a supply source used to maintain a constant head of water on the soil surface, gives the infiltration rate of the soil.

During infiltration of water into the soil, appreciable lateral movements of water also occur. To avoid the error due to this lateral movement, two concentric rings are used.

Equal heads of water are maintained in both the rings. The infiltration is measured in the inner ring only.

Apparatus: Double ring infiltrometer (diameter of inner ring 30-35 cm, outer ring 40-45 cm, and height 40-45 cm), metre scale, polyethylene sheet and watch.

Procedure: Drive the infiltrometer rings into a uniform and well leveled field to depth of 15-20 cm with the help of hammer. Care should be taken to keep the sides of the inner cylinder vertical and to avoid disturbance of the soil column within the cylinder. Tap the soil into the space between the soil column and the cylinder. Cover the soil with the polyethylene sheet and pond 15-20 cm of water in both the rings. Remove the sheet and fix a metre scale in the inner ring. Note down the receding water level at convenient intervals, for example, at 1, 5, 10, 15, 30, 45, 60, 90, 150 minutes and hourly thereafter till the water intake is constant. The time intervals of observation can, however, be varied according to objectives of the study and the soil's permeability. If all the applied water enters into the soil in a short period, add more water and the recession of water is recorded till the intake rate is constant. The water level and time just before and after is recorded. The interval between these two observations is kept as short as possible to avoid errors caused by intake during the refilling period.

Observations and calculations: Tabulate the observations and calculations in the following format.

Sr. No.	Cumulative time, t (min)	Metre scale reading (cm)	Cumulative intake, i (cm)	Infiltration rate, di/dt (cm min^{-1})
1	0			
2	1			
3	5			
4	10			
5	15			
6	30			
7	45			
8	60			
9	90			
10	150			
11	210			
12	270			

●●●●●

Exercise-IX

<div align="right">**SOIL TEXTURE**</div>

Texture expresses the relative proportions of sand, silt and clay content in the soil. Most of the physical and chemical properties of soil including its water intake, aeration, plant water availability, fertility, susceptibility to erosion and ease of tillage are affected by the texture. The determination of the percent sand, silt and clay in a soil is called mechanical analysis. Several conventional schemes exist for the classification of the soil particles according to their particle diameter ranges. Classifications of International Union of Soil Sciences (IUSS) previous known as International Society of Soil Science (ISSS) and United State Department of Agriculture (USDA) are widely in use (Table 1).

Table 1: Classification of soil fractions according to particle diameter ranges

Soil fraction	Particle diameter (mm)	
	IUSS/IISS	USDA
Very coarse sand	-	2.0-1.0
Coarse sand	2.0-0.2	1.0-0.5
Medium sand	-	0.5-0.25
Fine sand	0.2-0.02	0.25-0.10
Very fine sand	-	0.10-0.05
Silt	0.02-0.002	0.05-0.002
Clay	< 0.002	<0.002

In India, ISSS/IUSS system of classification of size fractions is largely in use. The general characteristics of each size fraction as per IUSS are provided in (Table 2).

Table 2: General characteristics of different size fractions of soil

Fraction	General characteristics
Sand	✓ Individual particle feels gritty when the soil is rubbed between the two fingers ✓ Not plastic or sticky when moist ✓ Settle to the bottom of Bouyoucos cylinder in 40 minutes
Silt	✓ Individual particle feels smooth powdery when the soil is rubbed between the two fingers but gritty to the teeth. ✓ Not plastic or sticky when moist ✓ Settle to the bottom of Bouyoucos cylinder in 2 hrs.

Clay	✓ Individual particle feels smooth powdery when the soil is rubbed between the two fingers and not gritty to the teeth.
	✓ Plastic or sticky when moist and forms hard clods when dry
	✓ Remain suspended in water for very long period of time.

1. Feel method:

Determining texture by feeling the soil between fingers and thumb requires extensive practice and wide experience. However, soil texture may be evaluated quite well by following the given steps while keeping the textural triangle in mind in a modified manner as shown in the Fig. 9.1.
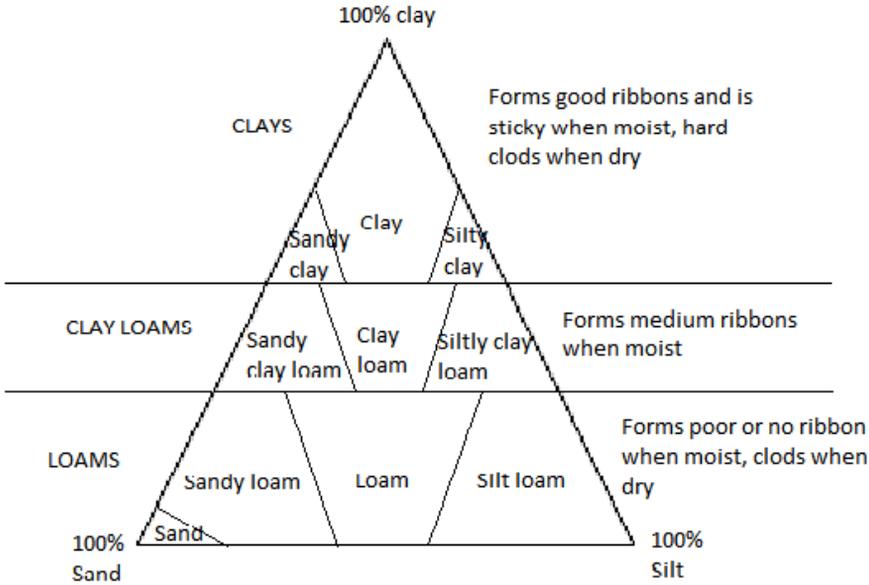

Fig. 9.1: Modified textural triangle for determining soil texture by feel method (www.nzdl.org)

The type of ribbon (good, medium or poor) a soil makes determines whether the soil best fits into a clay, clay loam or loam class. For making ribbon, put about half teaspoon of soil in the palm. Knead the soil while adding water drop by drop and bring it to the consistency of a moist, workable condition. At the proper consistency, try to form the ribbon by pressing the soil between your thumb and fore-finger. Based on judgment whether the ribbon formed is good, medium or poor, the soil are classified as a clay, clay loam or loam, respectively, as shown in Fig. 9.1.

After establishing the clay, clay loam or loam texture of the given soil sample, re-examine the sample for its grittiness or smoothness. The gritty feeling indicates the dominance of sand, therefore, soil is designated either a sandy clay, a sandy clay loam or a sandy loam depending on good, medium and poor ribbon, respectively, it made. If grittiness cannot be felt by rubbing the soil between the fingers but detected by teeth, the soil is designated as silty clay loam or silt loam. If the soil is neither sandy nor silty but has exceptionally smooth feeling, it is designated as clay or a clay loam depending on the type of ribbon it made. The soil that is loose and single grained when dry and forms a fragile cast when moist is designated as sand.

Record the results on data sheet given below and determine soil texture

Sample No.	Place an 'X' in the appropriate column						Textural class name
	Ribbon			Grittiness			
	Good	Medium	Poor	With fingers	With teeth	None	
1							
2							
3							
4							
5							

2. Bouyoucos hydrometer method

The mineral part of a given soil sample is separated into different size fractions. The proportions of these fractions are determined by the sedimentation principle based on Stokes' law which relates the radius of the particles to the velocity of sedimentation. Both the hydrometer and International Pipette methods are used for determination of soil texture. The hydrometer method is rapid, however, less accurate and gives approximate values only for silt and clay. The hydrometer method is sufficient to analyze soil texture without any pretreatment for most purposes, however for soils high in organic matter (> 5%), pre-treatment is still required. It also gives erroneous results for calcareous and saline soils since there is no pre-acid treatment and filtration.

Principle: The principle of hydrometer method is that there is a continuous reduction in the density of soil suspension over time at the rate the particles fall below the level of hydrometer. By

Fig. 9.2: Bouyoucos hydrometer

knowing the density of the suspension at required times with a calibrated hydrometer different sized particles are obtained.

Apparatus, equipment and reagents: Electric stirrer, one-litre sedimentation cylinders with rubber stoppers, thermometer, 5 % sodium hexametaphosphate, 30 per cent hydrogen peroxide, wash bottle, beaker (600 ml) with cover, water bath, Bouyoucos hydrometer (Fig. 9.2), watch glass and oven.

Procedure: Weigh 40 g air-dried soil in duplicate. Place one of the samples in an oven at 105°C for drying and determine the moisture content. Take the other sample in the beaker and add 200 ml of distilled water, stir it with glass rod and heat the contents of the beaker.

Add 4-5 ml of 30 % H_2O_2, cover the beaker with watch glass and keep it overnight for the reaction to complete. Next day, place the beaker on water bath until organic matter get oxidised. Take out the beaker from water bath and let it cool. This process is repeated until the colour of the suspension ceases, become lighter or frothing stops. Normally 15 ml of H_2O_2 will be sufficient for a 40 g sample except for soils having high amount organic matter content. To remove the excess of the H_2O_2, the beaker is placed on the water bath for two hours after the last addition of H_2O_2

Add 10 ml of sodium hexametaphosphate solution in one litre cylinder, fill it with distilled water up to the mark and bring it to room temperature. Place the stopper on the mouth of the sedimentation cylinder, mix the suspension thoroughly and keep it on the flat surface. Lower the hydrometer carefully in to the solution and record the scale reading, and designated this reading as RL i.e the calibration correction.

Now transfer the H_2O_2 treated soil sample into 250 ml beaker, add distilled water and 10 ml of sodium hexametaphosphate solution. Stir the suspension with an electric stirrer for 10 minutes.

Transfer and wash the whole suspension of the beaker with distilled water into the one-litre sedimentation cylinder. Close the mouth of the cylinder with a rubber stopper and shake it end-over-end for one minute.

After shaking, place the cylinder on the flat surface and record the time immediately. Take the first hydrometer reading after 4 minutes (R_4) when the particles > 0.02 mm in diameter have settled. The hydrometer is inserted 10 seconds in advance of reading time.

Remove the hydrometer and wash it. Record the temperature of the suspension. The hydrometer is calibrated at 19.4°C. Use correction factor (r) for other temperatures i.e. the difference between working temperature and 19.4°C, multiplied by 0.11. For

working temperature above 19.4°C, the correction factor is added and for below 19.4°C, it is subtracted.

Do not disturb the suspension and again place the hydrometer at the end of two hours after the initial shaking and record the reading (R_{120}). The particles > 0.002 mm (sand + silt) are settled by this time.

Calculations: Calculate the percentage of silt+clay from the 4 minute reading (P_4) and percent clay from 2 hrs reading (P_{120}) as:

$$P_4 = \frac{(R_4 - RL \pm r)}{M} \times 100; \; P_{120} = \frac{(R_{120} - RL \pm r)}{M} \times 100$$

where M represents the mass of the soil taken for textural analysis. Percent sand is calculated by difference of 100-P_4 and the percent silt is P_4-P_{120}.

3. International Pipette method

This method is a standard and accurate method for particle size analysis but it is very time consuming, therefore, sometimes create problem in analyzing large number of samples.

Principle: It is based on the principle that different sized particles having different weights fall at different velocities in suspension. A sample of soil suspension is taken at a given depth at a predetermined time containing all those particles which are still in suspension at that depth.

The method is based on separation of soil particles from each other i.e. complete dispersion into ultimate particles and then the measurement of the amount of each sized fraction in the sample.

To achieve complete dispersion of soil particles, the binding materials are removed from the soil. Then the sample is treated with hydrogen peroxide (H_2O_2) to oxidize organic matter and dilute hydrochloric acid (HCl) to remove lime and colloidal oxides of iron and aluminum. The soil solution is then filtered under suction to reduce concentration of soluble salts. Finally, the soil is treated with sodium hexametaphosphate (Calgon) solution to keep the clay particles dispersed. Separation of different particle size fractions is done by sieving and sedimentation techniques. The sieves used correspond to the desired particle size separation. Different sized sieves of circular holes are used for particle sizes > 0.5 mm and for the smaller sized particles, wire mesh screens are used. Usually, the relation of $\frac{16}{\text{number of mesh per inch length}}$ is used to convert it in mm. The particles with diameter > 0.05 mm could be separated by sieving.

The particles of size < 0.05 mm are determined by sedimentation technique. The sedimentation method of measuring particle size fractions is based on Stokes' law with certain assumptions. The law states that the terminal velocity of a spherical particle settling under the influence of gravity in a fluid of a known density and viscosity is proportional to the square of the particle radius, represented as:

$$V = \frac{2}{9} \frac{r^2 (\rho_p - \rho_s)g}{\eta}$$

where V = terminal velocity of falling particle (cm sec^{-1})

r = radius of the particle (cm)

ρ_p = density of particles (g cm^{-3})

ρ_s = density of the fluid (g cm^{-3})

η = viscosity of the fluid (g cm^{-1} sec^{-1}, poise)

g = acceleration due to gravity (981 cm sec^{-1})

The following are the assumptions and limitations of Stokes' law:

a) Particles should be spherical, smooth and rigid. But soil colloidal particles are platy and fall slower than spherical particles of the same mass.

b) Particle size should be larger than the size of molecules of the liquid, so that the medium can be considered homogeneous, i.e. no Brownian movement. The largest size limit of particles exhibiting Brownian movement is approximately 0.0002 mm.

c) Fall must be unhindered. Particles falling very near to the wall of the cylinder (0.1 mm distance) are slowed down in their drop. Fast falling larger particles may drag finer particles down along with them, therefore, concentration up to 3 per cent of solids is kept in the suspension.

d) All the particles must be of uniform density.

e) There should not be any turbulence in the suspension. The fast settling particles (> 0.05 mm) cause turbulence, therefore, should be analyzed by sieving techniques.

Apparatus: One litre sedimentation cylinder, balance, hot water bath, cover glass, vacuum pump, 70 mesh sieve, dish, oven, wash bottle, thermometer, 25 ml mechanical analysis pipette, rubber pestle, blue litmus paper, 600 ml beaker, shaking machine.

Reagents: Hydrogen peroxide (6%), hydrochloric acid (2N), distilled water, sodium hydroxide (1 N), phenolphthalein (1 %) and silver nitrate solution.

Procedure

A. *Treatment with hydrogen peroxide:* Take 20 g air of dried soil (2 mm sieved) in a 600 ml beaker. Add 50-60 ml of H_2O_2 to oxidize organic matter. Mix well and let the reaction to proceed, preferably overnight. Place the beaker with cover glass on a hot water bath for about 15 minutes. Avoid frothing over the beaker by continuous stirring. Remove the beaker and add further 25-40 ml H_2O_2. After 1-2 minutes, again place the beaker on water bath for 10 minutes and then immerse it for 5 minutes. After finishing the treatment with H_2O_2 on the water bath, rinse the cover and sides of the beaker with distilled water and dilute to about 150 ml. Boil it for 5 minutes while avoiding frothing. Keep repeating treatment with H_2O_2 till the organic matter is fully oxidized.

B. *Treatment with acid and filtration:* After cooling the contents, add 25 ml of 2 N HCl and shake to destroy $CaCO_3$ present in soil. If $CaCO_3$, content in soil is >2 per cent, an extra 2.5 ml of 2N HCl for each per cent of $CaCO_3$ is added. Dilute to approximately 250 ml and leave it for one hour. After one hour, do blue litmus test to know the excess of acid. Now filter using hardened filter paper (Whatman No. 50). Continue the leaching with water using $AgNO_3$ test the filtrate is nearly neutral or free from chlorides.

C. *Separation of coarse sand:* After washing, spread out the filter paper on a large watch glass. Place a 70 mesh sieve on a sedimentation cylinder and pour the suspension with a stream of water from the wash bottle, wash as much material as possible through the sieve until no more clay and silt remain on the sieve, and the cylinder is about one-half full. Transfer the coarse material left on the sieve to a pre-weighed beaker. Dry it in oven and weigh. Calculate the coarse sand percentage as:

Mass of beaker $= W_1$ g

Mass of beaker + dry coarse sand $= W_2$ g

Mass of coarse sand $= W_2 - W_1$ g

Percentage of coarse sand in air-dried soil $= \dfrac{(W_2 - W_1) \times 100}{20}$

D. *Dispersion:* Add 10 ml of 1N NaOH in the cylinder. Make the volume of the suspension in the sedimentation cylinder up to 1000 ml rendering it alkaline to phenolphthalein. Shake in an electric stirrer for 10 minutes prior to transfer to the sedimentation cylinder.

E. *Separation of silt+clay:* Shake the suspension by repeated inversions of the cylinder for about one minute. Place the sedimentation cylinder on the bench and note the time. After determining the temperature of the suspension, find out the time of

sedimentation corresponding to this temperature for silt+clay determination from Table 3. Withdraw 25 ml of the suspension by a mechanical analysis pipette and lowering it before 10 seconds at the depth of 10 cm taking care to avoid too rapid ingress of the suspension (Fig. 9.3). Transfer this sample into a pre-weighed beaker, dry at 105°C and weigh as silt+clay.

Mass of beaker $= W_1$ g

Mass of beaker + silt+clay in 25 ml suspension $= W_2$ g

Mass of silt+clay in 25 ml suspension $= (W_2 - W_1)$ g

Percentage of silt+clay $= \dfrac{(W2 - W1) \times 1000 \times 100}{25 \times 20}$

F. *Separation of clay:* Withdraw 25 ml of the suspension after the settling time for clay from Table 3 and calculate percentage of clay as in the case of silt+clay.

G. *Separation of fine sand:* Decant away the supernatant liquid. Transfer the sediment to a 400 ml beaker and add water to a height of 10 cm above the base. Stir well and allow standing for the requisite period taken from the silt+clay column in the Table 3 against the observed temperature. Siphon off the turbid suspension and fill the beaker again to the mark with water and repeat this process until the liquid is no longer turbid at the end of the specified period. Collect the fine sand in a beaker, dry it in oven at 105°C and weigh. Calculate the percentage of fine sand as follows:

Mass of beaker $= W_1$ g

Mass of beaker + fine sand $= W_2$ g

Mass of fine sand $= (W_2 - W_1)$

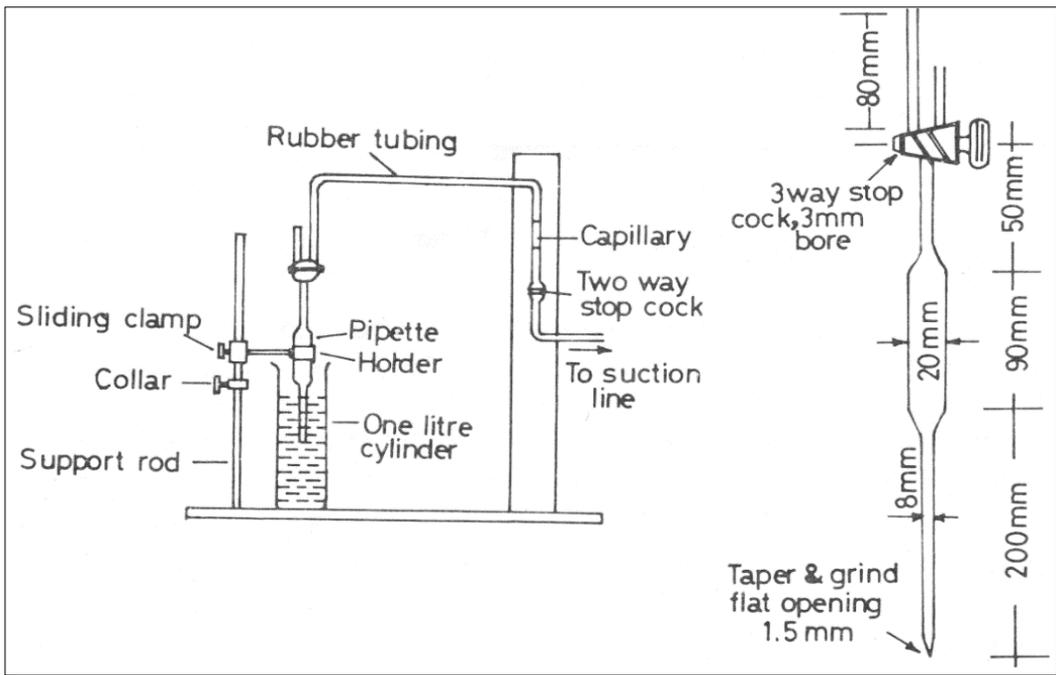Percentage of fine sand $= \dfrac{(W_2 - W_1) \times 100}{20}$

Fig. 9.3: Schematic diagram of sampling apparatus with special mechanical analysis pipette (Phogat *et al*. 1999; Laboratory manual for soil physical analysis, Department of Soil Science, CCSHAU, Hisar).

H. *Moisture determination:* Determine the soil moisture content by gravimetric method as described in exercise VI.

I. *Determination of loss on ignition;* Once the moisture has been determined, transfer the beaker containing oven dry soil to a furnace and raise the temperature to ignite the sample at a bright red heat for 30-40 minutes. Take out the sample, cool in a desiccator and take its weight. The further loss in weight is equal to the loss on ignition. Calculate the percentage loss of the air or oven dry soil.

J. *Determination of loss on solution:* The loss on solution means the loss due to the decomposition of $CaCO_3$ and oxidation of organic matter. It can be studied and determined in some higher courses in Soil Science.

Expression of results: Report the percentage of coarse sand, fine sand, silt and clay content in the given soil sample and determine its textural class.

Table 3. Sedimentation times for particles of silt and clay in water for the 10 cm depth

Temperature (°C)	Sedimentation time			
	Clay (<0.002 mm)		Silt + clay (< 0.02 mm)	
	Hrs	Min	Min	Sec
8	11	00	6	40
9	10	40	6	30
10	10	25	6	20
11	10	10	6	10
12	9	50	6	00
13	9	35	5	50
14	9	20	5	40
15	9	05	5	30
16	8	50	5	20
17	8	35	5	10
18	8	25	5	00
19	8	10	4	50
20	8	00	4	45
21	7	50	4	40
22	7	40	4	35
23	7	25	4	30
24	7	15	4	20
25	7	05	4	15
26	6	55	4	10
27	6	45	4	05
28	6	40	4	00
29	6	30	3	55
30	6	20	3	50
31	6	15	3	45
32	6	00	3	40
33	5	55	3	35

Textural triangle and its use:

A procedure for using the textural triangle (Fig. 9.4) to determine the textural class of a soil which contains 50 per cent clay, 20 per cent silt and 30 per cent sand is as follows:

i) Take the per cent clay (50) on the left side or clay side and draw a line parallel to the bottom or sand side of the triangle.

ii) Take the per cent silt (20) on the right side or silt side and draw a line parallel to the left side or clay side of the triangle.

iii) The area in which intersection of two lines occurs, gives the textural class or texture of the soil. In this case, it is clay.

iv) As a check, take the per cent sand (30) and draw a line parallel to the right side of the triangle.

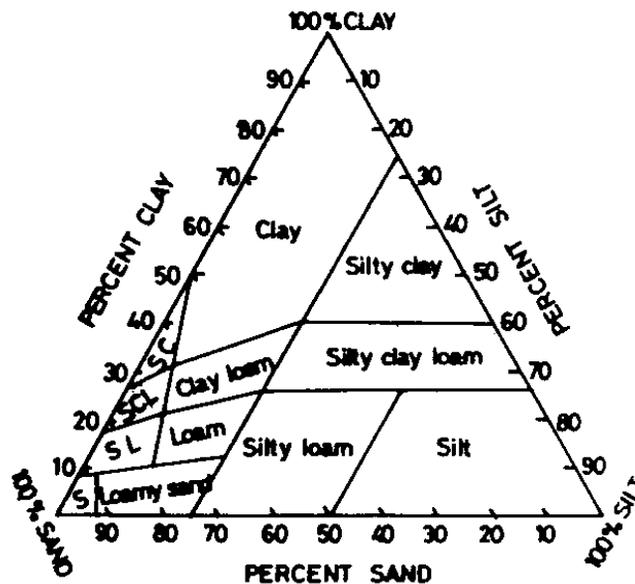v) If all the three lines intersect at the same point, the class name has been determined correctly.

Fig. 9.4: Triangular textural diagram based on ISSS/IUSS fractions with effective diameters of 0.002, 0.02 and 2 mm for the upper limits of clay, silt and sand fraction, respectively. (S = Sand; SL=Sandy loam; SCL = Sandy clay loam; SC = Sandy clay).

●●●●●

Exercise-X

CAPILLARY RISE PHENOMENON OF WATER IN SOIL COLUMN

In soils, capillarity is one of the important phenomena of surface tension. It is rise of water into openings of the approximate diameter of a hair. When a water table is present in soil, water rises due to capillary action. The length of soil to which water rises due to capillarity is called *capillary fringe*. Due to capillarity the dissolved salts in soil water move upwards and causing salinity in the surface soil layers. The depth to which water table be lowered during reclamation of soil essentially require knowledge of capillary rise phenomena in soil. It also helps to meet a part of water requirement of crops grown under shallow water table conditions and maintaining favorable air-water regime for crop growth.

Principle: Due to surface tension and adhesion properties of water, the water rises in a glass capillary tube when it is dipped in water. The adhesion between water molecules and the glass surface tends to make the water move upward and surface of water in the capillary is concave but the surface tension tends to flatten in order to decrease the surface area. This results in the rise of water in the capillary. Thus, surface tension is the upward force supporting the column of water and the weight of water column acts as a force tends to pull it down. At equilibrium, the force tending to move the liquid downward must be equal and opposite of the force tending to move the liquid upward. Thus

Downward force $= \dfrac{\pi d^2}{4}\rho h g$ (1)

Upward force $= \pi d \sigma \cos \alpha$ (2)

where d = diameter of capillary (cm)

     ρ = density of water (g cm^{-3})

     h = height to which water rises in the capillary (cm)

     g = acceleration due to gravity (cm s^{-2})

     σ = surface tension (dynes cm^{-1})

     α = contact angle between glass/soil and water

Solving for h,

$$h = \dfrac{4\sigma \cos \alpha}{\rho g d}$$ (3)

For water, the contact angle is so small that cos α is practically equal to one, therefore equation (3) becomes $h = \dfrac{4\sigma}{\rho g d}$ (4)

Assuming σ = 72.75 dyne cm^{-1}, ρ = 0.998 g cm^{-3} and g = 981 erg g^{-1} cm^{-1} for water at 20ºC.

$$h = \frac{0.297}{d} \text{ or } \frac{0.3}{d} \qquad\qquad (5)$$

This equation emphasizes the inverse relation between height of rise and size of the tube through which the water rises.

Equation 5 serves to calculate the height to which water will rise in a soil for which the size of the largest effective pore space is known, and also useful for calculate the pore size distribution of a soil.

Apparatus: Glass tubes of 1-2 cm in diameter and 70-80 cm long, paper strips graduated in centimeters to be pasted over the tube, tray of water, stands to hold the tubes, spoon, rubber hammer, muslin cloth and string.

Procedure: Take dry sample (2 mm sieved) of two texturally different (coarse and fine) soils. Place two folds of cheese cloth on one end of each glass tube and tie it firmly with the string. Carefully pack the two soils in two tubes separately spoon by spoon and gently tapping the sides of the tubes by the rubber hammer. Take two more tubes, fill the lower half of one tube with one soil and top with the other soil and fill the second tube by reversing the order of soils. Make sure that there is an abrupt boundary between the fine and coarse textured soils where two soils are filled in one tube. After placing a small piece of filter paper at the top of tubes and keep all the tubes at the same time in water. Observe the capillary rise phenomena and note down the height of water risen in the tubes after 10, 30 and 60 minutes, 3 hrs, 1, 2 and 5 days.

Observations and calculations: Record the results as:

Sr. No.	Observation time & date	Cumulative time (h)	Cumulative height of water rise (cm)			
			I	II	III	IV
1						
2						
3						
4						
5						
6						
7						

Plot the height of water rise versus time for each glass tube and calculate the minimum pore radii from the height of water rise in column of homogeneous and layered soils.

●●●●●

Exercise-XI

SOIL REACTION AND ELECTRICAL CONDUCTIVITY OF SOIL

Soil reaction (pH)

The soil reaction refers to acidity, neutrality or alkalinity of a soil and is expressed as pH of the soil. The pH is defined as the negative logarithm of H^+ activity of the soil-water system. The H^+ activity in a very dilute solution can be expressed as concentration in gram per litre. Thus, $pH = -\log_{10}[H^+]$

Principle: It is based on the measurement of electric potential developed across a glass electrode on account of the difference in activity of H^+ ions in and out of electrode in a saturated paste or a supernatant liquid that is in equilibrium with a soil suspension of a 1:2 soil to liquid mixture. The liquid is either water or an electrolyte (0.1M $CaCl_2$).

Equipment & apparatus: Glass electrode pH meter, balance, beakers, cylinder, spatula, glass rod.

Reagents: 0.1M $CaCl_2$ solution (1.47 g of $CaCl_2.2H_2O$ (AR grade) is dissolved in one litre of distilled water) and standard buffer solution (commercially available buffer tablets of pH 4.0, 7.0 and 9.2 are dissolved in freshly prepared double distilled water and final volume of 100 ml is made). It is necessary to prepare fresh buffer after every 4-5 days.

A. pH of saturated soil paste: Take 200 g of soil sample in a 500 ml beaker for making paste. Add small amount of distilled water to the soil while beating with a spatula, time and again till soil paste glitters and flows slightly without sticking to spatula or when the container is tilted. Allow the paste to equilibrate for about an hour. In no case, free water should appear on the soil surface nor should the paste stiffen or lose its glistening characteristics on standing. Switch on the pH meter; set the temperature knob. Calibrate the pH meter with at least two buffers i.e. for acidic, alkaline or neutral pH range. Carefully insert the combined electrode in the paste and measure the pH. Keep on moving the electrode a little for ensuring removal of water film around it and read the pH when a constant value is obtained.

B. pH in 1:2 soil-water suspension: Transfer 20 g of soil in a 100 ml beaker and add 40 ml of distilled water. Stir the suspension with glass rod intermittently for 30 minutes. Stir just before immersing the electrodes again and read the pH.

To determine pH in 0.1M $CaCl_2$, use 40 ml of 0.1M $CaCl_2$ solution instead of distilled water. Stir at regular intervals for one hour and take the reading.

Precautions: It is necessary to wash the electrodes with a jet of distilled water and make it dry gently with filter/ tissue paper before each measurement. The electrodes when not in use should be immersed in distilled water to avoid drying.

Interpretation of results: If pH is < 6.5 then soil reaction is acidic, 6.5-7.5 normal, >7.5 alkaline and > 8.5 alkali.

Electrical conductivity (EC)

Total soluble salts are estimated from electrical conductivity of aqueous soil extract. The extract is obtained from saturated paste or 1:2 soil to water mixture by vacuum filtration.

Principle: Electrolytes due to movement of ions, like metals due to movement of electrons, allow the electric current to pass through them, therefore, electrical conductivity (EC) of soil-water system increases with increasing content of soluble salts in the soil. Thus, the measurements of EC give the concentration of soluble salts in the soil at any particular temperature. The reverse of resistance is conductance.

Equipment and apparatus: Conductivity meter, balance, beakers, measuring cylinder, glass rod.

Reagents: 0.01N KCl solution (dissolve 0.7456 g of AR grade KCl (dried at 60 ^{o}C) in distilled water and make volume 1 litre. The electrical conductivity of this solution is 1.413 dS m^{-1} or mmhos cm^{-1} at 25°C.

Procedure: Take 20 g of soil in a 100 ml beaker and add 40 ml of distilled water. Stir the suspension intermittently for 30 minutes. Allow the suspension to stand until clear supernatant liquid is obtained. Standardize the conductivity or cell with standard KCl solution and establish the cell constant.

$$\text{Cell constant} = \frac{1.413 \text{ dS } m^{-1}}{\text{Observed conductivity of KCl solution}}$$

Measure the conductivity of the clear supernatant liquid with the help of Conductivity cell. Adjust the measurement of EC (mmhos cm^{-1} or dS m^{-1}) for the known temperature (25°C) of the solution by setting the temperature knob of the conductivity meter or applying temperature correction factor. Similarly, the conductivity of the saturation paste (EC$_e$) can be determined.

Calculations: EC (dS m^{-1}) = Observed value of EC $\times$ cell constant $\times$ temperature factor to express result at 25°C.

Total soluble salt (ppm) = EC (mmhos cm^{-1}) $\times$ 640

$$\text{Percentage of total soluble salts} = \frac{\text{Total soluble salts (ppm)}}{10000}$$

Interpretation of results: If EC$_e$ < 4 dS m^{-1}, soil in non-saline and if EC$_e$ > 4 dS m^{-1}, the soil is saline.
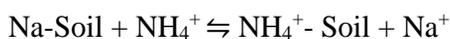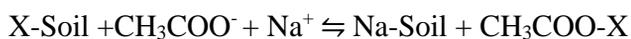
●●●●●

Exercise-XII

CATION EXCHANGE CAPACITY OF SOIL

The humus and clay fractions of soil are made up of very small particles, therefore, have a large surface area per unit mass. These colloidal particles have negatively charged sites on their surfaces which adsorb and hold positively charged ions (cations) by electrostatic force. Such adsorbed cations are held tightly enough by the soil to retard their loss from soil by leaching. They can, however, be replaced with or exchanged by other cations. This phenomenon is called *cation exchange* and defined as the phenomenon of attraction and retention by soil colloids of positive ions (cations) accompanied with the release of equivalent amount of other cations. The cations generally held on the colloidal particles are Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+ and H^+, and to a very small extent Mn^{2+}, Cu^{2+}, Zn^{2+} and Ba^{2+}. The capacity of a soil to hold exchangeable cations is called cation exchange capacity (CEC) and conventionally expressed in meq/100 g which is numerically equal to centimoles of positive charge per kilogram of soil (cmol(p+)/kg).

The CEC is an inherent soil characteristic influencing soil structure stability, nutrient availability and reaction to fertilizers and other ameliorants, and provides a buffer against soil acidification. Soils with a higher clay fraction tend to have a higher CEC while organic matter has a very high CEC. Sandy soils rely on the high CEC of organic matter for the retention of nutrients in the surface soil.

Principle: The soil is leached with sodium acetate solution (pH 8.2) for replacement of exchangeable cations by Na^+ ions. The excess of salt is washed down by alcohol and adsorbed Na^+ ions are replaced by NH_4^+, using neutral normal NH_4OAc solution. The Na^+ ions released from the exchanged sites are measured in NH_4OAc leachate with the help of flame photometer.

Reactions involved:

$CH_3COONa \rightleftharpoons CH_3COO^- + Na^+$

$X\text{-}Soil + CH_3COO^- + Na^+ \rightleftharpoons Na\text{-}Soil + CH_3COO\text{-}X$

$CH_3COONH_4 \rightleftharpoons CH_3COO^- + NH_4^+$

$Na\text{-}Soil + NH_4^+ \rightleftharpoons NH_4^+\text{-} Soil + Na^+$

where X represents exchangeable cations.

Equipment and apparatus: Centrifuge, centrifuge tubes, volumetric flask, funnels, flame photometer.

Reagents: 1N sodium acetate solution (dissolve 136 g of sodium acetate trihydrate in water and dilute to 1 litre and adjust pH to 8.2 by using dilute NaOH and acetic acid solution, 1N ammonium acetate solution (dilute 57 ml of glacial acetic acid and 68 ml of ammonium hydroxide to 800 ml of water, dilute to 1 litre and adjust to pH 7.0 by addition of more ammonium hydroxide or acetic acid). Alternatively, dissolve 77 g NH_4OAc in one litre distilled water and adjust pH to 7.0 by addition of more ammonium hydroxide or acetic acid, ethanol (95%), standard Na solution (dissolve 152 g of reagent grade NaCl in one litre of distilled water for making a stock solution of 60 ppm of Na. Transfer 2.5, 5, 10, 25, 50 and 75 ml of the stock solution in a series of 100 ml volumetric flask to obtain 1.5, 3, 6, 15, 30 and 45 ppm Na, respectively).

Procedure: Take the flame photometer readings for each of the working standards of Na after adjusting blank to zero and 100 at 60 ppm. Make a standard curve by plotting the readings against different concentrations of Na on ordinary graph paper.

Weigh 5 g of soil and transfer in a 50 ml centrifuge tube with stopper. Add 30 ml of sodium acetate solution and shake for 5 minutes. Centrifuge for about 5 minutes at about 8000 rpm until the supernatant liquid is clear. Decant and discard the liquid and repeat the shaking and centrifuging three times more with fresh sodium acetate solution. Shake the soil with 30 ml of 95% ethanol for 5 minutes, centrifuge and discard the supernatant. Repeat the ethanol washing three times to remove excessive amounts of sodium acetate. Finally extract the soil with three lots of 30 ml of NH_4OAc solution, centrifuging and decanting each washing into a 100 ml volumetric flask. Dilute the combined extracts with NH_4OAc to 100 ml. Determine Na concentration in the extract by using flame photometer.

Calculations:

Weight of soil taken = 5 g

Volume made after leaching of NH_4OAc = 100 ml

Concentration of Na in the leachate against reading from standard curve = X ppm

CEC [meq/100 g of soil or cmol (p^+) kg^{-1}] $= \dfrac{X}{23} \times 2$

Interpretation of results: The CEC (meq/100g) of < 10 is considered as low, 10-25 medium, 25-45 high and > 45 very high.

●●●●●

SOIL MAP

The base materials used for mapping the soils include cadastral map, topographical map, geographical map, aerial photograph and satellite imagery.

Cadastral maps are basically on large scale i.e.16″ or 8″ to a mile. For hilly area these maps may be on scale of 32″ to a mile. These maps consisted of field boundaries along with numbers. The details regarding ownership and land use are obtained from the *Khasra* and *Khatoni* records maintained by *Patwari*.

Topographical maps: A topographical map is on such a sufficiently large scale that representation of individual features shown on the map can be identified on the ground by their shape and position. Maps on scale 1:250,000 and larger are classified as topographical maps.

Geographical maps: A geographical map is on such a small scale that representation of individual features for identification on the ground is not possible. These maps intended to give a picture of the country as a whole. The maps on scales smaller than 1:250,000 are termed as geographical maps.

The Survey of India (SOI) is the national survey and mapping organisation of the country and publishes both topographical and geographical maps on different scales.

The techniques of identifying and delineating the boundary of soil type on maps are called *soil surveying*. Soil survey is essentially the study and mapping of soil in natural environment. The soil classification systems are developed on the basis of systematic study of soils at different places.

Different types of soils occur on the Earth differing in colour, texture, structure and other profile characteristics such as horizon differentiation, depth, clay and organic carbon contents, and wetness. Such differences in soil characteristics are noticed not only from state to state or region to region but also from one part of a field to another. Soil survey intends to study and record the important soil characteristics in the field, analyse the soil sample in laboratory, classify them into well defined Taxonomic units and locate their extent and boundaries on a map. A survey report, therefore, mainly consisted of two parts (i) a map showing location and (ii) written report showing soil type, geology, agriculture, climate and information about soil physical and chemical properties, genesis, productivity and profile description of the location, etc. In Taxonomy, soils are classified into well defined categories indicating different levels

of classification. The higher categories are order, suborder and great group which provide general understanding of the soils over large areas. The lower categories are subgroup families, series, types and phases which recognize the local differences and are considered important in assessing productive capacities of soils for their utilization purposes. The soils of Haryana State fall mainly under 4 orders- Entisols, Inceptisols, Aridisols and Alfisols on the bases of presence or absence of major diagnostic horizons and in about 13 sub-orders based on presence or absence of properties related to wetness, climate, parent material and vegetation. The information given in soil survey report and soil maps helps in:

i)   Predicting the behavior of soils for use under agriculture, forestry, irrigation engineering, urban development, recreation, etc.

ii) Transfer of technology by correlating the characteristics of soils and predicting their adaptability to various uses and productivity under defined set of management practices.

iii) Providing information for developing optimum land use plans, bringing new areas under irrigation and/or drainage network and evaluating suitability of soils for irrigation and agriculture crops.

iv) Delineating the degraded soils (saline, sodic, waterlogged or flood prone).

v)   Land settlement rehabilitation, tax assessment, designing highways, airports and other engineering structures, etc.

The following data sheet is used for the exercise.

Data sheet

Soil type	Area (ha)	Main crops grown	Management practices in use

For most common soil type, profile descriptions with dominating soil properties are to be recorded.
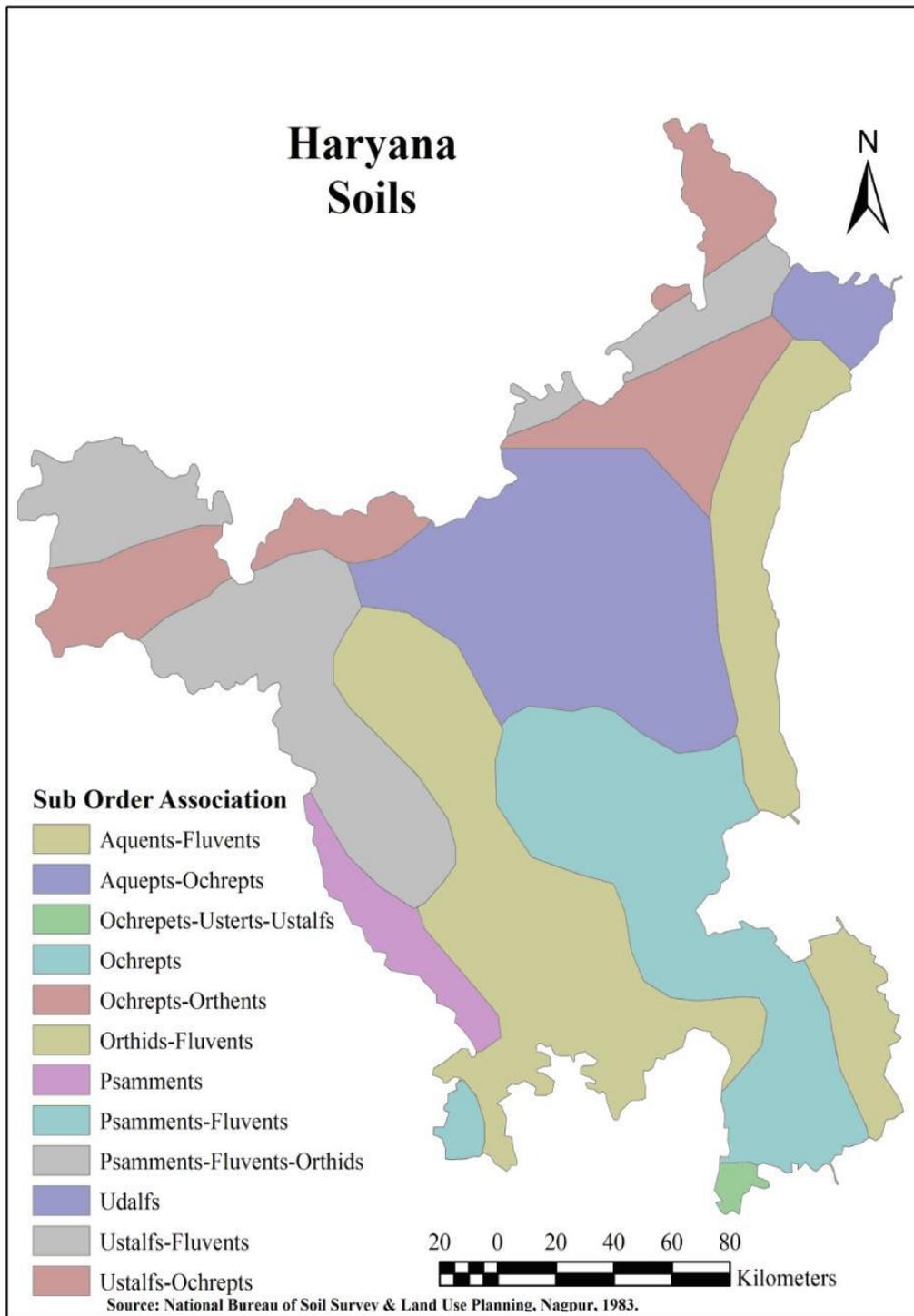
Fig. 13.1: Soil map of Haryana (ICAR-NBSS & LUP, Nagpur, 1983)

47

Description of soils of Haryana classified in different taxonomic sub-order associations

Sub-order	Descriptions
Ustalfs-Ochrepts (9) and Ustalfs-Fluvents (10)	Soils are mainly red, loam to sandy loam covering some parts of Ambala, Kurukshetra, Kaithal, Fatehabad and Sirsa districts.
Udalfs (20)	Soils are loam to sandy loam, rich in organic matter occurring mostly in the north-eastern part of Yamunanagar district.
Orthids-Fluvents (32)	Soils of the arid region with sandy loam texture. Reddish brown to dark brown covering Hisar, Bhiwani, Rohtak, Jhajjar, Rewari, Mahendragarh and Gurugram districts.
Psamments (35), Psamments-Fluvents (36), Pasamments – Fluvents Orthids (37)	Soils are mainly sandy. Sub-order (36) spreads in the western parts of Bhiwani and Mahendragarh districts, and a small area of Sirsa and (37) in the northern and-south-eastern parts of Sirsa, Fatehabad and Hisar, and north-western part of Bhiwani district.
Aquepts Orchepts (64)	Soils are shallow, black and brown with poor drainage occuring in eastern part of Hisar and Fatehabad, and almost entire Jind, northern Sonepat, western Karnal, western Panipat and south-western Kaithal districts.
Orchrepts, Ochrepts–(70), Orthents (72), Ochrepts-Psamments (73) and Ocherepts-Ustalfs (78).	Soils spread over parts of Panchkula, Ambala, Sonepat, Jind, Hisar, Bhiwani, Rohtak, Jhajjar, Rewari, Gurugram and Faridabad districts.

Note: The numbers in parentheses represent sub-order association for ease in identification of the association on the soil map.

The traditional nomenclatures of the soils of the State along with the description of soils of the major Taxonomic sub-order associations are:

Sub-order	Description
Ustalfs	High base status red loamy, red sandy and alluvial soils
Ochrepts	Shallow black, brown and alluvial soils of the northern region
Fluvents	Alluvial soils (recent alluvium)
Udalfs	High base status soils of humid regions
Orthids	Soils of arid region with some development
Aquents	Recently formed hydro orphic alluvial soil
Orthents	Recently formed soil
Usterts	Deep black soil

●●●●●

SOIL COLOUR

The soil colour depends on the wave length of light (380-750 nm) that is reflected by soil to the eyes. Soil colour is important in soil classification, interpretation and description of soil profiles. Though it has little influence on the behavior of soils but provides information regarding soil conditions and some properties of soils.
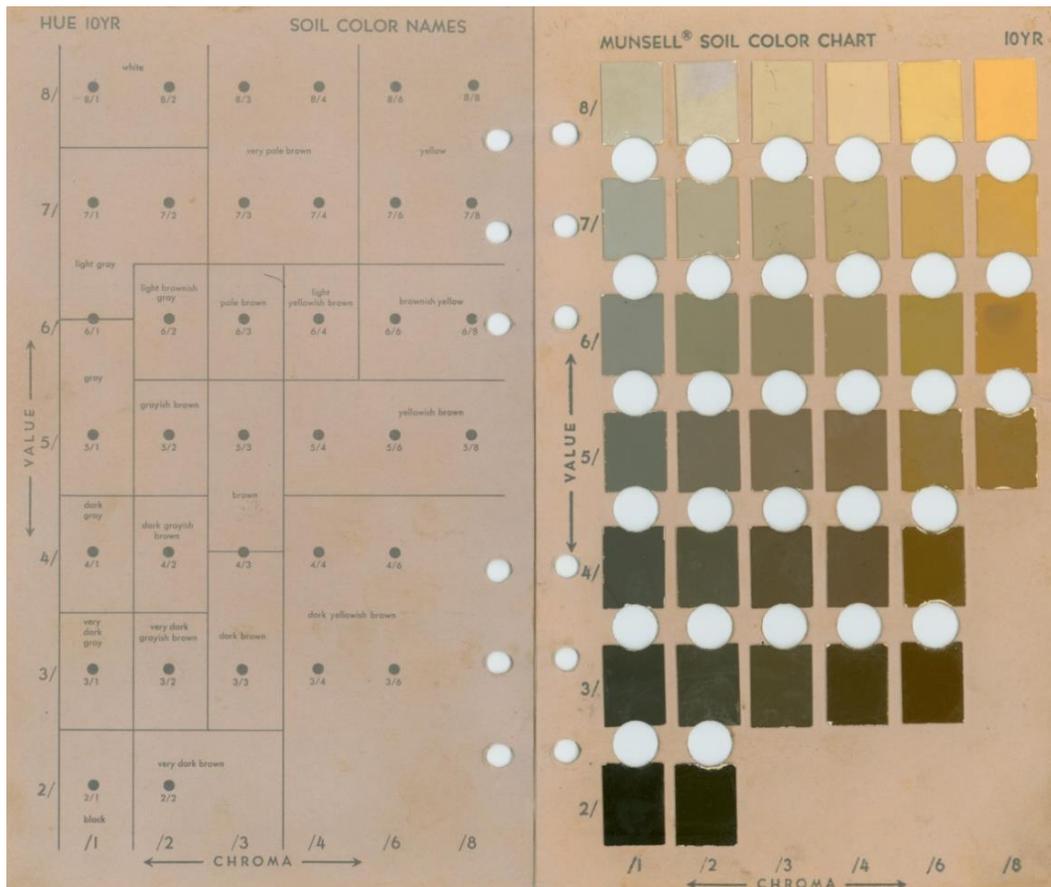

Fig. 14.1: Munsell soil colour chart (www.munsell.com)

Determination of soil colour: A standard system or method for description of soil colour involves *Munsell soil colour chart* (Fig. 14.1). In soil colour chart, a small piece of moist soil is compared to the standard colour chips. Each colour chip is described by three components- *hue, value and chroma*. The *hue* is the dominant spectral colour and refers usually to redness or yellowness of soil. The *value* refers to the relative lightness or darkness of colour, a value of 0 being black. The *chroma* is the relative intensity or

brightness of the dominant colour, a *chroma* of 0 being neutral 'grey' as shown in Fig 14.1.

The Munsell colour notations are systematic numerical and letter designations of each of these three parameters. For example, the 10YR5/1 means a *hue* of 10 YR, value 5 and *chroma* 1. The equivalent colour is 'grey'.

Soils may have a wide range of colours- black, brown, red, yellow, white and even green. Soil colours may vary from place to place in the landscape, even adjacent soils may have different colours e.g., black and red soils existing side by side in Andhra Pradesh. The colour in a soil profile may change with depth through the different horizons. The horizons may have colours of same *hue* but of different *chroma* and *value*.

Factors influencing soil colour: Mineralogy and chemical constituents of soil particles, organic matter content and soil moisture influence the soil colour. Red, yellow or brown colours are mostly related to the extent of oxidation, hydration and diffusion of iron oxides in the soils which form coatings on the soil particles. Therefore, the presence of goethite, hematite and magnetite tends to provide yellow, red and brown colours, respectively, to the soil. Organic matter tends to make the soil dark brown to black. As a consequence, soil horizons high in organic matter are darker in colour than those of low in organic matter. Similarly, moist soils are generally darker than dry soils. Water content of a soil also indirectly affects the soil colour through its influence on oxygen content of soil air. The oxygen determines the oxidation states of several elements, especially, of iron in its oxide forms. Minerals like manganese oxides and glauconite impart black and green colour, respectively to soils. Carbonates, such as calcite accumulating in soils of semi-arid regions impart a white colour to soil. Under prolonged anaerobic conditions, the coatings of the reduced iron oxide on soil particles change the soil colour to grey or bluish.

●●●●●

HEAT TRANSFER IN SOIL

Soil temperature regulates evaporation, aeration and chemical reactions taking place in the soil and considered as an important soil physical property. It also strongly influences biological process such as seed germination, seedling emergence and growth, root development and microbial activities. Temperature is a measure of heat energy in *calorie* or *joule*. The S.I. unit of temperature is Kelvin (K) but it is often convenient to use degree Celsius (ºC) or degree Fahrenheit (ºF). Calorie is defined as the amount of heat required to raise the temperature of one gram of pure water by 1ºC. The primary source of heat in soil is the solar radiation. Approximate soil temperature (°C) ranges required for some of the crops for their optimum growth and yield are given in Table 1.

Table 1. Estimated soil temperature (°C) ranges for optimum, growth and survival of some the crops

Range	Maize	Rice	Sorghum	Wheat
Optimum	25-35	25-30	20-30	15-27
Growth	10-39	15-38	15-35	5-35
Survival	0-43	12-42	7-37	0-40

The soil temperature is influenced by the thermal properties of soil such as specific heat capacity, thermal conductivity, thermal diffusivity, heat flux (movement) in soil, and heat exchange between soil and atmosphere.

Specific heat capacity: It is defined as 'the quantity of heat required to raise the temperature of one gram of the substance through $1\,^{\circ}C$'. In other words, it is heat capacity per unit mass of the substance. It is expressed as cal $^{\circ}C^{-1}$ g^{-1}. Specific heat capacity of water is 1 cal$^{\circ}C^{-1}g^{-1}$. Specific heat of many soil forming minerals is nearly 0.2 cal$^{\circ}C^{-1}g^{-1}$. Practically, all substances have specific heat capacities smaller than that of water. The specific heat of a soil increases with increase in moisture content.

Thermal conductivity: Thermal conductivity is defined as the quantity of heat transmitted through a unit length of a substance per unit cross-sectional area per unit temperature gradient per unit time. It is expressed in cal-cm^{-1}s^{-1}$^{\circ}C^{-1}$. Heat flows from higher temperature to lower temperature i.e. in the direction of decreasing soil temperature. Thermal conductivity depends upon moisture content, mineralogical composition, texture, structure, organic matter and level of compaction of soil.

Thermal conductivity of soils follows the order: sand > loam > clay. It increases with increase in moisture content of soil up to a certain limit beyond which it decreases. Thermal conductivity increases with compaction of the soil due to increased contact between soil particles. Thermal conductivity is low in soils with high organic matter as organic matter increases porosity and reduces the contact between soil particles.

Thermal diffusivity: Thermal diffusivity is defined as the ratio of thermal conductivity to volumetric heat capacity. It measures the rate of change of temperature with time. The temperature changes within soil are dependent on diffusivity rather than conductivity alone.

Measurement of soil temperature: The soil temperature is measured by different methods i.e., contact and non-contact types. The soil temperature measurements are based on changes in thermometric properties of the measuring system in equilibrium with the soil. The examples of contact type thermometers are bimetallic strip thermometer based on expansion of solid, mercury thermometer based on expansion of liquid, constant pressure or volume thermometer based on expansion of gas, and thermistors and thermocouple thermometer based on changes in electrical properties of material with change in temperature. The non-contact type thermometer measures temperature from thermal radiation emitted by the object such as optical pyrometers, infrared thermometers and total intensity radiometers. Most commonly used thermometers for measuring soil temperature are mercury thermometers, thermistors and thermocouple thermometers.

Heat transfer in soil: Heat flows in any material by conduction (through contact), convection (through air currents) and radiation (without any medium). In soil, the flow of heat is mainly through conduction while convection and radiation are of least importance.

The heat flow through conduction is described by Fourier's law. According to this law, the heat flux in a block of soil (Fig. 15.1) is directly proportional to the temperature difference $(T_1 - T_2)$ between hot and cool ends of the block and inversely proportional to its thickness $(x_1 - x_2)$. The proportionality constant is thermal conductivity, k.

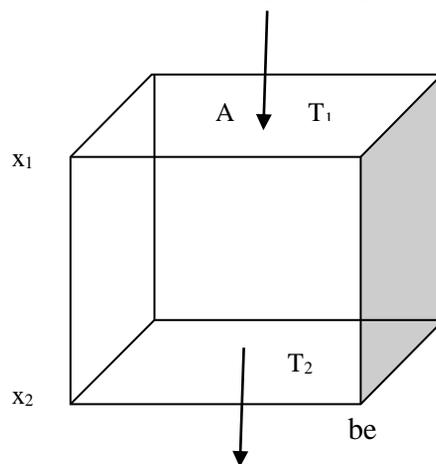The Fourier's law in the differential form may written as:

Fig. 15.1: A block of soil for illustration of heat flux

$$J_q = -k \frac{(T_1 - T_2)}{(x_1 - x_2)} = -k \frac{\Delta T}{x}$$

where J_q is heat flux (J m^{-2} sec^{-1}) i.e. quantity of heat, Q transferred across a unit cross-sectional area, A (m^2) of soil in a unit time, t (s) and $\frac{\Delta T}{x}$ is the temperature gradient over distance x (°C m^{-1}). The negative sign indicates that flux and gradients are in opposite direction. A major factor influencing the heat conduction in soil is its moisture content. A dry and loose soil is a poor conductor of heat than a wet and compacted soil.

The heat transfer may thus be studied by observing temperature of soil at two points of known distance between them at two different times.

●●●●●

Exercise-XVI

ORGANIC MATTER CONTENT OF SOIL

Organic matter largely influences all the physical, chemical and biological properties of the soil. It enhances aggregation, water holding capacity, cation exchange capacity, availability of nutrients microbial population and diversity. The organic matter of soil is composed of about 58 % of soil organic carbon. The organic carbon content of soil may be estimated by wet digestion and colorimetric methods. Wet digestion method is largely in use, therefore, discussed here.

Principle: The organic carbon in organic matter is oxidized by known but excess of chromic acid ($K_2Cr_2O_7$ + H_2SO_4). The excess chromic acid not reduced by organic matter is determined by back titration with standard reducing agent ferrous ammonium sulphate solution in the presence of sodium fluoride or phosphoric acid using diphenylamine as indicator.

Reactions involved

i) The oxidation of carbon

$K_2Cr_2O_7 + 4H_2SO_4 \rightarrow K_2SO_4 + Cr_2(SO_4)_3 + 4H_2O + 3O^{-2} \quad \times 2$

$3C + 6O^{-2} \rightarrow 3CO_2$

$2K_2Cr_2O_7 + 8H_2SO_4 + 3C \rightarrow 2K_2SO_4 + 2Cr_2(SO_4)_3 + 8H_2O + 3CO_2$
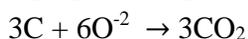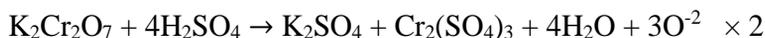
ii) Reactions involved during titration

$FeSO_4(NH_4)_2SO_4.6H_2O \rightarrow FeSO_4 + (NH_4)_2SO_4 + 6H_2O \quad \times 2$

$2FeSO_4 + H_2SO_4 + O^- \rightarrow Fe_2(SO_4)_3 + H_2O$

$2FeSO_4(NH_4)_2SO_4.12 H_2O + H_2SO_4 + O^- \rightarrow 2(NH_4)_2SO_4 + Fe_2(SO_4)_3 + 13 H_2O$

Equipment and apparatus: Conical flask, pipette, burette, measuring cylinder, balance

Reagents: 1N Potassium dichromate (49.04 g of AR grade of $K_2Cr_2O_7$ is dissolved in distilled water and final volume of one litre is made), concentrated H_2SO_4, 0.5N ferrous ammonium sulphate (Mohr's salt) (dissolve 196.1 g of AR grade $FeSO_4(NH_4)_2SO_4.6H_2O$ in about 400 ml of distilled water. Add 15 ml of concentrated H_2SO_4 and dilute to 1 liter with distilled water), sodium fluoride (NaF) and /or phosphoric acid (H_3PO_4) (85%) and diphenylamine indicator (dissolve 0.5 g of diphenylamine in a mixture of 100 ml of concentrated H_2SO_4 and 20 ml of distilled water and stored in a coloured bottle).

Procedure: Transfer 1 g soil (0.5 mm sieved) in a 500 ml conical flask. Add 10 ml of 1N $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4. Mix the contents of the flask thoroughly and keep it on asbestos sheet for about 30 minutes for reaction to proceed. Add 200 ml of

distilled water to the flask to dilute the suspension. Add 10 ml of phosphoric acid or 0.5 g of NaF and 1 ml of diphenylamine indicator solution. A deep violet color will appear. Titrate the excess of potassium dichromate against 0.5N ferrous ammonium sulphate solution until the violet color changes to purple and finally to green. Note the volume of the ferrous ammonium sulphate used in the titration. Run a blank titration side by side without soil.

Calculations:

i)   Weight of soil taken = W g

ii) Volume of 0.5N $FeSO_4$ $(NH_4)_2SO_4.6H_2O$ required for reducing 10 ml of $K_2C_2O_7$ solution (blank reading) = X ml

iii) Volume of 0.5N $FeSO_4(NH_4)_2SO_4.6H_2O$ required for reducing the excess of $K_2C_2O_7$ (sample reading) = Y ml

     Difference = (X-Y) ml

iv) 1 ml of 1N $K_2Cr_2O_7$ (1 meq.) $= \frac{12}{4} = 3$ mg of C, or $= 0.003$ g of C

     Organic carbon (%) in soil $= \frac{(X-Y) \times 0.003 \times 100}{2 \times W} = Z$

v)   There is incomplete oxidation of organic matter in this procedure. The organic carbon is multiplied by 1.3 on the assumption that there is a recovery of 77%, therefore, organic carbon (%) in soil $= Z \times 1.3 = R$

vi) Assuming that organic matter contains 58% of carbon, therefore, the organic matter content in the soil may be calculated as:

     Organic matter (%) in soil $= \frac{R \times 100}{58}$, or $R \times 1.724$

Precautions:

- Don't use an iron or steel mortar to grind the soil samples, especially coarse textured one, as ferrous ions result in positive error in the estimation.
- Ferrous ammonium sulphate should be standardized daily because of slow oxidation of Fe^{2+} to Fe^{3+}.
- For quality control, a minimum of one reference sample should be analyzed per batch of 20-25 samples.
- High chloride content (saline soils) interferes in the estimation of carbon which can be prevented by adding Ag_2SO_4 at the rate of 1.25% to the concentrated H_2SO_4.

Rating of soil organic carbon: < 0.4% - low; 0.40-0.75% - medium and > 0.75 high content of organic carbon.
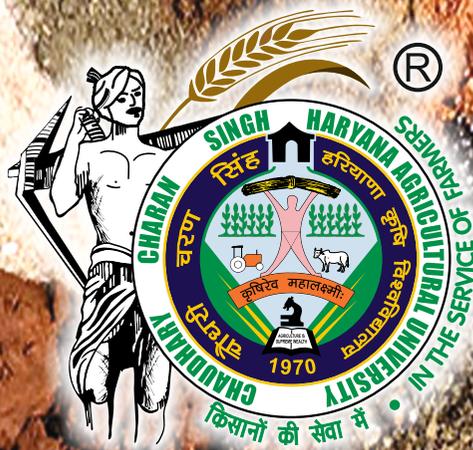
●●●●●

COURSE MANUAL

Problematic Soils
and
Their Management

V. K. PHOGAT
(Emeritus Professor)

HARDEEP SINGH SHEORAN
(Assistant Professor)

ROOHI
(Assistant Scientist)

Problematic Soils
and
Their Management

V. K. PHOGAT
(Emeritus Professor)

HARDEEP SINGH SHEORAN
(Assistant Professor)

ROOHI
(Assistant Scientist)

DEPARTMENT OF SOIL SCIENCE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR– 125004

2020

FOREWORD

Sustaining soil productivity is essential for increasing agricultural productivity to fulfil the demands of growing human and livestock populations. There is growing realisation that intensive agriculture and mismanagement of soil and water resources are resulting in deterioration of soil quality and degradation of the environment. The scientific planning for enhancing soil productivity needs a systematic understanding of the origin, factors, mechanisms and processes involved in the degradation of the land resources which help determining their capability and suitability for getting maximum production under a given set of management strategies and climatic conditions. The information regarding the physical, chemical and biological characteristics of soil plays an important role in identifying specific soil constraint(s) limiting agricultural production and in turn deciding the appropriate management practices need to be adopted for enhancing the production potential of the problematic soils.

The course curriculum for B.Sc. (Hons.) Agriculture has been revised as per the recommendation of 5th Deans' Committee of ICAR for under–graduate programme. Keeping this in view, a greater emphasis has been given on the understanding of the nature of the problematic soils for their amelioration through different management practices. In addition, outbreak of COVID–19 pandemic all over the world in the year 2020 also necessitates developing a self–explanatory course on manual on problematic soils for the undergraduate students.

I appreciate the sincere efforts made by Dr. V.K. Phogat, Emeritus Professor, Dr. Hardeep Singh Sheoran (Assistant Professor) and Dr. Roohi (Assistant Scientist), Department of Soil Science for preparation of this excellent manual entitled, "Course manual problematic soils and their management" which would be of immense use to the students, teachers and researchers in Soil Science and allied disciplines.

DR. S. K. SEHRAWAT
Dean, College of Agriculture, Hisar
CCSHAU, Hisar

PREFACE

The agricultural production primarily depends upon the soil quality. There are evidences that intensive agriculture has resulted in the degradation of the land and water resources and created problems in their optimum utilization without having specific management strategy. Looking at the importance of improving the degraded lands, ICAR has introduced a course on 'Problematic soil and their management' at undergraduate level in all the State Agricultural Universities and agricultural colleges of the country. Increasing productivity of the problematic soils requires proper understanding of the causes responsible for their degradation. The aim of the course manual is to inculcate among the under–graduate students, the precise understanding of the characteristics of problematic soils, reclamation procedures and their capability and suitability for different uses for getting maximum profits.

The manual contains 9 chapters. First chapter describes soil quality and health. Soil erosion– types, effects, mechanisms and control measures are discussed in detail in Chapter II. Waste lands and problematic soils– their distribution, categorisation, origin, basic concepts of problem soils and their reclamation and management are explained in chapter III. Chapter IV deals with topic on soil pollution– pesticides and inorganic contaminants, and prevention and mitigation of soil pollution while the subject of irrigation water– quality and standards, and use of saline water in agriculture is discussed in Chapter V. Remote sensing and GIS in diagnosis and management of problem soils has been explained in Chapter VI and multipurpose tree species (MTPs) and bio–remediation through MPTs of soils in Chapter VII. Land capability and suitability classifications have been describes in detail in Chapter VIII and finally the saline soils under different agro–ecosystems are presented in Chapter IX. Each chapter is explained in a simple and lucid language with suitable illustrations and tables for better understanding of the subject matter.

V. K. PHOGAT | H. S. SHEORAN | ROOHI

CONTENTS

Chapter-I

SOIL QUALITY AND SOIL HEALTH

Soil is the essence of life on the planet Earth. With increase in soil degradation, industrialization and urbanization, the area under cultivation is shrinking, and due to increasing population, the per capita arable land is decreasing. Thus, the security and safety of food for present and future generations depends on soil quality and its resilience under intensive agricultural use. Therefore, our interest must be on assessing the quality of the soil resources for quality food production and also for maintaining the environmental quality.

There are several definitions of soil quality. The Soil Science Society of America (SSSA, 1995) defines soil quality as the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance soil and water quality, and support human health and habitation. Maintaining high soil quality under different agricultural systems ensures sustained and productive growth of crops with minimal impacts on the environment.

Soil quality has two parts: an intrinsic and dynamic. An intrinsic part covers soil's inherent capacity for crop growth and dynamic part is influenced by the soil use. Attributes of inherent soil quality are usually static. Soil texture, mineralogy and cation exchange capacity are commonly included as properties of inherent soil quality for productivity. It is generally observed that soils having poor inherent qualities are not good enough for raising crops for good production but sometimes mismanagement and/or climatic effects can result in deterioration of the soil that originally possessed good inherent quality (Table 1). Inherent soil properties are the basis used in many land use capability and suitability assessments and considered as key components in land use planning and policy development.

Properties of dynamic soil quality are those which change in response to agricultural management practices generally over a relatively short period. Soils of high dynamic quality maintain adequate nutrient availability, permit sufficient water infiltration and good aeration, have relatively stable structure and sustain diverse population of soil organisms that support a high level of plant productivity.

Development of the concept of soil quality: The concept of soil quality is being developed to characterize the usefulness and health of soils. In the USA, soil quality includes soil fertility, potential productivity, resource sustainability and environmental quality. In Canada and Europe, contaminant level and their effects have become central to soil quality. It includes both human uses of soil and functions of soil within agricultural and natural ecosystems. In agricultural research, soil productivity is considered analogous to soil quality. Maintaining soil quality has become a great concern for human health as air and, surface and ground water for human and livestock populations could adversely be affected by mismanagement and

contamination of soils with heavy metals, toxic elements, excessive plant nutrients, volatile and non-volatile organic materials and radioactive substances.

A soil with good quality is one which does not pose any harm for normal use by human, plants or animals, and not adversely affect natural functions and contaminate the environment.

So far, neither the standards have not been established, nor regulations have been laid to maintain soil quality because of high complication in soil variability and heterogeneity.

Table 1: Processes and management practices that reduce soil quality

Process	Effects on soil quality	Possible effects on environment
Erosion	Removal of productive surface soil and reduction in the capacity soil to regulate water and heat flow.	Deposition of soil material and agro-chemicals in streams and rivers.
Loss of organic matter	Lowering in soil fertility, decline in soil structure and reduction in the capacity of soil to regulate heat flow.	Increased soil erosion, soil degradation and enhanced green-house effect from released CO_2
Deterioration of structure	Reduction in soil porosity and structural stability leading to reduction in the capacity to store and movement of water.	Increased runoff leading to water erosion and decline in ground water recharge.
Salinization	Excessive soluble salts and nutrient imbalance creating adverse conditions for growth of crops.	Decreased soil covers leading to erosion and moisture losses.
Chemical degradation	Accumulation of toxic substances and reduction in the capacity of soil to act as an environmental buffer.	Movement of chemicals to surface waters and/or leaching to groundwater.

After understanding dynamic soil quality, the terms "dynamic soil quality" and "soil health" may be used interchangeably, not inherent soil quality. For example, two soils may be equally healthy but attain different levels of productivity due to the differences in their inherent quality. A soil of poor quality for crop production (inherent soil quality) such as sand, may nevertheless is healthy. In general, soil quality is monitored to manage the agricultural system to enhance production without degrading soil and the environment.

As it is not practical to measure all soil properties for assessing the soil quality, therefore, soil quality indicators are used to facilitate the measurement of soil quality. These indicators are those soil properties which are easy to measure and respond rapidly to the changes in climate and management practices. The soil properties usually considered as soil quality indicators includes texture, bulk density, organic carbon content, plant available water, pH, EC, NPK status, microbial biomass, number of earthworms and termites. In specific situations, soil aggregation, micronutrient status, ESP, pesticide residues and heavy metals may also be used as quality indicators (Table 2). The link between soil quality and soil productivity is reflected if changes in soil properties used to assess soil quality are causing loss in soil productivity. The effects of management practices on productivity, therefore, can be assessed using soil quality attributes.

The soil management practices that can influence the soil quality include tillage, addition of fertilizers, manures and amendments, water management, crop rotation and crop cover. Apart from the positive effects of tillage, tillage exposures soil surface to wind and water erosion, and causes loss of soil organic matter through oxidation. Similarly, continuous application of ammonical fertilizers and leaching of NO_3-N can degrade soil quality through acidification. Crop rotations improve soil quality by changing the quantity and quality of residue added to the soil, utilizing varying soil volume for nutrient and water uptake by different rooting patterns of crops and providing surface cover to minimize soil erosion.

Water management is another important factor affecting soil quality. In rainfed farming, minimizing runoff, enhancing infiltration and storage of rain water in soil profile are of primary soil quality concerns. In irrigated areas, the irrigation water quality, irrigation scheduling, irrigation method and drainage potential of soils are of critical management aspects. Liming of acid soils and addition of gypsum in sodic soils substantially improve the quality and productivity of soils.

Pesticides have become inevitable in modern agricultural systems and their effects on soil are included when evaluating soil quality. Pesticides help maintain agricultural productivity by controlling pests but they may prove harmful to non-target soil biota and processes. Management threshold must be established to minimize non-target effects.

Table 2: Soil properties used as indicators for assessment of soil quality

Soil property	Information
Physical properties	
Texture	Retention and movement of water, nutrients and chemicals, stabilization of organic matter and soil structure, and susceptibility to erosion.
Rooting depth	Rooting volume, and nutrient and moisture availability.
Bulk density	Pore volume and compaction
Infiltration and hydraulic conductivity	Runoff, leaching potential and drainage
Moisture content	Plant available water
Water holding capacity and release curve	Aeration, plant available water, retention and movement water and chemicals, and drainage
Chemical properties	
pH	Acidity or alkalinity and nutrient availability
Electrical conductivity	Quantity of soluble salts
NPK status	Plant available primary nutrients
Organic C and N	Organic matter status, aggregation and nutrient cycling
Biological properties	
Mineralizable nitrogen	Potential to supply available N
Microbial biomass	Microbial population, rapidly cycling organic matter and nutrients
Respiration	Organic matter status and microbiological activity

Maintaining soil quality is considered key for sustainable agriculture. The key indicators for agricultural sustainability are selected to describe changes in i) long-term net income, ii) land and water quality under a given climate and land capability and iii) food quality, off-site landscape hydrology and native ecosystems caused by agricultural practice.

Sustainable soil management practices are those that maintain or improve dynamic soil quality. In the short term, agricultural production often results in a degradation of

the natural ecosystem. Sustainable management of soil for crop production may involve practices that approach a new steady state processes by restorative processes over relatively short time. In some cases a decline in soil quality may be compensated for by an increase in production inputs such as fertilizer, tillage, pesticides, which may ultimately lower profitability or result in adverse environmental impacts, e.g. nitrate leaching. Sustainable management of agricultural land should simultaneously maintain or enhance production and services, reduce the level of production risk, protect the potential of natural resources and prevent degradation of soil and water quality, be economically viable, and socially acceptable.

Integrative approaches to land use, such as conservation tillage and organic farming have shown that crop residues and crop rotation strongly influences dynamic soil properties. Similarly managing nutrients in an integrated manner nutrient has favorable effect on soil quality indicators.

Physical indicators: These include texture, structure, porosity, soil strength, consistency and plasticity, moisture content and water movement, hydraulic conductivity, infiltration, percolation and drainage, soil moisture potential, aeration and temperature. Only soil texture and soil structure as physical indicators are discussed here as these two properties could influence other indicators.

Soil texture: Soil porosity and surface area of soil particles meet the requirements of roots for growth and development of plants. In some conditions, soil also offers resistance against shoot emergence and root penetration for which some physical manipulations are necessary. The soil texture may affect plant growth directly through resistance offered against seedling emergence and root penetration but indirectly it affects almost all edaphic factors of plant growth. In general, available water capacity of medium to fine textured soils is greater than coarse textured soils (Table 3).

Table 3: Effect of soil texture on plant available water

Soil texture	Plant available water (cm/m soil profile)
Sand and loamy sand	6.2 – 10.5
Sandy loam and fine sandy loam	10.2 – 14.4
Very fine sandy loam, loam and silt loam	12.5 – 19.5
Clay loam, silty clay loam and sandy clay loam	14.4 – 20.6
Sandy clay, silty clay and clay	13.5 – 20.6

In humid region where rainfall is sufficient to saturate soils of all textures to their capacity at certain intervals, the amount of water available to plants will be greater in fine texture than coarse texture soils. But in arid and semi-arid regions where the rainfall is of high intensity but not sufficient to saturate soils of all textures to their capacity, the amount of water available to plants would depend on the rates of infiltration and evaporation. Because of high infiltration rate, coarse textured soils are

usually superior to those of fine textures under such conditions. Therefore, coarse textured soils are draughty in humid regions and fine textured soils are droughty in dry regions. Crop yields are generally higher in soils of medium to fine texture than in soils of coarse texture. However, all crops do not respond to soil texture in the same way.

Soil structure: Soil structure greatly influences many soil physical processes such as water retention and movement, porosity and aeration, transport of heat etc. Soil management practices such as tillage, cultivation, application of fertilizer, manure and amendments, irrigation etc., bring changes in soil structure that influences other soil properties, thereby affecting root growth, water and nutrient uptake, and crop growth and yield.

A quantitative characterization of aggregates is done by determining aggregates stability and size distribution of aggregates. The aggregate stability refers to the resistance of soil aggregates to breakdown by water, air and mechanical manipulations. Tillage operations at lower or higher water contents greatly decrease the aggregate stability and size distributions of aggregates in a soil. The size distribution of wet and dry aggregates determines overall tilth, size of pores and susceptibility of aggregates to movement by water and wind. The stability of aggregates is affected by different amendments and adoption of crop rotations.

Most of the structural problems are associated with texture, topography and rainfall. For example, crusting and hardening is common in sandy loam soils of alluvial (Inceptisols and Entisols), red (Alfisols) and laterites (Ultisols and Oxisols). Low permeability is common in clay and silty clay loam black soils (Vertisols), and high permeability in loamy sand and sand of desert soils (Aridisols). Some location specific problems associated with cropping system, such as break down of aggregates, and subsurface compaction in rice-wheat system is also common. Cultivation loosens the tilled layer, oxidizes organic matter, and creates compaction in the soil underneath. Movement of finer particles from the tilled layer into the compacted layer clogs the pores and further increases bulk density and reduce non-capillary pores. Tillage at above optimal water contents greatly crushes the aggregates. However since inception of agriculture, need for removing stones, breaking clods and crusts, pulverizing the surface soil and sub-soiling to break hard pans, clay pans, and compact layers is realized for better plant growth. Indirectly these impedances affect plant growth by influencing soil water, air, and temperature characteristics. Some special soil problems such as high and low permeability, saline-alkali conditions and shallow soils also affect plant growth through air, water and nutrient stresses.

Such characteristics play an important role in plant growth in all soils. The surface and sub surface texture, structure, and consistency affect plant growth either directly by offering mechanical resistance to root growth or indirectly by creating unfavourable moisture and air status. The structural changes are associated with

formation of compact layers by repeated tillage (plough pan) or different *in situ* formations (clay pans, hard pans) by weathering of rocks and minerals during soil development and movement of finer particles from A-horizon and their deposition in the B-horizon. Major subsurface characteristics affecting plant growth are sand and gravel strata, clay pan, and hard pan. The high-density layers formed on the surface or in the subsurface layers lead to water stagnation after a heavy rainfall or irrigation and, therefore, crops turn yellow due to oxygen stress. Since root penetration is greatly restricted, the crop is drought prone during dry periods and promotes lodging during unusually wet conditions. Runoff and soil loss is generally higher from these soils. The bulk density may exceed 1.6 Mg/m^3 in clay loam to silty clay loam as against a critical value of 1.4 Mg/m^3.

Hard pans: Hard pans are generally formed at or near the intersection of two distinctly different horizons of different particle-size distribution where the passage of water, and dissolved and suspended materials is blocked by clay layers. Usually the material above the pan is very high in silt and, therefore, also known as silt pan. These pans transform quickly when disturbed mechanically through tillage. The hard pan is formed by cementation of the deposited soil particles by organic and/or inorganic materials. Two types of hard pans have been recognized. One formed under almost in any climatic condition by deposition of hydrated ferric oxide and the second formed as calcareous or gypseous pans under arid to semiarid conditions. The hard pan may also be formed as a result of precipitation and dehydration of silica. These are impervious to water and roots because of their close packing. The clay content is usually too low. During monsoon season, the soil above the hard pan is too wet and, therefore, poorly aerated for good plant growth. The reduced conditions produce toxic substances of organic and inorganic origin. In dry periods, the soil above the hard pan may dry above the wilting point even if the water table existed below it as in the coastal areas. The hard pans are characteristically brittle and possess positional hardness that is readily lost by wetting. Percolation rate of water across the pan is greatly reduced and there is development of a temporary water table above them, usually called as perched water table. Chiseling to a depth of 0.40 - 0.45 m at 50- 90 m intervals can satisfactorily ameliorate the problem.

Clay pans: Clay pans develop due to weathering of minerals in the horizon itself or may have formed due to deposition of clay in B-horizon moved from A-horizon. A clay pan is characterized by high clay content, poor structure, high plasticity and stickiness, and low permeability to water and air. Clay pans offer great mechanical resistance to root penetration and limit their depth of penetration which results in poor root and shoot growth. Clay pans greatly reduce percolation rate and leaching of nutrients. It is the most commonly occurring horizon that impedes water movement. Soil with clay pan can be ameliorated by chiseling as suggested for breaking the hard pans.

Plough pan: A compact layer formed below the depth of usually tilled layer (ploughing). It may be formed in any soil tilled to a constant depth over the years. However, it is common in rice soils puddled to a constant depth over the years. Plough pan often restricts water movement, soil aeration and root growth. Deep ploughing and chiseling can break the plough pan.

Management of soil structure in relation to plant growth

a. Practices such as mulching and planting close growing or cover crops greatly reduce raindrop impact which prevents breakdown of soil aggregates and crust formation. Addition of FYM and chemical amendments like cationic, anionic and non-ionic surfactants and gypsum greatly reduces crust strength which in turn enhances seedling emergence. Crust strength is also reduced by irrigation. Seed-line mulch involving application of FYM or wheat straw @ 2.5 t/ha on rows after sowing of pearl millet and cotton seeds has been found useful in soils susceptible to crusting.

b. Soil structure changes as a result of tillage, crop growth, irrigation, rainfall and management practices which in turn affects plant growth through aeration, compaction, water relations and temperature. Soil structure problems are often described as poor aggregation, high permeability and low water retentivity, slow permeability, poor aeration, crusting and hardening, subsurface compaction and waterlogging. Except low water retention, crusting and hardening, and waterlogging, the remaining structural features may be good for certain crops and unfit for others. Thus, management of soil structure should be considered as improving soil tilth for high yields.

c. Incorporation of crop residue and animal manure (FYM, poultry manure) into the soil would stabilize soil aggregates through supply of decomposed products. Green manuring and cover crops are good source of organic matter. Suitable cropping systems, application of phosphate fertilizers, inclusion of grasses in crop rotation would enhance organic matter and favour stable aggregation.

Chemical indicators: Soil quality assessment based on chemical properties requires a sampling protocol, a proper method of chemical analysis, an understanding of the effects of chemical properties on biological systems and methods for locating possible contamination. Generally chemical properties which inhibit root growth, affect nutrient supply or modify the availability are selected for quality assessment indicators. Certain chemical parameters which are related to nutrients availability may also be considered for measurement of soil quality such as CEC, total N and P, pH and extractable P, S, Ca, Mg and K. Total and available plant nutrients and nutrients cycling rates may be considered in soil quality measurements. These properties are seriously affected by intentional or inadvertent anthropological interferences due to addition of heavy metals and organic chemicals exceeding the safe threshold levels. The

determination of an upper threshold level of such compounds is taken into account for their ecological risks.

Biological indicators: Soil ecosystem has a diverse population of organisms ranging from beneficial to harmful one. Most of the soil quality definitions focus on the presence of beneficial rather than the absence of detrimental organisms, although both are critically important. The use of biological factors as indicators of soil quality which often equate soil quality with relatively dynamic properties are microbial biomass, microbial respiration, organic matter mineralization and denitrification, organic matter content, soil microbial carbon, phospholipids, soil enzymes and total organic carbon and nitrogen.

The populations of meso- and macro-fauna in soil have also been considered as part of soil quality definition. One could choose to use presence or absence of a particular species or population of a particular species as a measure of soil quality. Measuring of soil fauna population involves decisions about which organisms to measure and how to measure them. For example, earth worm population (size of which is frequently mentioned as an important measure of soil quality) measurement choice include numbers of organisms per volume or weight of soil, number of species or a combination of number of organisms and species.

●●●●●

Chapter-II

Soil erosion: Detachment and transportation of soil materials from one place to another through flowing water, blowing wind, gravity and other forces is called soil erosion. It is a natural and inevitable process taking place continually and globally.

Types of soil erosion: The soil erosion is of two types:

a. **Geological erosion:** It is also called natural or normal erosion, and represents the erosion when land is in naturally undisturbed environment under a cover of vegetation. The rate of geological erosion is so slow that the loss of soil is compensated by the formation of new soil under natural weathering processes. It is considered a part of the natural soil forming processes which results in existing forms and distribution of soils, and quite useful, does not pose any problem. It is largely accounts for the leveling of mountains and development of plains, plateaus, valleys, river flats and deltas.

b. **Accelerated erosion:** When erosion exceeds the normal rate and becomes unusually destructive and unproductive. When man or animal interferes with the existing balance in nature by removing vegetative cover, indiscriminate cutting of trees, over grazing, faulty cultivation, decreasing organic matter in surface soils, excessive cultivation, etc., then the natural equilibrium between soil formation and soil removal is disturbed, and removal of surface soil is much faster than it is formed, therefore, it is very harmful.

Since erosion on cultivated land is of accelerated type, the term soil erosion or simply erosion is used for accelerated erosion. It has been a major process in degradation of land resources and has destroyed about 50% of the geographical area of India.

Soil erosion involves three steps:

  i. Detachment of soil particles from the main soil body by detaching agents like rain impact, flowing water, wind velocity, freezing and thawing, etc.

 ii. Transportation of detached soil particles by splashing, floating, rolling and dragging.

iii. Deposition of these particles at another place.

Soil erosion is caused mainly by water and wind. When it is caused by water, it is known as *water erosion* and when it is caused by wind, it is known as *wind erosion*.

Types of water erosion:

1. **Splash erosion or Raindrop erosion:** Splash erosion results from the soil splash caused by the impact of falling rain drops. The beating action of falling drops breaks the aggregates and disperses the soil material. The continuous impact of the raindrops compacts and seals the soil surface which causes surface runoff. Intensity of splash erosion depends upon size of raindrop and intensity of rainfall. Under low intensity and low rainfall, if the dispersed material is not removed by the runoff, it forms a hard crust after drying. Under such condition, the emergence of seeds is hampered and sometimes, if this condition developed just after sowing, the crop stand remains poor.

2. **Sheet erosion**: Sheet erosion is the removal of a fairly uniform layer of soil from the land surface by action of rainfall and runoff. Sheet erosion continuously makes the soil shallower and is extremely harmful. The eroding and transporting power of sheet flow is a function of depth and velocity of runoff for a given size, shape and amount of soil particles or aggregates. It is usually so slow that one cannot visualize its existence. The field appears to be the same but yield of crops begins to decline slowly. It can only be recognized from the change in the colour of surface soil over the years.

3. **Rill erosion**: Rill erosion is the removal of soil by flowing water in form of small and shallow channels which develop due to concentration of surface flow along the slope. Rills generally develop on bare and unprotected lands. Rill erosion is an intermediary stage between sheet and gully erosion and clearly visible. The shallow channels can be filled and leveled by normal tillage operations.
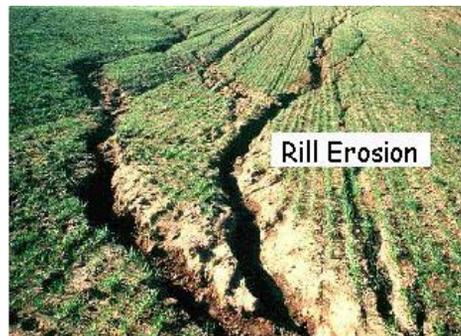
4. **Gully erosion**: Gully erosion is the extensive removal of soil by flowing water with the formation of deep channels (ravines) of either U or V shaped which cannot be leveled completely by normal cultivation. It is the advanced stage of rill

erosion. Unattended rills widened with time and begin to carry large sediment load. *Rills of more than 30 cm depth are generally called gullies*. Gullies are more spectacular than other types of erosion. They occur on sloppy lands. The rate of gully erosion depends on several factors like runoff producing characteristics of the rainfall receiving area, soil characteristics, channel alignment, slope and vegetative cover on the ground. Gully erosion indicates misuse, neglect and mismanagement of land over a long period of time.

Besides the main erosions as described above, there are some special types of erosion:

i. **Landslides/Slip erosion:** In the country, during monsoon season or heavy rainfall, the hills get water saturated resulting in instability of the land mass. The bulk soil may slip down from its actual position causing landslides. Landslides are very common in hilly areas and large quantities of soil are washed away in streams and rivers. Hills without vegetation are more prone to slip erosion causing damage to crops, orchards, communication systems, roads, railways and human lives. Minor land slips occur during the drying phase in the months of May and June, especially, in sandy hills of Shiwaliks.

ii. **Stream channel erosion:** It is caused by the water flowing over the banks of streams or scouring below the water surface, the latter being more serious. It is influenced by deforestation and overgrazing. Stream erosion is influenced by velocity of flow, depth and width of channel and texture of soil.

iii. **River bank erosion:** This is a common in rivers of the eastern and western Himalayan regions. During floods, the rivers weaken their banks and large land mass is carried by flood water. This leads to broadening of river beds and change in their courses. Best example used to be of *Koshi* river in Bihar which has now been managed by public participation.

iv. **Slumping:** It is the downward slipping of a mass of unconsolidated material or rock, moving as a unit or several sub-units. It is the process involves in widening of the stream channels and formation of gullies under high rainfall areas.

v. **Coastal erosion:** When strong waves of sea strike against the seashore, they cause soil erosion on a large scale due to combined effects of wind and water.

Adverse effects of water erosion

➢ *Loss of productive soil:* The fresh and active organic matter is lost along with the productive surface soil.

➢ *Deposition of sand on productive lands:* Deposition of coarse materials brought from the hills by streams/rivers makes the fertile lands unproductive.

➢ *Silting of lakes and reservoirs:* Soil erosion from the catchments results in the deposition of soil materials in the lakes and reservoirs reducing their storage capacity, shortening their useful life and raising the maintenance costs.

➢ *Silting of drainage and water channels:* Deposition of silt in drains, streams and rivers reduces their depth/volume and capacity to handle runoff as a result overflowing and flooding of the areas downstream increases causing big damage to crops, roads, bridges, railways, etc.

➢ *Lowering of water table:* With the increase in runoff, the quantity of water available for entering into the soil is decreased. This reduces the amount of water to replenish the groundwater in wells and tube-wells.

➢ *Fragmentation of land:* Formation of gullies divides the area into many valleys and ridges. Fields become smaller and more numerous. A large area in the Chamble ravines is a good example.

Factors affecting water erosion

1. *Climate:* Climate affects soil erosion through precipitation, temperature, wind, humidity and solar radiation.

a. *Precipitation:* Both amount and intensity of rainfall are important in affecting water erosion but rainfall intensity is more harmful than total volume of rain. Too high intensity rains may cause as much soil loss as all other storms during a season. Intensity of rain determines the velocity of runoff. Rainwater gains velocity and volume as it flows down a long slope. If velocity of flowing water is doubled, its soil carrying capacity is increased by 64 times and if tripped, the soil carrying capacity goes up to 720 times i.e. 6th power of the velocity.

b. *Temperature and wind:* Temperature and wind influences the erosion mostly through their effects on evaporation and transpiration. However, wind also affects the angle of impact and velocity of rain drops.

2. *Topography:* Topography features that influence erosion are degree of slope, length of slope, and size and shape of field. On flat lands, erosion is not a problem but sloppy land experiences the problem of erosion. Degree of slope and length of slope are two main features of topography. More the degree of slope more will be the erosion. If there is more length of slope more water accumulates leading to increased velocity of runoff. On steep slopes, high velocity causes serious erosion by scouring and sediment transportation. The velocity of runoff varies as the square root of the vertical drop.

3. *Soil factors:* The physical properties of soil (structure, texture, organic matter, moisture content, density) affect the infiltration capacity and the extent to which soil particles can be detached and transported. For example, a sandy soil or a tilled soil has more infiltration capacity but sandy soils are more erodible as the particles can be easily detached and carried away by flowing water than a soil of clayey in texture. If more the detachment of soil particles more will be the erosion. Similarly, if more is the infiltration rate less will be erosion.

4. *Vegetation:* The main role of vegetation in reducing erosion is through interception of rainfall and absorption of the energy of the raindrops which reduces the soil splash and soil detachment. Vegetation reduces surface sealing by reducing dispersion and maximizing infiltration and thereby reducing runoff. It retards erosion by decreasing velocity of runoff. Physical restraint of the movement of soil particles, improvement of aggregation and porosity of the soil by roots and plant residues, transpiration which decreases moisture resulting in increased storage capacity are also the factor associated with vegetation which reduces soil erosion.

Control measures of water erosion: Water erosion control requires best agronomic, soil management and engineering practices that protect the soil and reduce runoff.

1. *Agronomic practices:* Agronomic practices include crop rotation, contour cultivation, strip cropping, contour strip cropping and mulching. These practices help to reduce impact of raindrops as well as the runoff.

   i) *Crop rotation:* Erosion is much more from a fallow soil than under crops. It is greater in widely row spaced crops like cotton, maize than closely row spaced crops like wheat, berseem, etc. Forages crops and grasses reduce soil erosion quite considerably.

   ii) *Contour cultivation:* It is the practices of conducting field operations like ploughing, crop sowing, etc., across the slope rather along the slope *i.e.* circular furrows around the slopes. This leads to an increase in the infiltration of water and reduce the velocity of runoff.

   iii) *Mulching:* Any material spread over soil surface is called mulch. Mulching is effective in reducing runoff and increasing infiltration of water. Crop residues added to fields reduces erosion. Stubble mulch farming is also

effective in reducing runoff and increasing infiltration of water. *Stubble mulch farming is the crop and soil management practices that utilize the residues of previous crop.*

iv) *Strip cropping:* It is the practice of growing alternate strip of erosion controlling and erosion promoting crops such as grasses-maize-grasses-potato. It is a means of reducing the length of slope. When the strips are laid out on the contours on slopes, the system is called *contour strip cropping*.

v) *Tillage:* Low intensity tillage such as zero tillage or minimum tillage maintains the crop residues on the surface which reduces evaporation and increases soil organic matter. The organic matter helps in better aggregation, aeration and water infiltration. The zero tillage practice helps in reducing runoff and soil erosion.

2. **Soil management practices:** The soil management practices include maintenance of soil fertility and building of soil structure. Fertile soils result in high crop production and good plant cover and are resistant to soil erosion. These soils have a stable structure and high infiltration capacity. *Soil fertility is regarded as the key to soil erosion control*.

3. **Engineering practices:** Engineering practices are used to control the movement of water over land surface. The practice depends on whether the objective is to *reduce velocity* of runoff or *increase surface water storage capacity* or *safely dispose* off the excess water. The practices include terracing, bunding, dams, etc.

i. *Terracing:* It is a practice of decreasing the length and slope of the land. It needs leveling operations which are costly. On hills, terraces perpendicular to the slope are constricted. *A terrace is embankment of soil with a level or nearly level top and steep face constructed along the contour of sloping land*. Terraces make possible growing of crops in mountainous regions.

ii. *Bunding:* Bunds are constructed along the field boundaries without any reference to contours to give more time for water to infiltrate and reduce the runoff. On hills, contour bunds are constructed which consists of building earthen embankment across the slope along the contours.

iii. *Dams:* Dams are basically constructed for controlling gullies. These are called engineering structures constructed to reduce the speed of runoff and hence, the soil erosion. Different sized gullies may be controlled by the following practices.

Small gullies may be ploughed and crops like oats, barley or wheat may be sown to check runoff until the grass obtains a start. Once the grass is established, the erosion will almost be controlled. If the gully erosion is too active to be checked in this manner and the gully is still small, the barriers of manure or straw at the intervals of 4.5 - 6.0 m are very effective. Such barriers may be made more secure by net of wires. The gully may be then kept under grass for a long time before crops are grown.

Moderately sized gullies may be checked using larger sized barrier of various kinds. These are built at intervals along the gullies. Stakes can be used for this purpose. The stake barriers can be made firm by wiring them together.

Very large gullies may be checked successfully by using barriers of earth, concrete or stones. Most of the sediment is deposited above the barriers and gullies are slowly filled.

Wind erosion: It is movement of soil material by wind. Wind erosion is most common in arid and semi-arid regions where rainfall is less evaporation. It occurs to some extent in humid climates also. Wind erosion is mainly due to a strong winds, low humidity, high solar radiation and single grained structure.

*Damages due to wind erosion***:** The most serious damage caused by wind erosion is the change in soil texture as the smaller particles are more subjected to movement by wind. The finer fraction of the soil particles is reduced and the fertility of the soil is

declined. The roots of the plants are exposed causing plants to die. Growing plants may also be covered by the drifting debris. The abrasive action of sand particles on the tender seedlings is disastrous during wind erosion, and the damage is also caused to buildings, rails, roads, canals by sedimentation of the blown materials.

***Mechanics of wind erosion*:** Wind erodes the soil in three steps:

  i. Initiation of movement
 ii. Transportation either along the surface or in air
iii. Deposition of soil particles at new locations.

1. ***Initiation of movement*:** Soil particles movement is initiated due to turbulence and velocity of the wind. The wind threshold velocity for particle movement is about 3 km hr^{-1} for the surface wind. The abrasive action of the wind results in detachment of smaller soil particles from the aggregate or clods. When the wind is laden with these soil particles, its abrasive action is significantly increased. The impact of the rapidly moving particles dislodges other particles from the soil clods or aggregates. These particles are now ready for movement.

2. ***Transportation:*** After movement is initiated, the soil particles are carried by wind in three types of movement, i.e. *surface creep*, *saltation and suspension*. Usually, all the three types of movement occurs simultaneously.

   i) *Surface creep:* Surface creep is the rolling or sliding of large soil particles along the ground surface. The particles carried by this manner are too heavy to be lifted by the wind. Primarily, the particles are moved by the impact of the particles in saltation rather by direct force of the wind. The bouncing particles carried by saltation strike the larger particles and speed up their movement along the surface. The particles creeping on the surface have the size range of 0.5 to 1.0 mm which is too heavy to be transported by saltation. Surface creep forms sand dunes and account for 5 to 25% of the total movement.

   ii) *Saltation:* The movement of soil by series of short bounces or jumps, just like grasshoppers, along the surface of land at heights not more than one metre is called saltation. Saltation movement is caused by the pressure of the wind on the soil particles, and collision of a particle with other particles. Particles of 0.1 to 0.5 mm in size usually move in this manner. Wind

speed should be at least 10 km/hr. This process may account for 50 to 75% (major portion) of the total movement.

iii) *Suspension:* It represents the floating of small sized particles (<0.1 mm) in blowing wind. The movement of these particles in suspension is also usually initiated by the impact of particles in saltation. These particles are often carried few kilometers above the ground in the atmosphere and several kilometers horizontally from their original locations resulting in total loss of these particles to the eroding area. They return to the earth only when the wind subsides or precipitation washes them down. It accounts for about 40 percent of the total soil movement. The following figure illustrates all the three types of movement of soil particles during wind erosion.
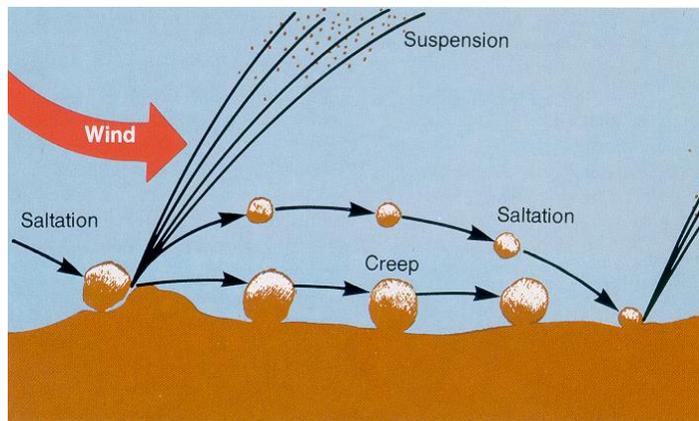

3. *Deposition*: Deposition of particles depends on gravitational force. When gravitational force is greater than the force holding the soil particles in air i.e. when wind velocity decreases, the particle starts depositing.

Factors affecting wind erosion: The following factors affect the wind erosion:

i) *Climate:* Wind velocity, precipitation, temperature, humidity and solar radiation influence wind erosion. Amount and distribution of rainfall are most important factors. The principal characteristics of wind which affect erosion are velocity, direction, duration and turbulence.

ii) *Soil:* The soil factors affecting wind erosion are texture, structure, particle density, organic matter, moisture and surface roughness. The moisture content is important as relatively dry soil is subjected to wind erosion. Surface roughness which changes with tillage reduces wind erosion. Surface crust decreases surface roughness and retard the effect of wind erosion due to the increase in cohesiveness among soil particles, particularly, clay particles.

iii) *Vegetation:* The height and density of plants, type and seasonal distribution of vegetation affect soil erosion by wind.

***Control of wind erosion*:** The basic principle in controlling wind erosion is to reduce wind velocity at the soil-atmosphere interface which can be achieved by following measures:

i) *Vegetation cover:* Protection of soil surface with a cover of vegetation or crop residues reduces the velocity of wind, therefore, grasses and stubble mulch are more effective.

ii) *Soil moisture conservation:* Adoption of soil moisture conservation practices are the most important for wind erosion control. This can be done by contour ploughing, strip cropping and deep ploughing during rainy season.

iii) *Increase surface roughness:* Rough land surface reduces wind velocity and traps some of the moving soil particles. Large clods formed on the soil surface by tillage operations and stubble mulch are very effective in increasing surface roughness.

iv) *Decreasing wind velocity:* Strip cropping and alternate strips of crops are effective in reducing wind velocity, if done perpendicular to prevailing wind direction. Barriers such as shelterbelts and wind breaks are effective in reducing wind velocities and for trapping drifting soil. A *wind break* is any type of barrier (mechanical or vegetative) for protecting the fields, gardens, etc. from wind erosion where as a *shelter belt* is a longer barrier than a wind break consisting of the combination of shrubs and trees intended for the conservation of soil and moisture, and for the protection of field crops.

●●●●●

Chapter-III

WASTE LANDS AND PROBLEMATIC SOILS
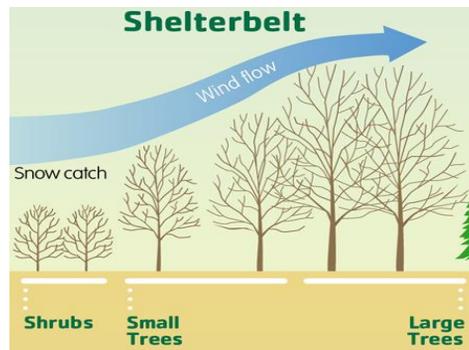
India is the 7th largest and the 2nd most populous country in the world with unique landscape. It supports over 16% of the world's population with only 2.4% of the global land area. The increased population in the country has decreased the per capita land holding and increased the demand for food, fibre, fuel and several other land products apart from the increased demand of land for houses and other infrastructures. The increased population has also resulted in the increase in the population of livestock leading to higher demands for fodder and fuel. Deterioration of land quality for agricultural production and environmental protection along with stagnating or decreasing yields has now become the matter of great concern. Considerable damage has already been done to soil and water resources due to salinization and erosion with the introduction of irrigation, and increasing desertification due to deforestation. To satisfy the increasing needs of the increasing population, it has become necessary not only to improve and reclaim waste lands and problematic soils but also to prevent the land resource from further fatigue.

Waste lands are those degraded lands which cannot be brought under cultivation with reasonable effort and the lands which are deteriorating either for the lack of appropriate soil and water management or on account of natural causes. The technical task force group constituted by Planning Commission and the National Wasteland Development Board (NWDB) defined wastelands in about thirteen categories. These are gullied and/or ravenous land, land with or without scrub (bush), waterlogged and marshy land, salt affected land, shifting cultivation area, degraded notified forest land, degraded pasture land, degraded land under plantation crops, sands (desertic and coastal), mining/industrial waste land, barren rocky/stony area, steep sloping area and snow covered and/or glacial areas.

Distribution of wasteland and problematic soils in India and Haryana

Land degradation assessment undertaken by the various Central and State agencies generated databases on the degraded and wastelands. But these agencies used different definitions of land degradation, data sources, classification systems, methodologies and scales which resulted in different estimates of degraded and wastelands for implementation of reclamation/ conservation and ameliorative measures.

The earliest assessment of the area affected by the land degradation was made by the National Commission on Agriculture at 148 M ha, followed by 175 M ha by the Ministry of Agriculture (Soil and Water Conservation Division). The NBSS&LUP estimates projected an area of 187 M ha as degraded lands in 1994 and revised it to 147 M ha in 2004. The National Wasteland Development Board estimated an area of 123 M ha under wastelands. Based on the area statistics, a preliminary assessment

showed that the total area under degraded and wastelands in the country stands at 114.01 M ha. The extent of area under water erosion is 23.62 M ha, and under wind erosion is 8.89 M ha. Similarly, the salt-affected area is estimated to be 6.73 M ha and under acid soils 16.03 M ha.

In Haryana, the extent of salt affected soils is estimated to be about 0.32 M ha out of which about 0.145 M ha is saline and 0.171 M ha under sodic soils. Significant areas are distributed in Sonipat (0.035 M ha), Jhajjar (0.042 M ha), Rohtak (0.033 M ha) and Jind (0.012 M ha) districts confiding at low-lying flats/ depressions in Central Haryana. Soil salinity exists in sandy plains in western districts viz., Hisar (0.034 M ha), Sirsa (0.030 M ha) and Bhiwani (0.016 M ha) of the State. The thick calcareous layer in these areas caused secondary soil salinization and waterlogging as a result of irrigation from canal and tube well. The sodic groundwater in Kaithal (0.010 M ha) district and the presence of carbonate and bicarbonate of sodium in parent materials in Ghaggar plains of Kurukshetra (0.016 M ha) district causes sodicity in these areas. Karnal (0.019 M ha) and Panipat (0.008 M ha) districts showed the sporadic occurrence of soil sodicity at the post-reclamation stage. The salinity and sodicity in an area of about 0.009 M ha in each of Faridabad, Gurugram, Palwal and Mewat districts are influenced largely by the Aravalli hills.

Problematic soils

The soils with decreased productivity due to deterioration in its physical, chemical and biological properties are termed as problematic soils. The origin, concept, mechanism, factors responsible for formation and management strategies of problematic soils are discussed in the following sections.

1. Salt affected soils

Soils containing excess soluble salts in the root zone that leads to decrease the growth and yield of crop plants are called as salt affected soils. The extent of reduction, however, depend upon the amount and type of salt constituents, their distribution soil profile, soil texture, irrigation management, type of crops and their varieties grown, and climatic conditions. These soils are mainly confined to arid and semi arid regions due to low annual rainfall for leaching of the salts deeper in soil profile and high evaporation causing accumulation of salts in the root zone. Such soils also occur in humid regions in areas having intrusion of sea water. These soils cover an area of 7 M ha in India. The process of accumulation of salts in soil is called salinization. Chlorides, sulphates, carbonates, bicarbonates of calcium, magnesium and sodium are the major constituents of the salts present in these soils.

Origin of soluble salts in soil: There are various sources from which soluble salts are accumulated in the soil.

a) Primary minerals: The direct source of salts in soil is the easily weatherable minerals (halite, gypsum, sulphides, calcite, dolomite, apatite, feldspars, olivine, layered silicates) which gradually release various constituents and make them soluble during the processes of chemical weathering like hydration, hydrolysis, carbonation, oxidation and reduction. The types of salt present in the soil depend upon the type of minerals and extent of their weathering. For example, the salt solution resulting from acidic rocks (granite, gneiss) contain carbonates, chlorides, silicates and sulphates of sodium, and that from alkaline rocks (basalt) contain mainly carbonates, sulphates and silicates of calcium and magnesium. The distribution and accumulation of salts released from minerals in any soil depend upon the physico-geographical and geo-hydrological conditions of the area.

b) Ocean water: Ocean water composed of dissolved salts (85.6% NaCl) enters into low lying coastal areas by inundation and deposited on the soil surface.

c) Blowing wind: The areas adjoining the sea may receive salts with strong winds.

d) Salt springs: The salt springs emerging from many regions add substantial amount of salts in the soil as volcanic gases and waters contain chlorides to a substantial amounts.

e) Ground water: Saline groundwater used for irrigation, particularly in arid and semi arid regions leads to accumulation of salts in surface soil.

f) Irrigation: Irrigation without proper drainage disturbs salt balance in soil leading to their buildup at certain places.

g) Excessive use of basic fertilizers: Use of basic fertilizers like sodium nitrate, basic slag, etc. may develop soil alkalinity.

h) Industrial effluents: Flooding the soil with industrial effluents may also result in accumulate of salts.

Characterization of salt affected soils: The salt affected soils are characterized into three groups: saline, sodic (alkali) and saline-sodic soils (Table 1)

Table 1: Characteristics of salt affected soils

Parameter	Saline	Sodic	Saline-sodic
EC_e (dS m^{-1})	> 4	< 4	> 4
ESP	< 15	> 15	> 15
pH	< 8.5	> 8.5	< 8.5

However, based on the effects of commonly present neutral and alkali salts on soil properties and plant growth, these soils have been grouped into only two categories: saline and sodic soils.

Saline soils: Due to presence of excess of soluble salts, the electrical conductivity of saturation extract (EC_e) of the saline (solonchak, Russian term) soils is > 4 dS m^{-1}. These soils usually contain chloride and sulphate of sodium, calcium and magnesium. In arid conditions, these soils may also possess excessive of nitrate, boron and fluoride. The presence of chloride and sulphate of sodium provides a white colour to soil surface whereas the occurrence of nitrates in excess quantity imparts a brown colour to the soil. Formerly, these soils were called white alkali soil because of surface crust of white salts. A concentration of $> 0.1\%$ of the total soluble salt is considered enough to impair the normal growth of most plant species. In saline soils, the ratio of Na$^+$ to Ca^{2+}+ Mg^{2+} is low. The exchange complex does not have high amount of adsorbed Na$^+$, therefore, exchangeable sodium percentage (ESP) is < 15. Due to low ESP, pH of saturation paste (pH$_s$) of these soils is < 8.5. Since Ca^{2+} and Mg^{2+} dominate in the soil solution as well as on the exchange sites, saline soils remain flocculated. Due to flocculation of soil particles (clay particles), saline soils are aggregated and permeable to both water and air. These soils have majority of chlorides and sulphates of sodium, calcium and magnesium.

Sodic or alkali soils: The characteristics of sodic (solonetz) soils include an excess of sodium on exchange sites and alkalinity to affect the plant growth adversely. The soils are dominated in carbonates (CO$_3^{2-}$ and HCO$_3^-$) of sodium as compared to the neutral salts of chlorides and sulphates. These soils are called *Usar* or *Kallar* in different parts of the country. Presence of high exchangeable sodium gives rise to an ESP of >15 in sodic soils. These soils have pH > 8.5 due to high value of ESP. Sodic soil contain $< 0.1\%$ of total soluble salt mainly of sodium, therefore, ECe is < 4 dS m^{-1} at 25^{0}C. Due to high ESP (dominance of exchangeable Na$^+$ as compared to Ca^{2+}), sodic soils are deflocculated and dispersed resulting in poor permeability to water and air. The deflocculation results in poor structure. When dispersed organic matter is accumulated on the surface, alkali soils appearance dark brown or black and termed as 'black alkali' soils. These soils mainly occur in arid and semi arid regions of Punjab, Haryana, Uttar Pradesh, Bihar and Rajasthan.

When clay particles are dispersed due to high ESP in sodic soils, they move downwards through soil pores and resulted in formation of a dense layer of very low permeability at certain depth. The hydraulic conductivity of alkali soils decreases

with increase in ESP resulting in stagnation of irrigation water. Clogging of pores in the surface soil followed by drying, results in the development of crust which hinders seedling emergence and deteriorates air-water relations in the root zone. These soils become very hard when dry and sticky when wet. The process by which a normal soil is converted into an alkali soil is called alkalization.

Saline-alkali soils: The salinization and alkalization processes lead to formation of saline-alkali soils. The saline-sodic soils have $EC_e > 4dS$ m^{-1} at 25^0C and ESP > 15. High EC_e due to high concentration of chlorides and sulphates of sodium rarely allow the pHs to exceed 8.5. But if high EC_e is due to high soluble carbonates of sodium, the pHs can be much higher than 8.5. In these soils, in spite of high ESP (> 15), clay particles remain flocculated. Upon leaching of soluble salts of chlorides and sulphates of sodium, these soils behave like alkali soils.

Management of salt affected soils: Plant growth is adversely affected in salt affected soils, therefore, it is necessary to reclaim these soils for maintaining their productivity. Salt affected soils could be reclaimed by providing adequate divalent cations, e.g. calcium to replace exchangeable sodium, enough fresh water and adequate drainage for leaching the soluble salts below the root zone. Systematic planning for reclamation of saline and sodic soils requires characterization of problem e.g., extent and kind of salinity or alkalinity/sodicity for using physical, hydro-technical, chemical or biological methods:

i. *Physical methods:* The physical methods for reclamation of salt affected soils include deep ploughing, sub-soiling, sand mixing and profile inversion. The first two methods are used to break the impermeable layer, hard pan or compacted sub-soil layer existing at various depths in the soil profile to improve the drainage and facilitate the transportation of salts dissolved in water beyond the root zone. Incorporation of sand changes the texture, increases soil permeability and improves air-water relations in root zone. In heavy soils, large amount of sand is required in sodic soils to improve their impermeability. If surface soil is good but sub-surface soil is sodic or saline then the practice of profile inversion is adopted. Since, this method is very tedious and energy consuming, therefore, generally avoided.

ii. *Hydro-technical methods:* The hydro-technical methods involve basically the removal of salts from the saline soil or displacement of Na+ from the exchange complex of sodic soils through the processes of leaching with fresh water and adequate drainage. This requires sufficient amount of fresh water to pass through the soil to decrease salt concentration in the soil below the permissible limits. Suitable measures should be taken for proper disposal of highly saline drainage water before initiating the leaching of salts, especially, under shallow ground water table conditions. Extent of leaching required depends upon many factors including soil properties (texture, structure, pore geometry, soil cracking and clay mineralogy) salinity level and composition of soluble salts; quality of water

available for leaching; method used for leaching; the depth of water table depth; efficiency of the drainage system and tolerance of the crops grown to the salts.

iii. ***Chemical amendments***: Reclamation of alkali soils requires neutralization of alkalinity and replacement of the Na^+ from the soil exchange complex by more favourable Ca^{2+}. The replacement of Na^+ can be achieved by the application of chemical amendments followed by leaching to remove soluble salts and other reaction products. The type of chemical compounds and their quantities required for reclamation of alkali/sodic soils depend upon physico-chemical properties of the soil and the required rate of replacement of Na^+. Commonly used chemicals for amelioration of these soils include soluble sources of calcium such as gypsum ($CaSO_4.H_2O$), calcium chloride ($CaCl_2$), and phosphor-gypsum, sparingly soluble calcium salts like calcite ($CaCO_3$) or acids and acid formers compounds like sulphur, sulphuric acid, sulphates of iron and aluminum, and pyrites.

The effectiveness of these amendments primarily depends on the presence or absence of alkaline earth carbonates (mainly $CaCO_3$) in the soil. Gypsum is, however, most economical and commonly used chemical amendment whose resources are estimated to be more than 1000 mt in the country. Lowering the ESP of sodic soil to the level of 10 is considered safe for tolerable physical conditions of the soil. The amount of gypsum required to lower the ESP of sodic soil to a desired value is known as *gypsum requirement* (GR). The GR, however, depends upon the amount of changeable Na^+ to be replaced, exchange efficiency and the depth of soil to be reclaimed. The GR is determined from the formula:

$$\text{GR (me Ca}^{2+}\text{/100g soil)} = \frac{[\text{ESP (initial) } - \text{ESP (final)}] \times \text{CEC}}{100} \qquad (1)$$

where ESP (initial) is obtained from soil analysis before reclamation, ESP (final) is usually kept at 10 with gypsum application, and CEC is cation exchange capacity in meq/100 g of soil. For illustration, the GR of soil having initial ESP of 40, final ESP 10 and CEC of 25 will be:

$$\text{GR (me Ca}^{2+}\text{/100g soil)} = \frac{(40 - 10) \times 25}{100} = 7.5$$

As one hectare furrow slice (15 cm depth) of soil weighs approximately 2×10^6 kg and 1 me of Ca/100g of soil as gypsum ($CaSO_4.2H_2O$) equals 86 mg of gypsum/100g of soil or 860 mg of gypsum /kg of soil or 860 ppm of gypsum, therefore, amount of gypsum required per hectare will be: GR = $(860 \times 2 \times 10^6 \times 7.5)/10^6$ = 12900 kg or 12.9 tons.

Further, the rate of gypsum application for its effective use depends on purity of gypsum, texture and specific surface area of soil, organic matter, etc. The gypsum requirement is calculated assuming that all the sodium is replaced by the calcium from the applied gypsum. To compensate these factors, the US Salinity

Laboratory Staff recommended that the GR calculated by equation (1) may be multiplied by a factor of 1.25 for the desired level of Na^+ replacement. Application of gypsum at the rate of 50% GR and mixing of gypsum up to 10 cm depth can be adopted for greater economy and efficiency of reclamation.

iv. *Organic materials* The organic materials and plant roots increase biological activities but at the same time their decomposition increases the concentration of CO_2 and organic acids in the soil which help in mobilizing calcium by dissolving calcium compounds. The organic matter content in soil may be increased by incorporation of crop residues, green manuring, and addition of FYM, press mud and other organic materials. Rice is preferred to be grown during reclamation of alkali soils due to its high tolerance to soil sodicity. The ponding of water for optimum rice growth promotes build up of partial pressure of CO_2 and leaching of salts resulting from exchange of sodium by calcium.

2. Acid soils

Acid soils are base unsaturated soils having enough amounts of exchangeable H^+ to provide soils a pH of < 6.5. Soils which are high in Al^{3+} and H^+ with a pH value of <5.5 and which respond to liming may be considered as acid soils. These soils normally belong to laterite and lateritic, red and yellow groups rich in kaolinite type of clay minerals of low CEC. Acid soils occupy about 27.0 M ha areas of Assam, West Bengal, Tripura, Manipur, Himachal Pradesh, Orissa, Karnataka, Tamilnadu, Bihar and Kerala. In general, humid climate is responsible for the formation of acid soils. In addition, the dissolution of aluminosilicate minerals produces aluminium ions which increase the acidity owing to hydrolysis. Similarly, hydrous oxides and humus also contribute to soil acidity.

Causes of the formation of acid soils

i. *Acidic parent material:* Some acid soils are formed from acidic parent materials such as granite that may contribute to some extent of soil acidity.

ii. *Leaching of exchangeable bases:* Acid soils are common in the humid regions where rainfall associated is high (> 100 cm) enough to leach appreciable amounts of exchangeable basic cations such as Ca and Mg and relatively insoluble compounds of Al and Fe remains in soil. The Ca and Mg is dissolved in water and leached out due to which the base saturation of soil decreases. The nature of Al and Fe compounds is acidic their oxides and hydroxides react with water and release H^+ in soil solution, and soil becomes acidic.

iii. *Acid forming fertilizer and soluble salts:* Continuous application of acid forming fertilizers such as ammonium sulphate- $(NH_4)_2SO_4$ or ammonium chloride- NH_4Cl depletes Ca^{2+} from the exchange sites. The Ca^{2+} is replaced by NH_4^+ from the exchange complex and calcium sulphate- $CaSO_4$ is formed and leached down. Application of elemental sulphur undergoes reactions resulting in formation of H_2SO_4.

iv. ***Humus and other organic acids:*** Humus contains different functional groups like carboxylic (-COOH), phenolic (-OH), etc. which are capable of attracting and dissociating H^+. During microbiological decomposition of organic matter, humus, organic acids and different acid salts may be produced which lead to increase the total acidity of soil.

v. ***Aluminosilicate minerals:*** At low pH (<5.0)most of the aluminium is present as hydrated aluminium Al^{3+} ions which undergoes hydrolysis and release hydrogen (H^+) ions in the soil solution.

$$Al^{3+} + H_2O \rightleftharpoons Al(OH)^{2+} + H^+$$

$$Al(OH)^{2+} + H_2O \rightleftharpoons Al(OH)_2^{+} + H^+$$

$$Al(OH)_2^{+} + H_2O \rightleftharpoons Al(OH)_3 + H^+$$

$$Al(OH)_3 + H_2O \rightleftharpoons Al(OH)_4^{-} + H^+$$

vi. ***Carbondioxide***: Root and microbial activities releases CO_2 that ultimately leads to acidity in soil. More the concentration of CO_2 less is the pH.

vii. ***Hydrous oxidizes***: These are mainly of iron and aluminum which undergo stepwise hydrolysis with release of H^+ in soil solution.

viii. ***Aluminium***: Aluminium contributes soil acidity indirectly through hydrolysis where as H^+ directly.

Types of soil acidity

Active acidity: The active acidity is a measure of H^+ ion activity in the soil solution. The H^+ ions concentration responsible for active acidity is very small as compared to the concentration of ions responsible for exchange and residual acidity. Active acidity is important as it influences the plant root and microbes around the rhizosphere.

Exchange (salt replaceable) acidity: Exchange acidity is due to presence of large quantity of exchangeable aluminum and hydrogen ions on exchange complex of soil colloids which are easily exchangeable by other cations in a simple salt solution such as KCl. In strongly acidic soils, the concentrations of exchangeable aluminum and hydrogen ions contribute to exchangeable acidity. In moderately acid soils, the quantity of easily exchangeable aluminium and hydrogen is quite limited, even then, the limestone needed to neutralize this type of acidity is more than 100 times than those for active acidity. At a given pH value, exchangeable acidity is generally highest for the smectites, intermediate for the vermiculites and lowest for kaolinites.

Residual acidity/potential acidity: Residual acidity is generally associated with aluminum hydroxyl ions, and hydrogen and aluminum atoms that are present in non–exchangeable forms with silicate clays and organic matter. If lime is added to a soil, the pH increases and the aluminum hydroxyl ions are changes into gibbsite (uncharged) i.e.

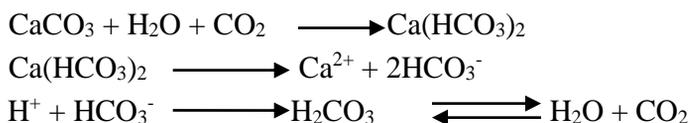$$Al(OH)^{+2} \longrightarrow Al(OH)_2^{+} \longrightarrow Al(OH)_3$$

It is measured by titration of soil suspension. The residual acidity is highest amongst the active and exchangeable acidity. It is estimated that the residual acidity may be 1000 times greater than the active acidity in a sandy soil and 50000 or even 100000 times greater in a clayey soil rich in organic matter. The amount of limestone recommended to partly neutralize residual acidity is commonly 4-8 tons per hectare furrow slice.

Total acidity is the sum of active, exchange and reserve acidity.

Nutrient availability in acid soils: There is a strong relationship between soil acidity and availability of plant nutrient, as well as the activities of soil-organisms. In acid soils, the availability of the macronutrients (N,P,K,Ca,Mg,S) as well as Mo and B is reduced whereas availability of most micro nutrients (Fe, Mn, Zn, Cu, and Co) is increased, even to the extent of toxicity to higher plants and microorganisms. Most microorganisms function at their best within a pH range 6.0 to 7.5 and their activities decreases as soil become acidic.

Management of acid soils: Generally, the soil fertility of acid soils is very poor and under strongly to moderately acidic soils, the plant growth and development affect to a great extent. The crop grown on such problematic soils do not give adequate yield. So the amelioration of soil acidity is very necessary. Soil acidity can be managed in the following ways.

i. *Addition of liming materials*: One of the most important management practices is the use of lime and liming materials to ameliorate the soil acidity. When lime is added to moist soil, the soil solution becomes charged with Ca^{2+}. These active Ca^{2+} exchange with H+ in the exchange complex. Hydrogen combines with OH^- to form water or CO_3 to form unstable H_2CO_3, which is readily changed to H_2O and CO_2 as:

$$CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2$$
$$Ca(HCO_3)_2 \longrightarrow Ca^{2+} + 2HCO_3^-$$
$$H^+ + HCO_3^- \longrightarrow H_2CO_3 \rightleftharpoons H_2O + CO_2$$

ii. *Application of basic fertilizer:* Use of basic fertilizers like sodium nitrate, basic slag, etc, reduces the acidity of soil.

iii. *Soil and water management*: Proper soil and water management checks leaching of bases and enhances decomposition of organic matter.

iv. *Growing of acid tolerant crops*: Acid tolerant crops should be grown. Choice of crops may be according to soil pH. Crops can be divided into following groups.

Highly acid tolerant: Rice, potato, sweet potato, oat, caster, etc.

Moderately acid tolerant: Barley, wheat, maize, turnip, brinjal etc.

Slightly acid tolerant: Tomato, carrot, red clover etc.

Liming materials: Liming materials are usually the oxides, hydroxides, carbonates and silicates of Ca or Ca and Mg. In addition of these compounds, the accompanying anion must be one that will reduce the activity of hydrogen ion and hence aluminium in the soil solution. These materials are called 'Agricultural liming materials'. Common liming materials are:

  i. Limestone ($CaCO_3$)
 ii. Quick lime (CaO)
iii. Hydrated (slaked) lime [$Ca(OH)_2$]
 iv. Dolomite limestone [$CaMg(CO_3)_2$]
  v. Blast furnace slag (Basic slag): These are the byproducts of iron and steel industry.
 vi. Wood ash, byproduct material of paper mills, sugar factories, fly ash and sludge are considered as liming materials for the amelioration of soil acidity.

Lime requirement: The lime requirement is the amount of liming material used to raise the pH of the acid soils to the required value i.e., 6.0-7.0 as it is considered optimum range for most of the crop plants. Lime requirement depends upon:

— Required change in pH
— Buffering capacity of the soil to be limed
— Chemical composition of the liming materials used
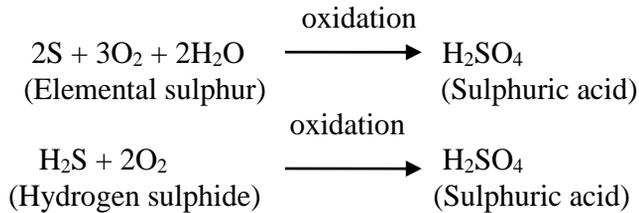— Fineness of the liming materials.

Method of applying lime: The most efficient way to use lime is to apply small amounts in every or alternate year. Normally, lime is applied one or two months before the sowing of crop. It is properly mixed with surface 15 cm soil depth. Sometimes excessive liming, particularly in sandy soils which are low in organic matter, may cause injury to the growing plants which may be reduced by application of compost, FYM, phosphorus, boron, etc.

Effect of lime on soil properties in relation to plant nutrition:
   i. Increases the availability of phosphorus.
  ii. Increases nitrification and nitrogen fixation and hence the availability of nitrogen.
 iii. Increases the decomposition of organic matter.
  iv. Potassium is utilized more efficiently.
   v. Encourages the beneficial bacteria.
  vi. Harmful aluminium, manganese and iron become insoluble.
 vii. Calcium and magnesium becomes available.
viii. Improves the physical condition of soil
  ix. Increases fertilizer use efficiency.
   x. Plant diseases favoured by acid soil decreases.

3. Acid Sulphate soils

Acid sulphate soils are extremely acid having pH < 4.0 in surface soil. The acidity is due to presence of sulphuric acid, and iron and aluminium sulphates. These soils are derived from marine sediments high in pyrites and poor in bases. The acidifying process associated with sulphur oxidation is illustrated as:

$$2S + 3O_2 + 2H_2O \xrightarrow{\text{oxidation}} H_2SO_4$$
(Elemental sulphur)   (Sulphuric acid)

$$H_2S + 2O_2 \xrightarrow{\text{oxidation}} H_2SO_4$$
(Hydrogen sulphide)   (Sulphuric acid)

During the submersed condition, sulphates (SO_4^{2-}) are reduced to sulphide (S^{2-}) and iron sulphides (FeS_2) is formed. Upon drainage, the sulphide or elemental sulphur (S) is oxidized forming sulphuric acid and the pH drops to a level as low as 1 or 2. Plant growth cannot occur under these conditions.

Characteristics acid sulphate soils: Acid sulfate soils are usually clay. The organic carbon content varies from 1.5 to 18 %. The cation exchange capacity is usually 10-15 meq/100 gm. Available nitrogen and phosphorus is low. There may be toxicity of iron, aluminium and H_2S. These soils when submerged are nearly neutral in reaction but when drained and dried they become extremely acidic and fatal to crop plants.

Reclamation: Reclamation measures depend on the availability of water. If water is available, the soils are kept continuously flooded or saturated to prevent acidification. If it is not possible, the soils are drained and leached to remove the acid materials. The soils are then limed, fertilized with nitrogen, phosphorus and crops grown in the wet season.

4. Physically constrained soils

i. **Eroded soils:** Soil erosion has been considered as the primary cause of soil degradation as it leads to the loss of topsoil and soil organic matter, which are essential for the growing of plants. The loss of soil may have serious impacts on the quantity and quality of soil ecosystem services, with serious economic, social, and political implications. Antecedent soil properties clearly have a large impact on how erosion affects crop productivity. Fertile soils with thick loess or alluvial parent material can experience high rates of erosion for many years with relatively little loss of productivity. In contrast, moderate soil loss can cause major declines in the productivity of soils with limited rooting depth. For example, an Ultisol with a fragipan at 30 centimeters would tend to be much more negatively impacted by the loss of 10 centimeters than a Mollisol with a 60-centimeter thick A horizon.

ii. **Soil crusting**: The surface soil consists of 60% coarse and 40% fine fractions, a proportion optimum for crust formation when organic carbon is < 1%. Due to surface mechanical impedance, the emerging plumules face resistance, bend below the crust and some of the seedlings injure their tips and fail to emerge. The emergence of pearl millet, cotton and jute seedlings is adversely affected if the crust is formed on the soil surface by the occurrence of rainfall within 48 hours of sowing.

iii. **Soil hardening:** The red sandy clay loam 'Chalka Soil' of Andhra Pradesh dries out very quickly due to low water retention capacity and becomes very hard. The maximum root growth of most of the crops is confined to the surface layer and crop suffers due to hardening. Pigeonpea, maize, castor, groundnut and sorghum are the major crops grown on these soils. The yield of groundnut is very low due to reduced size of pods caused by hardening of the soil.

iv. **Shallow soils:** The soils having <20 cm depth are called shallow soils. The coarse textured surface soil is underlain with soft disintegrated weathered rocks. The root growth is very poor due to quick drying of the soil and shallow depth of the soils. Shallow soils are proven to drought in dry weather and waterlogging in wet periods. The soil temperature fluctuations are rapid and wide. These soils, even on gentle slopes, are associated with erosion problems due to their low storage capacity.

v. **Compacted soils with subsurface mechanical impedance:** The soils with subsurface mechanical impedance cover about 10.63 mha and develop due to the formation of plough sole, use of heavy machinery on moist soil, accumulation of clay in B-horizon under sub-humid conditions or the presence of *kankar* layers. The mechanical impedance makes the layers impervious and water stagnates on the soil surface after heavy rainfall or irrigation and crops turn yellow due to oxygen stress. These layers do not allow the roots to penetrate deep into the soil. Shallow root system makes the plant drought prone during dry spells and promotes lodging during unusually wet conditions. In high rainfall areas, the presence of such layers at shallow depth reduces the water storage capacity of the soil resulting in runoff even after a short shower, which causes floods in the low lying areas. Due to presence of subsurface mechanical impedance for root growth, the bulk density increases to about 1.62 Mg m^{-3} at about 10-15 cm depth which is higher than the critical value of 1.40 Mg m^{-3} for clay and clay loam soils.

vi. **Flooded/ Paddy soils:** Rice-wheat cropping systems have been recognized to cause both surface and subsurface soil compaction and break down of aggregates in the tilled layer. Break down of aggregates as well as compaction decreases the percentage of large size pores, which is more serious in heavy-textured soils than in light-textured soils. The increase in bulk density, cause decrease in saturated hydraulic conductivity and infiltration rate and increase in oxygen stress following irrigation or rainfall. Increase in subsurface compaction restricts root.

Rice is generally grown on puddled soils ranging in texture from sandy loam to clay. Soil puddling reduces hydraulic conductivity, infiltration rate and increases bulk density and water retention. Puddled soils dry slowly and become very hard on drying, which makes it difficult to prepare a good seed bed for the subsequent crop.

Remediation/management of physically constrained soils

The crops grown on these problematic soils do not give adequate yield as they are suffering from physical constraints. So the amelioration of these soils is very necessary and can be managed in the following ways.

i. **Eroded soils:** In eroded soils, the primary focus is on maintaining on soil fertility. The reductions in yield due to erosion could be restored by the balanced fertilizer applications (nitrogen and phosphorus fertilizers) and sometimes micronutrients. As fertilizer use became more common, the organic amendments must be added realizing their restorative effects on soil structure and hydrologic function. The relative advantage of organic amendments over inorganic fertilizers is inversely related to the organic matter content of degraded soils. Now-a-days, the capacity of conservation tillage systems to remediate eroded soils is well recognized. Continuous no-till cropping systems with cover crops are very effective because of their ability to quickly enhance organic matter content in surface soil. Increased organic matter in the surface of an eroded soil can dramatically increase water infiltration, nutrient cycling and resistance to detachment.

ii. **Compacted soils with high mechanical impedance:** For management of compacted soils having high impedance layer at shallow depth such as plough soles or pans of clay accumulation in B-horizon, adoption of chisel technology is a useful practice. A chisel is used to break subsurface compacted soils layer. The chiseling increase infiltration of water which increases water storage in the subsurface soil, improves the aeration in the root zone and encourages deeper root penetration.

iii. **Flooded/Paddy soils:** Management of soil structure, and enhancing and sustaining crop yields under rice-wheat cropping system in alluvial soils of Indo-Gangetic Plains is a difficult job. Deep ploughing along with incorporation of crop residues, FYM, leguminous green manure crops during puddling for growing of paddy have been recommended. For subsequent wheat crop, tillage must be done with respect to soil moisture content to reduce and avoid clod formation. Adoption of resource conservation technology such as zero tillage or minimum tillage for growing wheat subsequent to rice has been found to be very useful and being adopted by large number of farmers in the state of Haryana and Punjab.

iv. **Waterlogged soils:** The problem of waterlogging may be tackled by adopting preventive measures which keep the land free from waterlogging and secondly by adopting curative measures to reclaim the waterlogged area. But in principle both measures aim at reducing the inflow and augmenting the outflow from the underground reservoir.

Preventive measures include the controlling the loss of water due to seepage from the canals. The seepage loss may be reduced by adopting various measures:

a) *Lowering of full supply level (FSL) of the canal:* Seepage losses are due to percolation or absorption of water but when FSL is lowered, these losses are reduced to a large extent. It is essential to see that while lowering the FSL, the demand of the command area should not suffer.

b) *Lining the canal section: When* the canal sections are made fairly water tight by providing lining, the seepage losses are reduced to a great extent.

c) *Introducing intercepting drains:* They are generally constructed parallel to the canal. They give exceptionally good results where the canal runs in high embankments.

The loss of water due to percolation from field channels and fields can be prevented by using water more economically. It may also be affected by keeping intensity of irrigation low. Then only small portion of the irrigable tract is flooded and consequently the percolation loss takes place only on the limited area. It keeps the water-table sufficiently low.

●●●●●

Chapter-IV

SOIL POLLUTION

Soil pollution is becoming a major challenge for Indian agriculture which needs to be conquered for establishing a healthy environment. As the economy of the country largely dependent on agriculture, therefore, always a high priority is given for the development of agriculture, fisheries and animal husbandry. For the production of enough food to meet the requirement of the growing population, it becomes important to protect crops from any damage from insects, weeds, rodents and diseases. Therefore, the use of pesticides and herbicides becomes inevitable. To improve soil and prevent soil pollution, however, require judiciously use of the pesticides as these pesticides contain substantial amount of harmful chemicals.

Concept of soil pollution

Soil pollution refers to the presence of toxic chemicals in soil in high enough concentrations to pose a risk to human health and/or the ecosystem. The soil acts as a natural filter by its filtering ability, adsorption and precipitation of chemical substances and decomposition of organic materials. But its capacity is limited for processing potentially toxic residues and waste products dumped into the soil. The presence of toxic substances and pathogens which deteriorate the soil physico-chemical properties and consequently reduces productivity and quality of soil refers to as *soil pollutants*. These pollutants make the soil uninhabitable for micro- and macro-organisms.

Causes of soil pollution

Both anthropogenic and natural processes may cause soil pollution but predominantly due to human activities. The soil pollution occurs due to the presence of chemicals such as pesticides, herbicides, petroleum hydrocarbons, ammonia, nitrate, lead, mercury, naphthalene, etc., in an excess amount. Some of the major causes of soil pollution are:

Pesticides: These are synthetic chemical substances used to control insects and pests causing damage to agriculture but these chemicals have many ecological consequences. Pesticides, in general, have low water solubility and some of them are non-biodegradable which gradually accumulate in soil and persist for a longer period of time, especially, under the temperate conditions. The concentration of these chemicals increases upon their transfer to higher trophic level via food chain. Due to their regular use and residual effects, some of the pesticides such as DDT, Eldrin, etc., have been banned. When the filtering and buffering capacity of the soil is over exploited by applying substantial amounts of various kinds of pesticides, the soil may act as medium for their transmission to the ground resources or directly to the growing plants and finally to the food chain causing many metabolic and physiological disorders in human and livestock populations.

Chlorinated organic toxins: The harmful effects caused by pesticides led to the adoption of less persistent and more-biodegradable organic substance such as carbamates and organophosphates. These chemicals, however, act as harmful toxins for nerves in the body and at times led to the death of the farm labourers.

Herbicides: Though herbicides decompose within few months but still not considered environmental friendly. They are less harmful than pesticides but most of the herbicides are toxic and known to cause birth defects. Majority of the causes of soil pollution are though related to manufacturing activities in chemical and industrial processes that are released in the environment.

Inorganic fertilizers: Higher doses of fertilizers added in soil for getting maximum production may contaminate the soil with the toxic elements present in the fertilizers. For example, single super phosphate (SSP) contains cadmium and lead. Application of inorganic nitrogen fertilizers in excess creates soil acidity and contaminates the soil.

Industrial pollution: The improper waste disposal from chemical industries, paper and pulp mills, tanneries, textile mills, steel industries, distilleries, refineries, pesticides and fertilizer factories, pharmaceutical industries, cement industries, etc. can cause contamination of soil. Discharging wastes into the soil or disposes off on the soil surface lead to acidification of soil and the toxic metals like mercury, lead, cadmium, arsenic, etc. contained in the industrial wastes pollute the soil.

Improper irrigation method: Poor irrigation methods increase the soil salinity. In addition, excessive irrigation, improper maintenance of canals and channels, mono-cropping and intensive agriculture gradually decrease the soil quality and cause land degradation.

Solid waste: Disposal of solid waste such as plastics, metal cans and glasses also causes soil pollution. Disposal of electrical goods such as lithium batteries causes soil pollution due to the presence of harmful chemicals. .

Urban activities: Regular construction activities without proper waste disposal sites also cause soil pollution due to lack of proper drainage and surface run-off facilities. Chemical waste from residential areas and leakages from sewerage system can also affect soil quality and pollute the soil by changing its chemical composition.

Radioactive substances: The radioactive wastes discharged from industries, laboratories, and the aerial falls out during nuclear tests are the sources of the soil pollution. These nuclear wastes contain radio isotopes of radium, uranium, thorium, strontium, iodine, cesium, etc., persist for a long time in the soil and continue to emit hazardous radiations.

Effects of soil pollution:

i) Decline in crop quality: Regular use of inorganic fertilizers and pesticides decreases the soil fertility and alter the soil structure leading to a decrease in productivity and quality of soil.

ii) Harmful effect on human health: The increased exposure to toxic and harmful chemicals increases health threats to human and livestock populations. Living, working or playing in the contaminated soil can lead to respiratory problems, skin diseases and other health problems.

iii) Contamination of water sources: The surface run-off can carry the polluted soil and deposit into water resources and can cause surface and ground water pollution. Polluted water becomes unfit for human and animal use due to the presence of toxic chemicals.

iv) Adverse effect on ecosystem and biodiversity: Soil pollution creates an imbalance of the soil-ecosystem as soil is an important habitat for different types of microorganisms, animals, reptiles, mammals, birds, and insects. Thus, soil pollution can negatively impact the lives of these living organisms and result in the gradual death of many organisms.

Human activities are mainly responsible for majority of the soil pollution. Therefore, it is necessary to educate community about the importance of environment and impact of agricultural chemicals on soil quality and human health.

Fate of pesticides in soil:

The fate and behaviour of pesticides added into the soil involve several different and often simultaneous phenomena including chemical, biological and photochemical degradation, transport and accumulation, volatilization and leaching that are influenced to different extents by various physical, physico-chemical, biochemical, pedological and climatic factors.

The mineral composition and the amount and nature of organic matter (OM) content in the soil determine the performance of the applied pesticides. The major component of soil OM is constituted by humic substances which interact with pesticides molecule in several modes including adsorption, partitioning and solubilization, catalysis in hydrolysis and photosensitization. All these processes have implications in the fate and behaviour of pesticides in the soil system, affecting their degradation and detoxication, residue persistence and monitoring, mobilization and transport, bioavailability, phytotoxicity, and bioaccumulation.
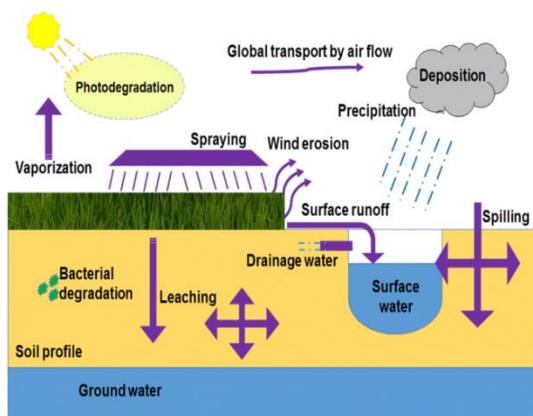
The nature of the binding forces involved and the types of mechanisms that operate, often simultaneously, in the adsorptive interaction between humic substances and pesticides includes ionic, hydrogen and covalent bonding, charge-transfer and electron donor-acceptor mechanisms, Van der Waals forces, legend exchange and hydrophobic bonding or partitioning.

i) *Ionic bonding (Ion Exchange):* Adsorption via ionic bonding, or cation exchange, applies only to those pesticides which are in cationic form in soil solution or can accept a proton (protonate) and become cationic. It involves ionized, easily ionizable, carboxylic and phenolic hydroxyl groups of humic substances.

ii) *Charge-transfer (Electron donor-acceptor mechanism):* The presence electron-deficient structures, such as quinones, and electron-rich moieties, such as diphenols in humic substances may generate possibilities for the formation of charge-transfer complexes through electron donor acceptor mechanisms with pesticides possessing electron donor or electron acceptor properties.

iii) *Covalent binding:* Formation of covalent bonds, mediated by chemical, photochemical or enzymatic catalysts and leading to stable, mostly irreversible incorporation of pesticides into humic substance, their intermediates and products of degradation (anilines and phenols) is known to occur. Acylanilides, phenylcarbamates, phenylamide, phenylureas, dinitroaniline herbicides, nitroaniline fungicides and organophosphate insecticides, such as parathion and methylparathion, are known to be biodegraded in soil with the release of aromatic amines, such as chloroanilines. These residues can be chemically bound to soil organic matter without the intervention of microbial activity.

iv) *Van der Waals forces*: Van der Waals forces consist of weak, short-range dipolar or induced dipolar attractions that operate, eventually in addition to stronger binding forces, in all adsorbent-adsorbate interactions. They assume particular importance in the adsorption of non-ionic and non-polar pesticides on suitable sites of humic molecules. Since these forces are additive, their contribution increases with increase in the size of the interacting molecule and its capacity to adapt to the surface of humic substances.

v) *Ligand exchange:* Adsorption by ligand exchange mechanism involves the replacement of hydration water or other weak ligands partially holding polyvalent cations associated to soil organic matter by suitable adsorbent molecules.

vi) *Hydrophobic adsorption and partitioning:* Hydrophobic adsorption is proposed as a pH-independent mechanism for retention by hydrophobic active sites of humic substance of non-polar pesticides that interact weakly with water. These sites include aliphatic side-chains or lipid portions and lignin-derived moieties with high carbon content and a small number of polar groups of the humic macromolecules.

Soil-inorganic pollutants interaction

Inorganic contaminants include toxic metals, different types of nutrients and salts which generally occur in the form of anions and cations. Toxic metals, such as lead, cadmium are problematic contaminants in soils, surface waters, recent sediments and aerosols mainly in urban environments. Some inorganic contaminants have infinite life. For example, cadmium will always stay as cadmium, though, it can be attenuated by adsorption or other processes but no natural process reduces the total mass of cadmium. Other compounds, such as nitrate (NO_3^-) or ammonia (NH_4^+), can be transformed into other compounds, such as N_2 or N_2O gas.

Sources of inorganic pollutants in problematic soils: Heavy metals are common contaminants in the soil and bio-accumulate, thus, their concentration in the organism increases with time as compared to the level measured in the environment. Heavy metals in the soil from anthropogenic activities tend to be more mobile, hence, bio-available than pedogenic or lithogenic. Metal-bearing solids in problematic soils can originate from various anthropogenic sources such as metal mine tailings, disposal of high metal wastes in improperly protected landfills, leaded gasoline and lead-based paints, application of fertilizer, animal manures, bio-solids (sewage sludge), compost, pesticides, coal combustion residues, petrochemicals, and atmospheric deposition.

Fate and transport of inorganic pollutants: The fate and transport of inorganic pollutants in soil depends largely on the chemical form of the metal. Upon addition, heavy metals are adsorbed by initial fast reactions (minutes, hours) followed by slow adsorption reactions (days, years) and are, therefore, redistributed into different chemical forms with varying bioavailability, mobility, and toxicity. This distribution is controlled by reactions of heavy metals in soils such as (i) mineral precipitation and dissolution, (ii) ion exchange, adsorption, and desorption, (iii) aqueous complexation, (iv) biological immobilization and mobilization and (v) plant uptake.

The organic fraction has a great influence on metal mobility and bioavailability due to the tendency of metals to bind with humic compounds in both the solid and solution phases in soil. The formation of soluble complexes with organic matter, in particular the fulvic fraction, is responsible for increasing the metal content of soil solutions. However, higher molecular weight humic acids can greatly reduce heavy metal bioavailability due to the strength of the linkages. Both complexation and adsorption mechanisms are involved in the linking of metals by organic matter thus including inner sphere reactions and ion exchange. Negatively-charged functional groups (phenol, carboxyl, amino groups) are essential in metals retained by organic matter. The increase in these functional groups during humification produces an increase in the stability of metal organic complexes which also show a greater stability at higher pH values. Soil concentration ranges and regulatory guidelines for some of the heavy metals are given in Table 1.

Table 1. Soil concentration ranges and regulatory guidelines for some heavy metals

Metal	Soil concentration range* (mg kg^{-1})	Regulatory limits** (mg kg^{-1})
Pb	1.00–69000	600
Cd	0.10–345	100
Cr	0.05–3950	100
Hg	< 0.01–1800	270
Zn	150–5000	1500

*   R. G. Riley, J. M. Zachara, and F. J. Wobber, "Chemical contaminants on DOE lands and selection of contaminated mixtures for subsurface science research," US-DOE, Energy Resource Subsurface Science Program, Washington, DC, USA, 1992. View at: Google Scholar

**   NJDEP, *Soil Cleanup Criteria*, New Jersey Department of Environmental Protection, Proposed Cleanup Standards for Contaminated Sites, NJAC 7:26D, 1996.

●●●●●

Chapter-V

Salt-affected soils develop from a wide range of factors including soil type, field slope and drainage, type of irrigation and management, fertilizer and manuring practices, and other soil and water management practices. The most critical factor in predicting, managing, and reducing salt-affected soils is the quality of irrigation water. The quality of irrigation water is critical for crop yields and quantity of crop produces, maintenance of soil productivity and protection of the environment. For example, the physical properties like soil structure, structural stability and permeability are very sensitive to the type of ions present in irrigation waters. Besides, irrigation water quality can affect need for nutrients, choice of irrigation method, and performance and longevity of irrigation system. Therefore, knowledge of irrigation water quality is essential for understanding changes in management practices to be made for achieving long-term productivity.

Criteria of irrigation water quality: The basic criteria for evaluating water quality for irrigation purposes is to determine the concentration of total soluble salts, relative proportion of Na^+ to Ca^{2+} and Mg^{2+} i.e. sodium adsorption ratio, residual sodium carbonates (RSC) i.e. the concentration of HCO_3^- and CO_3^{2-} in relation to the concentration of Ca^{2+} and Mg^{2+} and finally the excessive concentrations of elements that may cause an ionic imbalance in plants or toxicity.

The pH of the irrigation water is not an acceptable criterion of water quality as it tends to be buffered by the soil, and most crops can tolerate a wide range of pH.

1. Salinity hazard: Excessive soluble salt increases the osmotic potential of the soil solution resulting in a physiological drought condition. In spite of enough moisture in the soil, the plant roots unable to absorb moisture due to its high osmotic potential. In such situations, the water lost from the plant shoot through the process of transpiration cannot be replenished, and plants wilt.

The total soluble salts (TSS) content of irrigation water is measured by determining its electrical conductivity, EC (μS cm^{-1}) or the actual salt content (ppm). The TSS content can also be obtained by using the following relationship if EC of water is between 0.1 and 10 mS cm^{-1} or dS m^{-1}.

Total cations or anions (meq l^{-1}) = 10$\times$EC (mS cm^{-1}or dS m^{-1})

Thus, once the concentrations of total cations or anions are known, the sum of cations or anions represents concentration of total salts contained in the solution. The guidelines for water use in relation to its salt content are given in Table 1. The salinity classes of irrigation waters as per USSL Staff (1954) are presented in Table 2.

Table 1. Salinity hazard of irrigation water (Bauder *et al.* 2011)

Hazard	Dissolved salt content	
	ppm	EC (μS cm^{-1})
None- No detrimental effects on crops.	< 500	< 750
Some- Detrimental effects on sensitive crops.	500-1000	750-1500
Moderate- Adverse effects on many crops, requiring careful management practices.	1000-2000	1500-3000
Severe- Can only be used for salt tolerant plants on permeable soils with careful management practices.	2000-5000	3000-7500

Table 2. Salinity classes of irrigation waters (USSL Staff, 1954)

Salinity of irrigation water- EC (μS cm^{-1})	Salinity class	Salinity hazard	Remarks
100–250	C1	Low	Suitable to irrigate most crops on most soils.
250–750	C2	Medium	Suitable to irrigate moderate salt tolerant plants if a moderate amount of leaching occurs.
750–2250	C3	High	Can be use for irrigating good salt tolerant crops on soils not possessing restricted drainage i.e. poor leaching abilities.
> 2250	C4	Very high	Not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances.

As the USSL Staff (1954) water classification does not present an EC over 2250 μS cm^{-1} and most of the irrigation waters possess salinity higher than 2250 μS cm^{-1}. Therefore, for accommodating higher water salinity levels, Shahid and Mahmoudi (2014) modified the USSL Staff (1954) water classification by extending water

salinity up to 30,000 μS cm^{-1} (Fig. 1). The SAR as shown on y-axis (Fig.1) can be calculated by using the following formula:

$$SAR = \frac{Na^+}{\sqrt{\frac{1}{2}\ (Ca^{2+} + Mg^{2+})}}$$

where, the concentrations of Na$^+$, Ca^{2+} and Mg^{2+} are expressed as meq l^{-1}. The values of the electrical conductivity given on the x-axis are expressed in μS cm^{-1}. The position of the SAR and EC points determines the quality class assigned to the water.

2. Sodium hazard

The sodium hazard of irrigation water is expressed in term of SAR. Although sodium contributes directly to the total salinity and may also be toxic to sensitive crops and fruit trees, but the major problem with a high sodium concentration is its effect on the physical properties of soil. Continued use of high SAR water leads to breakdown of soil aggregates as result of adsorption of excessive amounts of sodium on soil colloids. This breakdown results in the dispersion of soil colloids which causes the soil to become hard and compact upon drying. The soil becomes increasingly impervious to water due to dispersion and swelling when wet. Soils high in clay content are especially subject to this action. When sodium exceeds the concentration of calcium plus magnesium, the soil is called sodic. Soils having calcium and magnesium as predominant cations on the exchange complex, the soil can be easily be tilled and will have a permeable granular structure. Sodicity classes of irrigation water as per USSL Staff (1954) are presented in Table 3.

Table 3. Sodicity classes and hazard of irrigation water (USSL Staff, 1954)

SAR**	Class	Remarks
< 10	S1 (Low*)	Suitable to irrigate almost all soils with little danger
10-18	S2 (Medium)	May be used in coarse textured or organic soils with good permeability. Cause appreciable sodium hazard in fine textured soils having high cation exchange capacity, especially, under low leaching conditions
18-26	S3 (High)	Harmful levels of exchangeable sodium in most soils. Its use will require special soil management methods, good drainage, a high leaching ability and high organic matter conditions.
> 26	S4 (Very High)	Unsuitable for irrigation purposes

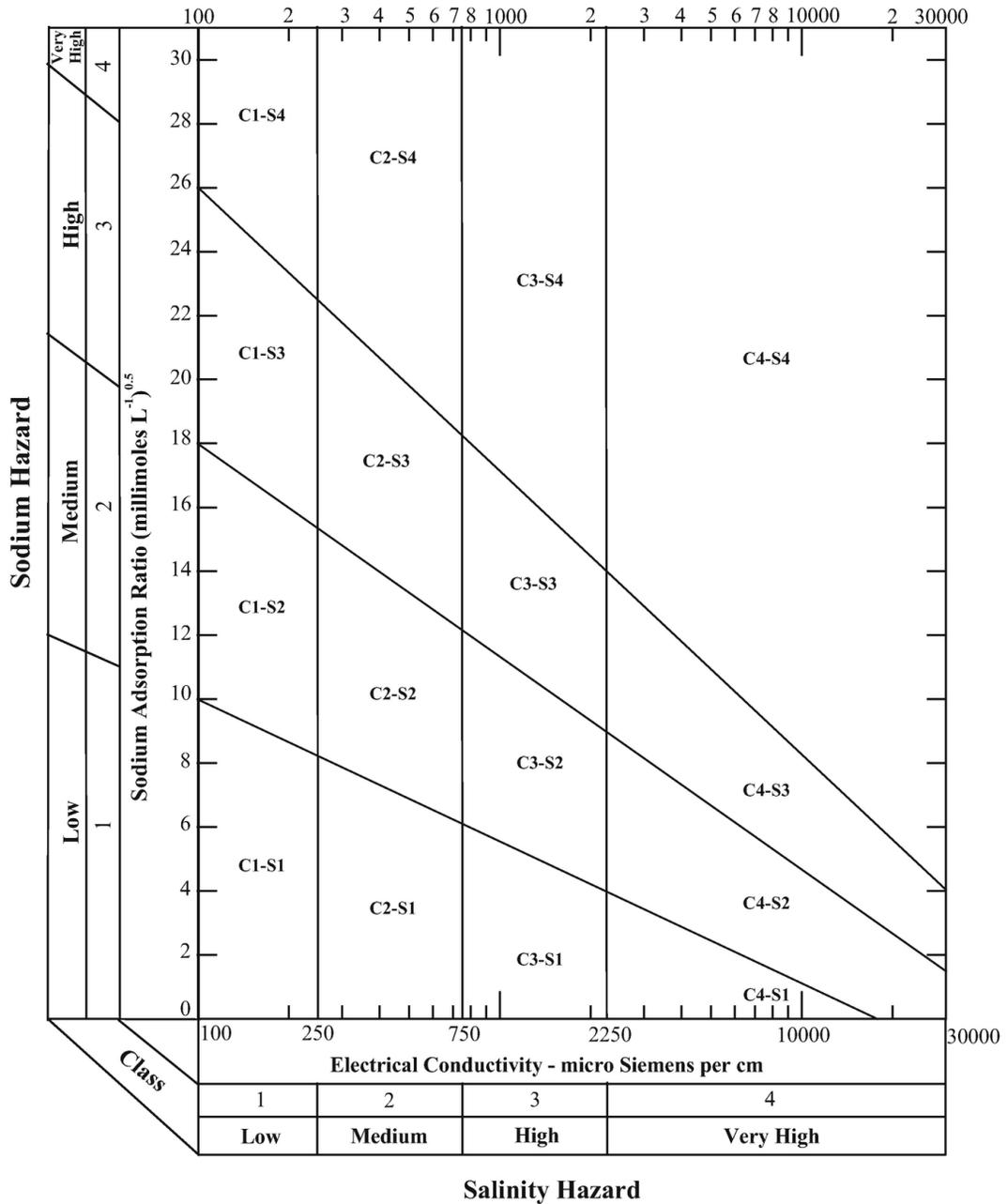*sodicity hazard is shown in parentheses, ** Unit of SAR- (mmoles l^{-1})$^{0.5}$

Fig. 1. Illustration for the classification of irrigation waters (USSL Staff 1954; modified by Shahid and Mahmoudi, 2014)

3. Concentration of carbonates and bicarbonates

Irrigation water having high concentration of CO_3^{2-} and HCO_3^- tends to precipitate $CaCO_3$ and $MgCO_3$ when the soil solution becomes concentrated by loss of water through evapotranspiration. The SAR increases and the relative proportion of Na^+ become greater which in turn, increases the Na^+ hazard of the soil solution to a level greater than that indicated by the SAR value. Another approach widely used to predict the additional sodium hazard associated with precipitation of $CaCO_3$ and $MgCO_3$ involves a calculation of RSC.

RSC (meq l^{-1}) = $(CO_3^{-2} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ where the concentrations of the ions are in meq l^{-1}.

If RSC (meq l^{-1}) is < 1.25, the water is safe for irrigation; 1.25-2.50,- water is marginal for irrigation and if it is > 2.5 then water is unsuitable for irrigation.

4. Specific ion effects

Certain crops may be sensitive to moderate to high concentrations of specific ions in the irrigation waters or soil solution, in addition to salinity and sodium hazards. When an element is added to the soil through irrigation, it may be inactivated by chemical reactions or buildup in the soil until it reaches a toxic level. An element at a given concentration in irrigation water may be immediately toxic to a crop or require years to accumulate in the soil before it becoming toxic.

4.1 Sodium toxicity: Sodium toxicity appears in the form of leaf burn, leaf scorch and dead tissues running along the outside edges of leaves. In trees, sodium concentration in excess of 0.25-0.5% in the leaf tissue is often considered to be toxic. FAO-UNESCO (1973) proposed exchangeable sodium percentage (ESP) corresponds to tolerance levels in some crops/plants (Table 4).

Table 4. Exchangeable sodium percentage (ESP) corresponds to tolerance levels in some crops/plants (FAO-UNESCO 1973)

ESP	Tolerance	Crops/Plants
< 15	Sensitive	Beans, Maize, Peas, Orange, Peach, Mungbean, Mash, Lentil, Gram and Cowpea.
15-40	Semi-tolerant	Carrot, Clover, Lettuce, Berseem, Oat, Onion, Radish, Rye, Sorghum, Spinach and Tomato
> 40	Tolerant	Alfalfa, Barley, Beet, Rhodes grass and Karnal (Kallar) grass.

4.2 Boron toxicity: Boron, though, is an essential element in low concentration, for normal growth of all plants. Upon exceeding a certain level of tolerance depending on the crop, it may cause injury. For maintain an adequate availability of boron to the plant, a concentration of at least 0.02 ppm is required in irrigation water but the concentration exceeding 1.0 ppm may toxicity to boron sensitive crops. Boron toxicity may include characteristic leaf burning, chlorosis and necrosis, however some boron sensitive species do not develop clear symptoms. The symptoms first appear on older leaves as yellowing, spotting, or drying of tissues at the tips and edges. The drying and chlorosis often progresses toward the center of the leaf and between the veins upon its accumulation over time. The irrigation water having the concentration of < 0.5 ppm of boron may be used satisfactorily in all crops, 0.5-1.0 ppm in most crops, 1-2 ppm in semi tolerant and 2-4 ppm only in tolerant crops.

4.3 Chloride toxicity: The chloride toxicity is most common in all irrigation waters. The chlorides are soluble and readily leach. Chlorides are essential but high concentrations may inhibit plant growth, and can be highly toxic to some plant species. In sensitive crops, symptoms occur when Cl^- levels of 0.3–1.0% (dry weight basis) accumulate in leaves. The toxicity appears first at the leaf tips (very common symptom) and advances back along the edges as severity of the toxic effect increases. Excessive necrosis is often accompanied by early leaf drop or even total plant defoliation.

Use of saline water in agriculture

The fresh water from the surface and ground resources is only < 1% of the total water available on planet Earth, of which about 70% is used for agriculture. Earlier, it was a common belief that saline water and salt-affected land are unusable. But scientific research has provided a practical solution and made possible to grow crops on salt-affected lands (saline agriculture) as long as the salt tolerant crops are taken in combination with alternative techniques in irrigation, fertilization and water management. In saline agriculture, crops are grown on salt-affected soils and brackish water is used for irrigation.

1. **Crop and cultivar choice:** There are different crop species differing in their tolerance to salinity ranging from some beans (very sensitive) that may die at salinity level of ~5 dS m^{-1} up to a very tolerant species (halophytes) that can survive and reproduce at seawater salinity levels. This means that for most salinity levels, a suitable crop can be identified.

2. **Irrigation:** It is important to irrigate regularly in saline agriculture with fresh or brackish water because salts concentrate in the soil with decrease in the amount of water through evapotranspiration. Therefore, it is important to keep the soil moisture as constant as possible. While irrigating with brackish water it becomes important to irrigate enough so that salts don't accumulate in the surface layer but are drained to deeper soil layers or, preferably, a drainage system. Only sandy

soils are to irrigate with brackish water as it leads to structural problems in clayey and in turn affects the permeability to water and the soil aeration.

3. *Fertilization:* The application of fertilizers further enhances the problem of salinity in saline agriculture and can increase the osmotic stress of crops. Foliar spray of fertilizers is the solution to the problem.

4. *Soil management:* Soil management includes the management of organic matter in the soil by practicing zero tillage, application of soil additives, etc. Manure and compost should be applied regularly, if available. Bed shape can be important depending on irrigation method. Use of microbial-based soil additives may also help boost yields.

Reference

Bauder TA, Waskom RM, Sutherland PL, Davis JG (2011) Irrigation water quality criteria. Colorado State University Extension Publication, Crop series/irrigation. Fact sheet no. 0.506, 4 pp.

USSL Staff (1954) Diagnosis and improvement of saline and alkali soils. USDA Handbook No 60. Washington DC, USA 160 pp

Shahid SA, Mahmoudi H (2014) National strategy to improve plant and animal production in the United Arab Emirates. Soil and water resources Annexes.

FAO/UNESCO (1973) Irrigation, drainage and salinity. An International source book. UNESCO/FAO, Hutchinson & Co (Publishers) Ltd, London, 510 pp

●●●●●

REMOTE SENSING AND GIS

Remote sensing is the science of acquiring information about the Earth's surface or object without any physical contact. It is done by sensing and recording reflected or emitted energy, and processing, analyzing and applying that information. In most of remote sensing, the process involves an interaction between incident radiation and the object of interest (Fig. 1). The components of remote sensing are:
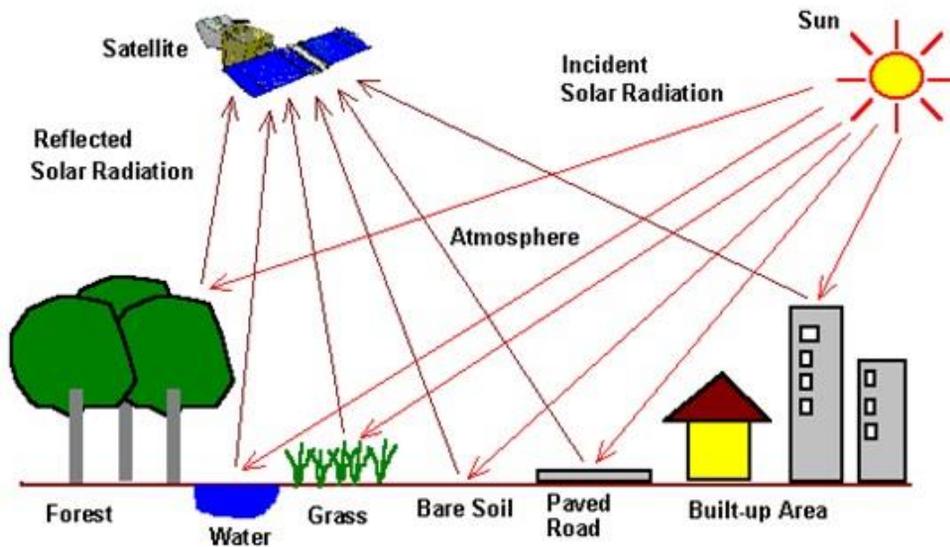

Fig. 1: Components of remote sensing

A. *Energy source or Illumination:* An energy source which illuminates or provides electromagnetic energy to the object of interest is the basic requirement of remote sensor.

B. *Radiation and the atmosphere*: While traveling from its source to the object, energy interacts with the atmosphere it passes through. This interaction takes place again as the energy travels from the target to the sensor.

C. *Interaction with the object:* The interaction of the energy reaching to the object through the atmosphere depends on the properties of both the object and the radiation.

D. *Recording of energy by the sensor:* After the energy has been scattered by or emitted from the object, a remote sensor collects and records the electromagnetic radiation.

E. *Transmission, reception, and processing:* Energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing

station where the data are processed into an image (hardcopy /soft copy or digital).

F. *Interpretation and analysis:* Processed image is interpreted, visually and/or digitally or electronically to extract information about the object which was illuminated.

G. *Application:* Finally, the information is extracted from the imagery for better understanding about the object and to reveal some new information which assists in solving a particular problem.

Use of remote sensing in identification and monitoring of salt affected soils:

- All ground-based, air-borne and space-borne sensors have been used to identify and monitor salt affected soils. The air-borne or space-borne remotely sensed data are generally matched with the field measurement in order to determine the relations between the spectral signature and the surface properties.

- The major soil components affecting image interpretation for salt affected soils include minerals and amorphous materials, organic matter, air and soil solution containing a variety of dissolved compounds.

- There is a high correlation between soil reflectance and soil properties such as mineralogy, organic matter content, moisture content, particle size distribution, iron oxide content and surface conditions.

- Ground observations and radiometric measurements indicated that amount and composition of salts, moisture content, colour, and surface roughness are the main factors affecting the reflectance.

- Most of the features seen in spectrum of saline minerals (400–2500 nm) can be attributed to internal vibration modes of certain molecular groups, particularly, carbonate, borate, hydroxyl anion groups and neutral water molecules.

Field work: Initially traverse of the study area is made to identify the sampling points in the area. Detailed field investigations are carried out in various physiographic units to observe the broad physiographic-soil relationship. The study area is surveyed periodically during the year and the ground truth is collected from different locations and soil samples are taken from different depths from both salt affected and non-salt affected areas along with their geographic location using GPS. Ground water samples from the existing tube-wells are also collected for assessing the quality of the groundwater for irrigation in the study area.

Soil samples collected from different locations and depths are processed i.e. air dried, ground using mortar and pestle and passed through a 2 mm brass sieve and stored for further analysis. The standard methods are used for determination of different physico-chemical properties of soil such as pH, EC, organic carbon, calcium carbonate content, soluble cations and anions.

Geoinformatics based methodology: The base maps indicating permanent features such as major canals, highways, roads, railways, villages and sand dunes are prepared using SOI topographical sheets and ground truthing. Preparation of base maps is followed by image processing as depicted in flow chart and interpretation.

Standard false colour composite (FCC) is visually interpreted for salt affected soils and waterlogged areas with the help of image elements like tone, texture, shape, size, pattern and association, etc. The salt affected soils usually appear in tones of bright white to dull white with medium to coarse texture on standard FCC due to the presence of salts on soil surface. The landforms associated with the occurrence of salt affected soils are also considered during interpretation.

The obstruction of natural drainage like roads, railway lines and canal distributaries can easily be identified on the FCC image. The waterlogged areas appear on the FCC image in dark blue to a black tone with a smooth texture.

Along with visual image interpretation, various indices such as Normalized difference vegetative index (NDVI), normalized difference salinity index (NDSI), vegetation soil salinity index (VSSI) and salinity index (SI) are also worked out to confirm the results of image interpretation and laboratory studies.

●●●●●
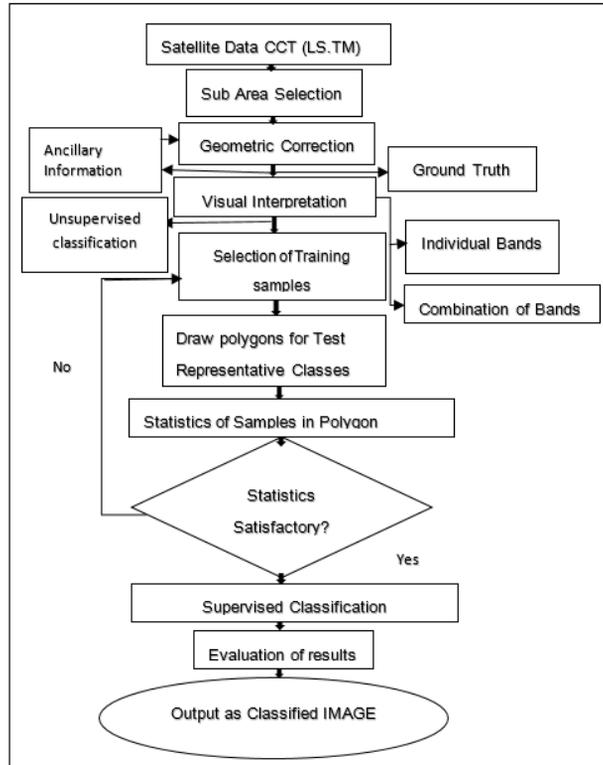
Chapter-VII

The tree species that are grown for more than one purpose such as fuel, wood, timber, fibre, fodder, food environment conservation, shade, or medicine or any other purpose are known as *multipurpose tree species* (MPTs).Some of these trees having deep root system bring subsoil nutrients to the surface and also help in reducing soil erosion. Many trees provide fodder, living fence, fruit and other edible parts, shade, insecticides, and wood. All have some role in soil stabilization and offer substances for quality life like aesthetic value and shelter for informal gatherings.
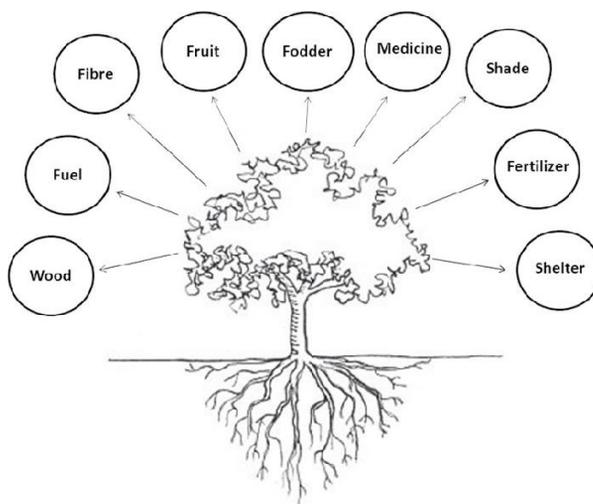

Fig. 7.1: Multipurpose trees and their uses

Tree species can be multipurpose in two ways:

- Trees of the same species when managed differently can yield different crops. For example, *Leucaena leucocephala* is managed in many countries in such a way that some trees will principally yield wood while others produce tree fodder for utilisation as leaf meal.

- A single tree can yield more than one crop. For example, *Gliricidia sepium* is grown in some countries as living fences that provide fuel, fodder, and green manure for agricultural crops, all at the same time.

One can grow multipurpose trees in various combinations with other crops as in agroforestry, block plantations of trees, boundary plantation or naturally regenerating tree farms. Sometimes, these are grown and managed for only one purpose e.g. *Gliricida sepium* is grown only to provide shade in coffee plantations while the same species are planted and managed in such a way that results in different shapes and uses. The market and environmental conditions may also change the way to manage a tree. For example, market changes may persuade the trees grown for fodder and fuel, to cut for sale as round wood for construction material.

Common multipurpose trees of the tropics include:

- Moringa (*Moringa oleifera*)– edible leaves, pods and beans, commonly used for animal forage and shade but does not fix nitrogen as commonly believed.

- Gliricidia (*Gliricidia sepium*)– the most common tree used for living fences, firewood, fodder and fixing nitrogen into the soil.

- Neem (*Azadirachta indica*)– used as insect repellent, antibiotic, adding nitrogen to the soil, windbreaks, biomass production for use as mulch and firewood, and neem oil for neem coated urea.

- Coconut palm (*Cocos nucifera*)– used for body and hair oil, soaps, cosmetics, food, juice, roof thatching, firewood and shade.

Some of the forest trees species with their multiuse found in India

Tree specie	Local name	Uses
Acacia auriculiformis	Babool	Fuel wood, timber wood used for toys and handicraft, shade and ornamental.
Acacia nilotica	Kikar	Gum/resin extracted from the pod used for inks and dyes. Wood used for agricultural implements such as plough.
Morus alba	Shehtut	Rearing silk-worms, fuel wood, timber wood, fodder and medicinal uses.
Leucaena leucocephala	Safed babool	Fodder, fuel wood, small timber and leaf as soil mulch.
Dalbergia sissoo	Sheesham	Paper pulp, fuel wood, timber wood, fodder and lubricant.
Azadirachta indica	Neem	Medicinal or insecticidal properties, fodder, fuel wood and small timber.
Eucalyptus hybrida	Safeda	Pulp wood, fuel wood, charcoal, timber wood and leaf oil.
Tectona grandis	Sagwan	Timber wood, fuel wood and wind break. Insect and termite resistant.
Syzygium cuminii	Jamun	Edible fruit, medicinal use, hedge
Bambusa arundinacea	Baans	Fodder, paper pulp, wood used for making furniture, ornamental vases, boxes, etc.
Populus sp.	Poplar	Wood and bark used for making plywood, boards, matchsticks & pencil.
Salvadora persica	Pilu	Reclaim salt affected soil, used as a natural toothbrush and medicinal value
Terminalia arjuna	Arjun	Avenue tree, medicinal value and reclaim alkali soil
Albizzia procera	Siris	Timber wood, fuel wood and fodder.

Advantages of multipurpose tree species

1. ***Reduced risk of total crop failure:*** Growing multipurpose trees can reduce the risk of total crop failure. For example, if *Leucaena leucocephala* is grown for animal fodder and its leaves are destroyed by pests, the wood of the tree still be used for fuel, pulp or light weight construction material. Growing different varieties of trees on a farm can also reduce the risk of total crop failure and provide a type of insurance. If the economic benefit of one crop is reduced by pest damage or market failure that can make up by harvesting another crop. Growing a variety of tree species makes the farm less vulnerable to any one pest.

2. ***Income generation and distribution:*** Adopting agroforestry practices can increase annual income by harvesting different tree crops in different seasons. For example, in many Asian countries, the leaves of *Artocarpus heterophyllus* (jackfruit) are used as fodder during the driest season but the trees produce fruits providing income and food at other times. *Azadirachta indica* provides additional income through neem oil used for various insecticidal properties. Thus, the income and employment are distributed more evenly throughout the year. Other reasons for growing different tree species on farms include shade to reduce soil temperature, reduce loss of soil moisture and protect the soil from wind and water erosions.

3. ***Bio-drainage for saline and waterlogged soils:*** Bio-drainage using tree species is a promising technology to remediate the saline and waterlogged soils. It is cost-effective and environment-friendly biological technology to lower the rising water table below the root zone of crop and eliminate the drainage effluent hazards. It simultaneously produces higher economic returns through fodder, fuel wood or fibre and sequesters carbon in biomass. The whole process of bio-drainage system includes absorption, translocation and transpiration of excess groundwater into the atmosphere by deep rooted vegetation having high consumptive demand for water. Apart from lowering of the groundwater table, bio-drainage plantation improves ecology of the area and combats wind erosion.

Quick growing tree species like *Eucalyptus* having luxurious water consumption are suitable for bio-drainage under excess soil moisture conditions. *Eucalyptus* has a special rooting system which consists of a shallow rooting system just beneath the soil surface and deep tap roots that penetrate deep into the soil reaching the water table. The shallow roots extend horizontally to more than 3-5 m, absorb surface soil moisture but they are not very dense. The tap roots could grow up to 9 m deep into the soil take up groundwater which is permanently available than surface soil moisture. In dry conditions, *Eucalyptus* shifts their water uptake to the deep roots which enable them to survive and even grow during dry periods.

Other species suitable for biodrainage are *Acacia nilotica, Casuarina glauca, Terminalia arjuna, Pongamia pinnata, Syzygium cuminii, Bambusa arundinacea and Poplar*. The species for plantation in the salt affected areas for reclamation are *Salvadora, Tamarix, Eucalyptus, Prosopis juliflora*.

Limitation of bio-drainage:

i. Applicable in areas having plenty of inexpensive land as certain portion of farm land is needed for tree plantation.

ii. Non-availability of proper guidelines and suitable bio-drainage model specific in different agro-climatic conditions.

iii. Still need to explore the potential of different bio-drainage species, geometric approaches of effective plantations, proper spacing and physiological aspects relating to companion crop and tree interactions.

iv. Quantification of the time required for a certain water table drawdown, the effect of declined water table under plantation to the adjoining areas and the salt balance between the soil and the plants in a bio-drained saline land is still lacking.

Bio-remediation: Bio-remediation refers to the use of biological organisms to solve environmental problems such as contaminated soil or groundwater. Apart from waterlogged soils as discussed earlier, other problematic soils could also be reclaimed using different tree species through various mechanisms as described below.

1. Agroforestry practices: Agroforestry is the collective name for all land use systems in which woody perennials tree are deliberately grown with agricultural crops, with or without animals, in some form of spatial or temporal sequences. It is practiced for better utilization of resources, minimize the environmental degradation, improve the soil organic matter content through leaf litter and plant debris, and maximize the efficient nutrient cycling within system. Proficient utilization of nutrients, biological nitrogen fixation and increased availability plant nutrients are added advantages of agroforestry. Problematic soils can also be improved under agroforestry systems without using any pesticide, fertilizer and insecticide. The desirable properties which are likely to make a woody perennial suitable for soil fertility maintenance or reclaiming are:

❖ A high production rate leafy biomass.

❖ A dense network of fine roots with a capacity for abundant mycorrhizal association.

❖ The existence of deep roots.

❖ A high rate of nitrogen fixation.

❖ A high and balanced nutrient content in the foliage and litter of high quality (high in nitrogen, low in lignin and polyphones).

❖ An appreciable nutrient content in the root system.

❖ A rapid rate of litter decay, if nutrient release is desired and a moderate rate where maintenance of a soil cover is required.

❖ Absence of toxic substances in the litter or root residues.

❖ For soil reclamation, a capacity to grow on poor soils.

❖ Absence of severe competitive effects with crops, particularly, for water.

❖ Productive or service functions other than soil improvement.

2. Agroforestry in salt affected soils: Trees grown with agricultural crops in salt affected soils improve the physical condition of soil, minimizes the salt accumulation in the surface soil, improves water permeability and facilitate leaching of salts, decreases the bicarbonates, reduces soil pH and soluble salts, increases water holding capacity and enhances soil fertility. In addition, enhanced cation exchange capacity, reduced exchangeable sodium percentage and improved desodification processes in the soil profile can take place through tree planning in salt affected soils. Various agroforestry systems which are proposed to remediate the chemically degraded soil are:

Sodic/alkali soils:

- Salt tolerant MPTs are raised in block plantation with reduced spacing for production of fuel wood, fodder and other non-timber forest produces. These species ameliorate alkali soils at a faster rate due to build up of organic matter and the recycling of important nutrients. *A. nilotica, Albizia procera, L. leucocephala, Azadirachta indica* and *Eucalyptus* hybrid are most suitable tree species for rehabilitation of alkali soils.

- *Prosopis juliflora* and Karnal grass improves the soil condition to such an extent that after some time or years, less tolerant but more palatable fodder species such as Berseem (*Trifolium alexandricum*), senji (*Melilotus parviflora*) and shaftal (*Trifolium resupinatum*) can be grown successfully under the trees.

- Salt tolerant agri-horticultural systems are also practiced for production of various products and reclamation of soils. Agricultural crops such as Egyptian clover, wheat, onion, and garlic cultivated under *Carissa carandus* (karonda), *Punica granatum* (pomegranate), *Emblica officinalis* (amla), *Psidium guajava* (guava), *Syzygium cumini* (jamun) *and Ziziphus mauritiana (plum)* also improve the properties of alkali soils.

- Promising salt tolerant MPTs along with grasses (Silvipastoral system**s)** are adopted in the agroforestry system to reclaim the alkali soils. Most suited tree species for reclamation of alkali soils are *Prosopis juliflora, Acacia nilotica, Casuarina equisetifolia, Terminalia arjuna, Tamarix articulata* and *Pongamia pinnata*. Similarly, the grass species like *Leptochloa fusca, Chloris gayana, Brachiaria mutica, and Sporobolus spp*. also improve alkali soils.

- Trees such as *Eucalyptus tereticornis, Acacia nilotica, Albizia lebbeck, Terminalia arjuna, Prosopis juliflora* (Agrisilvicultural system) are selected on the basis of the ability of the species to tolerate sodicity, however, agricultural crops are grown as intercrops on the basis of local need such as berseem, rice, wheat and mustard to reclaim alkali soils.

Saline soils: Silvipastoral system: Promising woody species for saline soils are *Salvadora spp., Prosopis juliflora, Acacia nilotica, Parkinsonia aculeata, Butea monosperma, Terminalia arjuna, Salix spp., Dalbergia sissoo and Casurina equisetifolia*. Similarly, highly salt tolerant and high biomass producing grass species include *Aeluropus lagopoides, Sporobolus helvolus, Cynodon dactylon and Brachiaria ramose* are taken together with tree species to reclaim saline soils.

Saline-sodic soils Acacia auriculiformis, Azadirachta indica, Casurina equisetifoia, Dalbergia sissoo, Alianthus excelsa, Prosopis cineraria, Acacia tortilis and A. nilotica tree species are used for bioremediation of the saline-sodic soils.

3. Agroforestry in physically constraint soils: Soils such as paddy soil, sandy soil, sub-soil mechanical impedance or hardpan, surface crusting, peat and marshy, and waterlogged soils could be reclaimed by using Silvipastoral system including tree species such as *Eucalyptus robusta, Syzygium cumuni, Terminalia arjuna, Salix tetrasperma, Dalbergia latifolia, Eucalyptus camaldulensis, Eucalyptus grandis* and grasses like *Brachiaria mutica, Dichanthium caricosum, Paspalum notatum, Brachiaria decumbens*.

●●●●●

Exercise-VIII

LAND CAPABILITY AND SUITABILITY CLASSIFICATIONS

The land is used for several purposes such as crop and livestock production, forestry, housing, recreation, markets, roads, railways, etc. The most desired way of using a particular land requires understanding the type of soil in the land capability classification. The technique which allows determination of the most suitable use for any area of land is called *land classification*. Large number of systems of land classification is in practice varying mainly based on the purpose for which the land is classified. Land may be classified according to its present land use, its suitability for a specific crop under the existing management practices, its capability for producing crops or combinations of crops under optimum management, or its suitability for non-agricultural uses.

"Land capability classification is the grouping of land into defined classes based on their capability to produce crops. The capability of land unit depends on their limitations and is designed to emphasize on the hazards in different kinds of soils"

The capability classification is consisted of a number of interpretive groupings of lands made primarily for agricultural purposes. This classification begins with the individual soil-mapping units which are considered as building stones of the system. The arable soils are grouped according to their potentialities and limitations for sustained production of the common cultivated crops that do not require specialized site treatment. Non-arable (unsuitable for sustained use for crops) soils are grouped according to their potentialities and limitations for the production of permanent vegetation including the risks upon mismanagement.

The grouping of soils into different capability classes and sub-classes is based on of their capability to produce crops and pasture biomass sustainably. Land capability classification systems study and record data relevant to determine the combination of agricultural and conservation measures that would permit the most intensive and appropriate agricultural land use without soil degradation. The criteria used for assessing land unit are mainly based on inherent soil properties, land features and the environmental factors that limit land use. The factors that determine the capability of a soil include depth, stoniness, rockiness, texture, structure and permeability of soil; slope; extent of erosion; susceptibility to flooding and wetness; presence of toxic salts; alkali and other unfavorable chemical properties such as pH, salt; and severely of climate (soil temperature and moisture regimes).

Land capability classification: It is done at class, sub-class and unit levels.

i. Class

The soils are grouped into eight classes depending upon the degree of limitations on the land use and designated in Roman numeral from I to VIII. Soils with greatest capabilities and least limitations are included in Class I while those with least capabilities and greatest limitations are placed in Class VIII. Class I to Class IV include land suited for cultivation but can be used for other purposes. Class V to Class VIII includes lands that are unfit for cultivation under normal management but can maintain natural forest or grasses.

Class I: Excellent soils for cultivation almost without any limitation to restrict their use. These soils are deep, productive, easily worked, posses low erosion hazards, and need ordinary management practices for maintaining their productivity. These are shown green on land capability maps.

Class II: Soils have some limitations that reduce the choice of plants or require moderate conservation practices. Limitations include (singly or in combination) gentle slopes, moderate susceptibility to erosion, less than ideal soil depth, unfavorable soil structure to some extent, slight to moderate correctable salinity, occasional damaging overflow, wetness correctable by drainage, slight climatic limitation. Soils require more than ordinary management practices for obtaining optimum production and for maintaining productivity. These are shown yellow on land capability maps.

Class III: Soils have severe limitations reducing the choice of plants or require special conservation practices. The limitations of soils are the same as those of Class II but of higher degree including additional limitations such as shallow depth, low moisture-holding capacity, low fertility that is not easily corrected, require considerable management inputs. These are shown brown on land capability maps.

Class IV: Soils have very severe limitations that restrict the choice of plants and/or require very careful management. Restrictions in choice of plants, management and conservation practices are greater than in Class III to the extent that production is often marginal in relation to the inputs required. Limiting factors are of the same nature as in the previous classes but more severe and difficult to overcome. Several limitations like steep slopes are a permanent feature of the land. These are shown pink on land capability maps.

Soils of classes V to VIII are generally not suited for cultivation but some of them may be made suitable with costly measures.

Class V: Soils have few or no erosion hazards but have other limitations which are not practical to be removed, therefore, restricting their use to pasture, range, woodland, or wildlife food and cover. Soils may be level or nearly level but many of these soils are subject to inundation or are stony or rocky. These are shown dark grey on land capability maps.

Class VI: Soils have severe limitations that cannot be corrected restricting their use largely to pasture, range, woodland, or wildlife food cover. They may serve for some tree crops with unusually intensive management practiced. These are shown orange on land capability maps.

Class VII: Soils have very severe limitations that make them unsuited to cultivation and restrict their use largely to grazing, woodland, or wildlife and are not suitable for any of the common crops. These are shown red on land capability maps.

Class VIII: Soils and land forms have maximum limitations such as rocky, arid, wet or extremely saline and cannot be used for commercial plant production but suitable only for wild life and recreation. These are shown purple on land capability maps.

ii. Sub-class

Sub-classes are groups of capability units within the classes that have the same kinds of dominant limitations for agricultural use due to soil and climatic conditions. Sub classes explain the reason for the limitation for intensive crop production. These are based on climate, erosion, soil hazard and wetness. There are four kinds of limitations recognized at the subclass level i.e. risks of erosion, designated by the symbol (e), wetness, drainage, or overflow (w), rooting-zone limitations (s) and climatic limitations (c). The subclass provides the information about the degree and kind of limitation to the map users. Capability class I has no subclasses. Adding limitation symbol to the capability class designates the subclass such as IIIc and IVe indicate the Class III with climatic limitation and Class IV with risk of erosion, respectively.

iii. Unit

The capability unit is the smallest and last category in land capability classification system providing more specific and detailed information than the subclass for application to specific farm fields. The soils in capability unit are nearly similar in suitability for plant growth and responses to the same kinds of soil management. Soils grouped into a capability unit should be sufficiently uniform in the combinations of soil characteristics that influence their qualities to have similar potentialities and continuing limitations or hazards. Therefore, the soils in a capability unit should be sufficiently uniform to (a) produce similar kinds of cultivated crops and pasture plants with similar management practices, (b) require similar conservation treatment and management under the same kind and condition of vegetative cover, and (c) have comparable potential productivity. Adding number to the sub-classes forms land capability units. For example, capability units IIc1 would represent Class II with climate arises from different causes.

Land suitability classification

Land suitability is the fitness of a given type of land for a defined use in its present condition or after improvements. The land suitability classification is the evaluation and grouping of specific areas of land for their suitability to defined uses. For example, in a region where arable use, animal production and forestry are believed to be possible on certain areas, a separate suitability classification is made for each of these three kinds of use. There may be certain parts of the area in which particular kinds of use are not relevant e.g. irrigated agriculture beyond a limit of water availability. In such situations, suitability need not be assessed. Such parts are shown on maps or in tables by the symbol NR: Not Relevant.

Structure of the suitability classification

The structure recognizes the same categories in all of the interpretative classification as given below. Each category retains its basic meaning within the context of the different classifications and as applied to different kinds of land use. The four land suitability categories of decreasing generalization recognised are:

i.	Orders	Tell the kinds of suitability
ii.	Classes	Reflect degrees of suitability within Orders.
iii.	Subclasses	Tell kinds of limitation or main kinds of improvement measures required, within Classes.
iv.	Units	Reflect minor differences in required management within Subclasses.

i) Land suitability orders: Land suitability orders indicate whether land is assessed as suitable or not suitable for the given use. There are two orders represented in maps, tables, etc. by the symbols S and N respectively.

Order S Suitable	Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs without risk of damage to land resources.
Order N Not Suitable	Land which has qualities that appear to prevent sustained use of the kind under consideration.

Land may be classed as 'Not Suitable' for a given use for various reasons. For example, the proposed use may be technically impracticable such as the irrigation of rocky steep land, or it would cause severe environmental degradation upon cultivation of steep slopes. The reason is, however, economic i.e. the value of the expected benefits does not justify the expected costs of the inputs.

ii) Land suitability classes: Land suitability classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic numerals, in sequence of decreasing degrees of suitability within the Order. Within the 'Order Suitable' the number of classes is not specified. There might, for example, be only two, S1 and S2.

The number of classes recognized should be kept to the minimum necessary to meet interpretative aims; five should probably be the most ever used. If three Classes are recognized within the Order Suitable, often recommended, the following names and definitions may be appropriate in a qualitative classification:

Class S1 Highly Suitable	Land having no significant limitations to sustained application of a given use, or only minor limitations not significantly reducing productivity or benefits and raising inputs above an acceptable level.
Class S2 Moderately Suitable	Land having limitations which in combinations are moderately severe for sustained application of a given use reducing productivity or benefits and increasing the required inputs to the extent that the overall gained from the use is still attractive, though appreciably inferior to that expected on Class S1 land.
Class S3 Marginally Suitable	Land having limitations which in aggregate are severe for sustained application of a given use reducing productivity or benefits, or increasing required inputs in such a way that the expenditure is only marginally justified.

In a quantitative classification, both inputs and benefits must be expressed in economic terms. In different circumstances different variables may express most clearly the degree of suitability e.g. the range of expected net income per unit area, per standard management unit or the net return per unit of irrigation water applied to different types of land for a given use.

If additional refinement is considered necessary, additional classes may be added e.g. S4 and not by subdividing the classes as the degrees of suitability are represented by only one level of the classification structure, that of the suitability class. If four classes are employed for classifying land with respect to arable use and only three with respect to forestry, the 'Marginally Suitable' could refer to S4 in the former case but S3 in the latter. An alternative practice has been adopted in some countries. In order to give a constant numbering to the lowest Suitable class, classes have been subdivided as, e.g. S2.1, S2.2.

Suitability Class S1, Highly Suitable, may sometimes not appear on a map of a limited area, but could still be included in the classification if such land occurs in other areas relevant to the study. Differences in degrees of suitability are determined mainly by the relationship between benefits and inputs. The benefits may consist of goods (crops, livestock products or timber) or services (recreational facilities). The inputs needed to obtain such benefits may comprise of capital investment, labour, fertilizers and power. Thus, an area of land might be classed as Highly Suitable for rainfed agriculture, because the value of crops produced substantially exceeds the costs of farming but only Marginally Suitable for forestry on grounds that the value of timber only slightly exceeds the costs of obtaining it. It is expected that boundaries between suitability classes need to be reviewed and revised with time in the light of technical developments, and economic and social changes.

Within the Order Not Suitable, there are normally two Classes:

Class N1 Currently Not Suitable	Land having limitations which may be surmountable in time but cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Class N2 Permanently Not Suitable	Land having limitations which appear so severe to preclude any possibilities of successful sustained use of the land in the given manner.

Quantitative definition of these classes is normally unnecessary, since by definition both are uneconomic for the given use. The upper limit of Class N1 is already defined by the lower limit of the least suitable class in Order S. The boundary of Class N2, Permanently Not Suitable, is normally physical and permanent. In contrast, the boundary between the two orders, Suitable and Not Suitable is likely to be variable over time through changes in the economic and social context.

iii) Land suitability sub classes: Land suitability sub classes reflect kinds of limitations, e.g. moisture deficiency, erosion hazard and are indicated by lower-case letters with significance, e.g. S2m, S2e, and S3me. There are no subclasses in Class S1. The number of subclasses recognized and the limitations chosen to distinguish them differ in classifications for different purposes. There are two guidelines:

1. The number of subclasses should be kept to a minimum that will satisfactorily distinguish lands within a class likely to differ significantly in their management requirements or potential for improvement due to differing limitations.

2. As few limitations as possible should be used in the symbol for any subclass. One, rarely two, letters should normally suffice. The dominant symbol i.e. that which determines the class should be used alone, if possible. If two suitable may be divided into suitability sub classes according to kinds of limitation e.g. N1m, N1me, N1m, although this is not essential. As this land will not be placed under management for the use concerned it should not be subdivided into suitability units.

iv) Land suitability units: Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. The units differ from each other in their production characteristics or in minor aspects of their management requirement. Their recognition permits detailed interpretation at the farm planning level. Suitability units are distinguished by Arabic numerals following a hyphen, e.g. S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass.

●●●●●

Chapter-IX

PROBLEMTIC SOILS UNDER DIFFERENT AGRO-ECOSYSTEMS

The salt affected soils under different agro-ecosystems have different problems in achieving maximum productivity. Their general characteristics are:

i. **Arid and semi-arid regions (rainfall <500 mm):** Saline soils of these region are characterised by neutral to alkaline pH, high EC and low ESP; sulphates and chlorides are invariably much higher than carbonates, shallow saline groundwater table, and remained waterlogged for some part of the year. These are distributed in parts of Haryana, Punjab, Rajasthan, Uttar Pradesh and Jammu Kashmir.

ii. **Sub-humid regions (rainfall 1000-1400 mm):** Sali8ne soils of sub-humid regions are characterised by neutral to alkaline pH, high EC, preponderance of chlorides and sulphates developed on dolomitic alluvium. These may also contain sizable quantities of carbonates of sodium and are distributed mainly in Bihar.

iii. **Salt affected medium to deep black soil (rainfall 700-1000 mm):** These soils are characterised by neutral to highly alkaline pH, high EC, preponderance of chlorides and sulphates with or without bicarbonates, salinization and alkalization process associated with rising water table, montmorillonitic clay mineralogy and high clay content (upto 80%). These are distributed in Madhya Pradesh, Maharashtra, Rajasthan, Andhra Pradesh, Gujarat and Karnataka.

iv. **Medium to deep black soils of Deltaic and coastal semi arid regions (rainfall 700-900 mm):** These soils are characterised by neutral pH, high EC, preponderance of chlorides and sulphates with traces of bicarbonates, alkaline vertisols with shallow water table, high clay content and montmorillonitic mineralogy and distributed in Saurashtra coast in Gujarat and deltas of the Godavari and Krishna rivers in Andhra Pradesh.

v. **Saline micaceous deltaic alluvium of humid region (rainfall 1400-1600 mm):** These soils are characterised by deep micaceous fine texture, neutral to slightly acid pH, high EC, preponderance of chlorides and sulphates over bicarbonates; absence of $CaCO_3$; and perpetual shallow saline groundwater table. These are distributed in Sunderban delta in west Bengal and parts of Mahanadi delta in Orissa.

vi. **Saline Humic and acid sulphate soils of humid tropical region (rainfall 2000-3000 mm):** Developed under marine cycles, these soils are characterised by low

pH, high EC, presence of humic (organic) horizon, preponderance of chlorides and sulphates, have Ochric epipedon, shallow saline water table and variable amounts of Pyritous clay. These are distributed in Malabar Coast of Kerala.

vii. **Saline marsh of Rann of Kutch (rainfall <300 mm):** These soils are characterised by neutral to slightly alkaline pH, high EC and preponderance of chlorides and sulphates. Their textural stratification is interspersed with gypsum, $CaCO_3$ and hydrated iron oxide accumulation. These are distributed in Rann of Kutch in Gujarat.

viii. **Saline and alkali soils of Indo-Gangetic alluvium (rainfall around 550 mm):** Characterised by sandy to loamy in texture, slightly alkaline to high pH, variable EC, high ESP, preponderance of carbonates of sodium, with some quantities of neutral salts, calcareous having a Calcic or Petrocalcic horizon and poor permeability. These are distributed in parts of the states existing in the Indo-Gangetic alluvial region.

●●●●●

INSPIRING AGRIPRENEURS

www.hau.ac.in