TRAINING MANUAL

(For Education Purpose Only and Not for Commercial Use)

Entrepreneurship Development Programme (EDP) on

Soil and Plant Analysis for Nutrient Recommendations in Horticultural Crops

02-04 September, 2025

Compiled and Edited by

Dr. T.R. Rupa

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Organized by

Agri-Business Incubation Centre &
Division of Natural Resources
ICAR - Indian Institute of Horticultural Research
Hesaraghatta Lake Post, Bengaluru – 560 089

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Entrepreneurship Development Training Programme

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(*Instruction Material*)

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This training manual has been specially developed for participants of the "Entrepreneurship Development Training on Soil and Plant Analysis for Nutrient Recommendations in Horticultural Crops," conducted by the Agri-Business Incubation Centre and the Division of Natural Resources, ICAR-IIHR, Bengaluru, from September 2 to 4, 2025. The content has been primarily compiled from lectures, presentations, and discussions held during the training program. All sources referenced in the preparation of this manual are acknowledged and listed in the reference section. This manual is intended exclusively for educational and training purposes and is not meant for commercial use or public distribution.

Training Manual on
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Compiled and Edited by
Course Director, Course Co-Directors and Course Co-ordinators

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Agri-Business Incubation Centre
ICAR - Indian Institute of Horticultural Research
Hesaraghatta Lake Post, Bengaluru – 560 089

Entrepreneurship Development Program

3 days Training on Soil and PlantAnalysis for Nutrient Recommendations in Horticultural Crops

Venue: ICAR-IIHR, Bengaluru

Date: 02nd to 04th September, 2025 Time: 9.30 AM to 5.30 PM

Course Director: Dr. T.R. Rupa
Course Co-Directors: Dr. Yukti Verma, Dr. K.G. Shilpashree, Dr. T.K. Radha, and Dr. S. Ramachandran
Course Co-Coordinators: Dr. S.S. Hebbar, Dr. Anuradha Sane and Dr. Vittal Kamble

Programme Schedule

DAY-1; 02nd September, 2025

9.00 - 9.15AM	Registration	
9.15 - 9.25 AM	Video of Success Stories	
9.25 - 9.35 AM	ICAR Song followed by IIHR Jingle	
9.35 - 9.40AM	Welcome Address and Introduction about the Training Programme	**Dr. T.R. Rupa** Principal Scientist Division of Natural Resources
9.40 - 9.45 AM	Introduction about the Institute and ABI	**Dr. S.S. Hebbar** Nodal Officer, ITMU & ABI Principal Scientist Division of Vegetable crops
9.45 – 9.55 AM	Introduction by the Participants	**All Participants**
9.55–10.00 AM	Presidential Address	**Dr. T.K. Behera** Director ICAR-IIHR
10.00 – 10.05 AM	Vote of thanks	**Dr. K.G. Shilpashree** Senior Scientist Division of Natural Resources

10.05 – 10.10 AM	Group Photo	
10.15 - 11.10 AM	Soil sampling, chemical parameters analysis and their interpretation	**Dr. T.R. Rupa** Principal Scientist Division of Natural Resources
11.10 – 12.05PM	Soil physical parameters analysis and their interpretation	**Dr. S. Ramachandran** Senior Scientist Division of Natural Resources
12.05 – 1.00 PM	Laboratory instruments used in soil and plant analysis	**Dr. Yukti Verma** Scientist Division of Natural Resources
1.00 - 1.30 PM	Lunch Break	
1.30 - 5.30 PM	Practical session (Soil chemical parameters)	**Dr. T.R. Rupa** **Dr. K.G. Shilpashree** **Dr. Yukti Verma**

DAY-2; 03rd September, 2025

9.30 - 10.25 AM	Soil microbial parameters analysis and their interpretation	**Dr. T.K. Radha** Senior Scientist Division of Natural Resources
10.25 - 11.20 AM	Problem soils and their management	**Dr. K.G. Shilpashree** Senior Scientist Division of Natural Resources
11.20 - 12.10 PM	Plant sampling guidelines and methodology for plant analysis	**Dr. T.R. Rupa** Principal Scientist Division of Natural Resources
12.10 - 1.00 PM	Foliar nutrition in horticultural crops	**Dr. Yukti Verma** Scientist Division of Natural Resources
1.00 - 1.30 PM	Lunch Break	
1.30 – 5.30 PM	Practical session (Plant analysis, assessment of soil microbial parameters and hands-on training in usage of laboratory instruments)	**Dr. T.R. Rupa** **Dr. T.K. Radha** **Dr. Yukti Verma**

DAY-3; 04th September, 2025

9.30 - 10.25 AM	Diagnosis of nutrient deficiency and toxicity symptoms	**Dr. K.G. Shilpashree** Senior Scientist Division of Natural Resources
10.25 - 11.20 AM	Microbial inoculants for nutrient management	**Dr. T.K. Radha** Senior Scientist Division of Natural Resources
11.20 - 12.10 PM	Nutrient management practices for sustainable crops production	**Dr. T.R. Rupa** Principal Scientist Division of Natural Resources
12.10 - 1.00 PM	Soil physical constraints and their management in horticultural crops	**Dr. S. Ramachandran** Senior Scientist Division of Natural Resources
1.00 - 1.30 PM	Lunch Break	
1.30 - 4.30 PM	Practical session (Soil physical and microbial parameters)	**Dr. S. Ramachandran** **Dr. T.K. Radha**
4.30 - 5.25 PM	Valedictory and Certificate distribution • Feedback of the Participants • Certificate Distribution • Remarks of Director, ICAR-IIHR	
5.25 – 5.30 PM	Vote of thanks	**Dr. T.K. Radha** Senior Scientist Division of Natural Resources

CONTENTS

Soil sampling, chemical parameter analysis and their interpretation

T. R. Rupa

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Knowledge of characteristics and nutrient status of soil is fundamental in formulating suitable soil management strategies for higher yield and quality of horticultural crops. Such knowledge can be obtained through quantitative evaluation of soil properties and assessment of soil fertility status. However, for fine-tuning fertilizer needs of perennial horticultural crops, a combination of soil testing and tissue analysis should be used. Recommendations for fertilizing fruits, vegetables and other horticultural crops are based in part on soil test results. The main aim of soil testing is to evaluate the fertility status of the soil and plan a nutrient management programme. Soil analyses can provide information that is important for maximizing nutrient use efficiency and agricultural productivity. The soil extractant is designed to evaluate a portion of the nutrients from the same 'pool' used by the plant. The results of a soil analysis provide the agricultural producer with an estimate of the amount of fertilizer nutrients needed to supplement those in the soil. Applying the appropriate type and amount of needed fertilizer will give the agricultural a more reasonable chance to obtain the desired crop yield.

Soil testing is comprised of four steps viz., a) Collection of a representative soil sample, b) Laboratory analyses of the soil sample, c) Interpretation of analytical results and d) Management recommendations based on interpreted analytical results.

i) Collection of a representative soil sample

The first and most critical step in soil testing is collecting a soil sample. For soil testing to be meaningful, it is essential that the soil samples should be a representative of the root zone of a field/plot for which the fertility evaluation is desired. It is important to be aware of that a small portion of a field is actually analyzed in the laboratory. Proper soil sampling saves time, energy and money. The methods and procedures for obtaining soil samples vary according to the purpose of the sampling. Only 1 to 10 g of soil is used for each chemical determination and this sample needs to represent as accurately as possible the entire surface 0 to 22 cm of soil, weighing about 2 million kg/ha.

Materials required

- Spade or auger
- Polythene or cloth bags
- A pan or bucket
- Khurpi (for collecting profile samples)

Procedure

It is advisable to sample after the harvest of the crop and if sampling is to be done in standing crop, collection should be done between rows. Collection of sample in a zigzag pattern across the field ensures homogeneity. During sampling, dead furrows, wet spots, areas near main bunds and trees, manure heaps and irrigation channels need to be avoided.

For making composite sample, small portion of soil sample to be collected up to the desired depth (0-15 cm depth for cereals, vegetables, flower crops and other seasonal crops, in case of fruit trees/longer duration crops the soil depth should be 0-45 cm depth or more). The surface litter is removed at the sampling spot before sampling. Then the auger is driven to a plough depth of 15cm and the soil sample drawn. At least 10 to 15 samples are collected from each sampling unit and placed in a bucket or container. If auger is not available, a 'V' shaped cut is made to a depth of 15cm in the sampling spot. Then thick slices of soil from top to bottom of exposed face of the 'V' shaped cut is removed and placed in a clean container.

The samples thus collected are thoroughly mixed and foreign material like roots, stones, pebbles and gravels are removed. Then the bulk is reduced to about half to one kilogram either by quartering or compartmentalization. Quartering is done by dividing the thoroughly mixed sample into four equal parts. The two opposite quarters are discarded and the remaining two quarters are remixed and the process is repeated until the desired sample size is obtained. In the case of compartmentalization, the thoroughly mixed soil is uniformly spread over a clean hard surface and divided into smaller compartments by drawing lines along and across the length and breadth with fingers or small twigs. Then from each compartment a pinch of soil is collected. This process is repeated till the desired quantity of sample is obtained. The sample so collected is put in to a clean labelled cloth/polythene bag.

Processing and storing

The samples collected from the field is dried in shade by spreading on a clean sheet of paper after breaking the large lumps, if present, with a wooden mallet. Then the soil material is sieved through 2 mm sieve. The material passing through the sieve is collected and stored in a clean container (or) polythene bag with proper labelling for laboratory analysis.For the determination of organic matter, it is desirable to grind a representative sub sample and sieve it through 0.2 mm sieve.

If the samples are meant for the analysis of micronutrients at most care is needed in handling the sample to avoid contamination of iron, zinc and copper. Brass sieves should be avoided and it is better to use stainless steel or polythene materials.Air-drying of soils must be avoided if the samples are to be analysed for NO_3-N and NH_4-N as well as for bacterial count.

ii) Soil chemical parameters analysis and their interpretation

A number of laboratory extraction techniques have been developed to estimate soil nutrient availability. The choice of which technique to use for a particular nutrient depends on the chemical characteristics of the soil, particularly pH.For example, tests used for measuring soil phosphorus are quite different in the acidic soils. Individual analyses included in a standard soil test which include soil pH, Electrical conductivity (EC), organic carbon and available nitrogen

(N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B) and molybdenum (Mo). Based on the estimated available nutrient status, the soils are then categorized into 'low', 'medium', or 'high' categories. This has to be done for each nutrient. In case of nutrients other than N, P and K, usually a single critical level is designated below which a soil is considered to be deficient in that nutrient, hence requiring its application. There are different extractants for assessing plant available nutrient content in soils. The elements so extracted can be estimated quantitatively through chemical methods or instrumental techniques.

Soil reaction (pH)

The pH of a soil is a measure of the hydrogen or hydroxyl ion activity of the soil - water system. It indicated whether the soil is acidic, neutral or alkaline in reaction. The determination of pH in soil is important as it plays a great role in availability of nutrients to plants. This determination can be done more accurately in the laboratory by electrometric method. The pH determination is useful for soil classification on the basis of acidity or alkalinity. The estimation of pH in soil - water system is done with the help of a pH meter.

pH Ratings

< 4.5	: Extremely Acidic
4.6 to 5.2	: Strongly Acidic
5.3 to 6.0	: Moderately Acidic
6.1 to 6.5	: Slightly Acidic
6.6 to 7.0	: Neutral
7.1 to 7.5	: Slightly Alkaline
7.6 to 8.3	: Moderately Alkaline
8.4 to 9.0	: Strongly Alkaline
> 9.0	: Extremely Alkaline

Electrical conductivity (EC) in soil

The electrical conductivity of water extract of soil gives a measure of soluble salt content of the soil. The measurement of electrical conductivity of an extract gives a satisfactory indication of the total concentration of ionized constituents. It is measured on a conductivity meter and normally reported in dS/m or mmhos/cm and the value gives information on the total amount of the soluble salts present in soil, *i.e.* on the degree of salinity.

EC (dS m^{-1}) Ratings

0 to 1	: Good soil
1 to 2	: poor seed emergence
2 to 4	: Harmful to some crops, e.g. Pulses
>4	: Harmful to most of crops

Soil organic matter (SOM)

Soil organic matter is derived from decomposing plant and animal remains. Is the most chemically active portion of the soil and is a reservoir for various essential elements. Humus is the dark, moist layer found on the top of a soil profile. It acts as nutrient sink and source. A major portion of N (90-95% of the total), P (33-67% of the total) and S (75% of the total) in soils occur in organic combinations which mineralize to release the nutrients in inorganic forms to be used by plants. Higher organic matter content in soils leads to better soil health as it improves soil structure, nutrient cycling, increases infiltration and percolation, higher water holding capacity, regulates microbial activity, pest suppression etc. The organic matter level of a soil can be determined by several analytical techniques which are quite accurate. Organic matter content of a soil is estimated by the amount of organic carbon present in it and on an average organic matter contains 52 to 58 per cent organic carbon. In order to find out the amount of organic matter, organic carbon content is multiplied by 1.724 factor.

Organic carbon (%) Ratings

<0.5 : Low
0.5 to 0.75 : Medium
>0.75 : High

Available nitrogen

The available N in soil refers to a fraction of total N which is converted into forms accessible to the plant. This constitute only 0.5 to 2.5 per cent of the total N in a soil at any given time. Soil N exists both in mineral (inorganic) forms, available for plant uptake, and in complex organic forms that are not readily available. There are two mineral N forms, NO_3-N and ammonium-nitrogen (NH_4-N); the NO_3-N form usually predominates. Nitrate analyses can provide an accurate determination of the N available to plants at the time of soil sampling, although this may not provide reliable information concerning N availability later in the growing season. If soil N analysis is to be used for making fertilizer recommendations, soil samples should be collected either shortly before planting time or during the growing season. Following methods are being used for the determination of available N in soils.

1. Alkaline potassium permanganate method
2. Calcium hydroxide method
3. Incubation method
4. Nitrate determination by colorimetric method.

Available N (kg/ha) ratings

<280 : Low
281-560 : Medium
>560 : High

Available phosphorus

The term available phosphorus refers to the inorganic form occurring in the soil solution which is almost exclusively orthophosphate. The orthophosphate occurs in several forms and combinations. Only a small fraction of the total amount present may be available to plants which is of direct relevance in assessing P fertility level. Most soil P is tightly bound to soil particles or contained in relatively insoluble complexes. The P-containing complexes in alkaline soils are very different than those in neutral or acidic soils. The amount of P removed during soil extraction is very much dependent on the nature of P complexes and on the specific extractant used, so it is critical that P extractants be matched to soil properties. The Olsen or bicarbonate extractant, a dilute sodium bicarbonate solution, is used to extract P from calcareous, alkaline, and neutral soils. The Bray and Kurtz method, NH_4F + HClextractant is used for soils which are moderate to strongly acidic with pH around 5.5 or less. The estimation of P in the extract is done with the help of a Spectrophotometer.

Available P (kg/ha) ratings

<10	Low
11-25	Medium
>25	High

Available potassium

The total potassium content of a soil varies from 0.05 to 2.5 per cent. The total K is distributed in mineral form (lattice K, 90-98%), fixed or non-exchangeable K (1-10%) and exchangeable plus water soluble K (1-2%). Both water soluble and exchangeable K are most accessible to the plant. The neutral normal ammonium acetate extract contains both water soluble and exchangeable K. Potassium extracted by this extractant is considered as a suitable index of K availability in most soils. The K content in the soil is estimated with a flame photometer.

Available K (kg/ha) ratings

<120	: Low
121-280	: Medium
>280	: High

Available sulphur

Sulfur, like N, may be contained primarily in the soil organic matter, but plants absorb only the inorganic sulfate (SO_4^{2-}) form. Sulfate can be extracted from the soil with several extractants, including water or weak salt solutions. Analysis of SO_4-S is relatively easy, but it usually provides a measure of immediately available S, and not the soil's long-term ability to provide S to a growing plant. The S content in the soil is estimated with a Spectrophotometer. The critical limit for available S in soil is 20 kg/ha.

Exchangeable calcium and magnesium

Calcium and magnesium are the two most abundant alkaline earth cations in soil. They occur in three forms i) soluble ions in soil solution, ii) ions in the adsorbed state (exchangeable) and iii) non exchangeable ions in primary and secondary minerals. Exchangeable cations are usually determined in a neutral normal ammonium acetate extract of soil. Extraction is carried out by shaking the soil–extractant mixture, followed by filtration or centrifugation. Calcium and Mg are determined either by the Ethylene diamine tetra acetic acid (EDTA) titration method or by using an Atomic absorption spectroscopy (AAS) after the removal of ammonium acetate and organic matter.The critical limit for exchangeable Ca and Mg in soil is 1.5 and 1.0 me/100 g soil, respectively.

DTPA-Micronutrients

The micronutrients Zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) exist in a variety of chemical compounds in the soil, and determining the fraction that is plant-available is difficult. The most commonly used technique is extraction with diethylenetriaminepenta acetic acid (*DTPA*),a chelating compound. The critical limit for DTPA extractable Zn, Fe, Mn and Cu in soil is 0.6, 4.5, 2.0 and 0.2 mg/kg soil, respectively.

Available boron

Boron in soil exists in organic and inorganic forms. The compounds of boron, which have high availability, are water soluble. Boron deficiency is encountered in highly calcareous and acid soils, while toxicity in salt affected soils as well as soils irrigated with high B water. The most common method of extracting B from soils is with hot water. This is an accurate test, but soil B levels can change rapidly. Boron is highly water soluble and can quickly be leached from the rooting zone, or moved laterally during monsoon rainfall events. Therefore, extractable soil B provides estimates of plant availability that are less reliable than those of many other nutrients, not because of shortcomings with the analytical method, but because of rapid B movement in the soil. Water-soluble B is the available form of B. It is extracted from the soil by water suspension. In the extract, B can be analysed by colorimetric methods using reagents such as carmine, azomethine-H, and, most recently, by inductively coupled plasma (ICP) and atomic Absorption Spectrometry (AAS). The critical limit for available B in soil is 0.5 mg/kg soil.

Available Molybdenum

Amongst the essential nutrients for plants, Mo is required in the smallest quantity. It is used by plants in the form of MoO_4^- ions and its availability, unlike other elements, is high in the alkaline pH range. As it is required in very small amount, tests for availability of Mo are rarely carried out, particularly in alkaline soils. Ammonium oxalate method is, however, the most popular for extraction of available Mo from soil. Estimations can be done both by the AAS and colorimetric methods, with preference for the latter owing to the formation of oxide in the flame in the case of estimation by AAS. The critical limit for available Mo in soil is 0.2 mg/kg soil.

Soil physical parameters: Importance and their interpretation

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Introduction

Soil is a dynamic, complex natural resource that plays a crucial role in sustaining life on Earth. It serves as the medium for plant growth, a habitat for various organisms, and a reservoir for water and nutrients. The physical properties of soil are fundamental in determining its capacity to support plant life and its role in the broader environmental context. These physical properties include soil texture, structure, consistency, density, porosity, and the ability to hold and transmit water and air. Understanding and analyzing these parameters are essential for effective soil management, agricultural productivity, environmental sustainability, and ecological balance.

Importance of Soil Physical Parameters

Understanding soil physical properties is essential for:

- **Agriculture:** Optimizing soil for crop growth, improving irrigation systems, and enhancing nutrient availability.
- **Construction Engineering:** Designing foundations and drainage systems based on soil strength, compaction, and permeability.
- **Environmental Management:** Managing soil erosion, conservation, and sustainability practices.
- **Water Management:** Ensuring appropriate drainage, irrigation, and water retention in agricultural and natural ecosystems.

Important soil physical properties

1. Soil texture, 2. Soil structure, 3. Soil colour, 4. Soil consistence, 5. Soil density, 6. Soil water content, 7. Soil temperature, 8. Soil aeration.

1. Soil texture

Definition

Soil texture refers to the relative proportion of particles or it is the relative percentage by weight of the three soils separates viz., sand, silt and clay or simply refers to the size of soil particles.

Table. 1. Classification of soil texture by USDA classification

Soil separates	Diameter (mm)
Clay	< 0.002 mm
Silt	0.002 – 0.05
Very Fine Sand	0.05 – 0.10
Fine Sand	0.10 – 0.25
Medium Sand	0.25 - 0.50
Coarse Sand	0.50 - 1.00
Very Coarse Sand	1.00 – 2.00

- **Sand**: The largest particles, which allow for quick water drainage but poor nutrient retention.
- **Silt**: Medium-sized particles that retain more water and nutrients compared to sand but have slower drainage.
- **Clay**: The smallest particles, which hold water and nutrients effectively but may cause poor drainage if not managed properly.
-

Importance of Soil Texture

1. **Water Retention and Drainage:**
   - Sandy soils drain quickly but may not retain enough moisture for plants.
   - Clay soils hold more water but may suffer from poor drainage, leading to water logging.
   - Loam soils (a balance of sand, silt, and clay) offer the best water retention and drainage, ideal for most crops.
2. **Nutrient Holding Capacity:**
   - Soils with more clay and silt hold more nutrients, as they have more surface area for nutrients to cling to.
   - Sandy soils have less nutrient-holding capacity, requiring more frequent fertilization.
3. **Root Growth:**
   - Soil texture affects how easily roots can penetrate the soil. Loam soils are optimal for root growth, while compacted or poorly textured soils can impede root development.
4. **Soil Aeration:**
   - Soil texture influences the amount of air in the soil. Sandy soils are more aerated, allowing better root oxygenation. On the other hand, clay soils can become compacted, reducing oxygen availability to roots.
5. **Soil Texture Classification (Soil Triangle)**
   - Soils are classified based on their relative proportions of sand, silt, and clay. A soil texture triangle is often used to identify soil texture and its characteristics. The most desirable texture for agriculture is loam, which offers balanced water retention, nutrient availability, and drainage.

- ❖ Generally, the best agriculture/horticultural soils are those contain 10 – 20 per cent clay, 5 – 10 per cent organic matter and the rest equally shared by silt and sand and 30% silt - called as clay rather than clay loam.

Soil texture is a critical factor in determining soil fertility, water management, and overall plant health. Understanding and managing soil texture can significantly improve crop yields and plant growth in agricultural and horticultural systems.

Determination of soil textural class:

1. **Feel method** – Evaluated by attempting to squeeze the moistened soil into a thin ribbon as it is pressed with rolling motion between thumb and pre finger or alternately to roll the soil into a thin wire. Four aspects to be seen – i) Feel by fingers, ii) Ball formation, iii) Stickiness and iv) Ribbon formation.
2. **Laboratory method**
    a) International Pipette Method
    b) Hydrometer Method.

a) International Pipette Method (most widely used) – Accurate method

Particle size analysis is based on a simple principle i.e. "when soil particles are suspended in water they tend to sink. Because there is little variation in the density of most soil particles, their velocity (V) of settling is proportional to the square of the radius 'r' of each particles.
Thus $V = kr^2$
, where k is a constant. This equation is referred to as Stokes' law.
Stokes (1851) was the first to suggest the relationship between the radius of the particles and its rate of fall in a liquid. He stated that "the velocity of a falling particle is proportional to the square of the radius and not to its surface. The relation between the diameter of a particle and its settling velocity is governed by Stokes' Law:

$$V = \frac{2\ gr^2(ds - dw)}{9n}$$

Where ,
V - velocity of settling particle (cm/sec.)
g - acceleration due to gravity cm/ sec^2
ds - density of soil particle (2.65)
dw - density of water (1)
n - coefficient of viscosity of water (0.0015 at 4^oC)
r - radius of spherical particles (cm).

Assumptions and Limitations of Stokes' Law
Particles are rigid and spherical / smooth. This requirement is very difficult to fulfill, because the particles are not completely smooth over the surface and spherical. It is established that the

particles are not spherical and irregularly shaped such as plate and other shapes. The particles are large in comparison with the molecules of the liquid so that in comparison with the particle the medium can be considered as homogenous. Ie the particles must be big enough to avoid Brownian movement. The particles less than 0.0002 mm exhibit this movement so that the rate of falling is varied.

The fall of the particles is not hindered or affected by the proximity (very near) of the wall of the vessel or of the adjacent particles. Many fast falling particles may drag finer particles down along with them. The density of the particles and water and as well as the viscosity of the medium remain constant. But this is usually not so because of their different chemical and mineralogical composition.

The suspension must be still. Any movement in the suspension will alter the velocity of fall and such movement is brought by the sedimentation of larger particles (> 0.08 mm). They settle so fast and create turbulence in the medium.
The temperature should be kept constant so that convection currents are not set up.

b). Hydrometer method

Main principle of this method is based on continuous reduction of density of the soil suspension with time at the rate of the particles drops below the level of hydrometer. This method is less accurate due to high OM and $CaCO_3$.

3). Determination of Textural Class

In the American system as developed by the United State Department of Agriculture twelve textural classes are proposed.

The textural triangle

It is used to determine the soil textural name after the percentages of sand, silt, and clay are determined from a laboratory analysis. Since the soil's textural classification includes only mineral particles and those of less than 2mm diameter, the sand plus silt plus clay percentages equal 100 percent. (note that organic matter is not included.) Knowing the amount of any two fractions automatically fixes the percentage of the third one.

To use the diagram, locate the percentage of clay first and project inward parallel to sand line. Do likewise for the per cent silt and project inward parallel to clay line and for sand, project inward parallel to silt. The point at which the projections cross or intersect will identify the class name Some times, the intersecting point exactly fall on the line between the textural classes. Then it is customary to use the name of the finer fraction when it happens. (eg). 42% sand, 35% silt, and 23% clay. The soil would be *loam*.

2. Soil Structure

Definition

The arrangement and organization of primary and secondary particles in a soil mass is known as soil structure. Soil structure controls the amount of water and air present in soil. Plant roots and germinating seeds require sufficient air and oxygen for respiration. Bacterial activities also depend upon the supply of water and air in the soil.

Classification

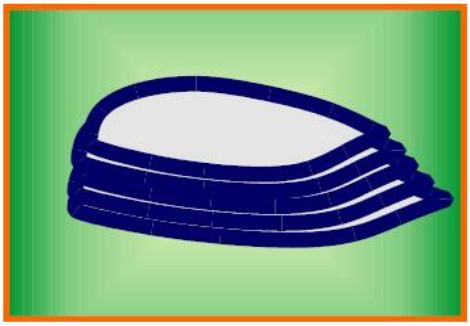
The primary particles –sand, silt and clay - usually occur grouped together in the form of aggregates. Natural aggregates are called peds whereas clod is an artificially formed soil mass. Structure is studied in the field under natural conditions and it is described under three categories

1. **Type** - Shape or form and arrangement pattern of peds
2. **Class** - Size of Peds
3. **Grade** - Degree of distinctness of peds

1. Types of Structure: There are four principal forms of soil structure

a) Plate-like (Platy)

In this type, the aggregates are arranged in relatively thin horizontal plates or leaflets. The horizontal axis or dimensions are larger than the vertical axis. When the units/ layers are thick they are called platy. When they are thin then it is laminar. Platy structure is most noticeable in the surface layers of virgin soils but may be present in the subsoil. This type is inherited from the parent material, especially by the action of water or ice.

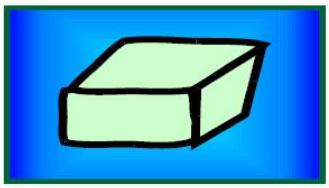


b. Prism-like

The vertical axis is more developed than horizontal, giving a pillar like shape. Vary in length from 1- 10 cm. Commonly occur in sub soil horizons of Arid and Semi-arid regions. When the tops are rounded, the structure is termed as columnar when the tops are flat / plane, level and clear cut - prismatic.

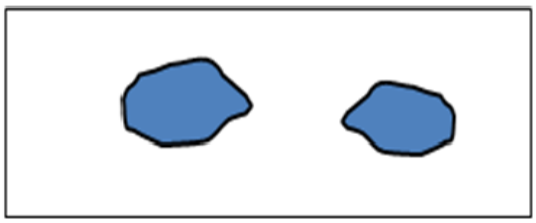
c. Block like

All three dimensions are about the same size. The aggregates have been reduced to blocks. Irregularly six faced with their three dimensions more or less equal. When the faces are flat and distinct and the edges are sharp angular, the structure is named as angular blocky. When the faces and edges are mainly rounded it is called sub angular blocky. These types usually are confined to the sub soil and characteristics have much to do with soil drainage, aeration and root penetration.



d. Spheroidal (Sphere like)

All rounded aggregates (peds) may be placed in this category. Not exceeding an inch in diameter. These rounded complexes usually loosely arranged and readily separated. When wetted, the intervening spaces generally are not closed so readily by swelling as may be the case with a blocky structural condition. Therefore in sphere-like structure, infiltration, percolation and aeration are not affected by wetting of soil. The aggregates of this group are usually termed as granular which are relatively less porous. When the granules are very porous, it is termed as crumb. This is specific to surface soil particularly high in organic matter/ grass land soils. Classes of Structure: Each primary structural type of soil is differentiated into 5 size classes depending upon the size of the individual peds.



2. **Size classes are-** Size of Peds (cm)

1. Very fine or very thin
2. Fine or thin
3. Medium
4. Coarse or thick
5. Very coarse or very thick

The terms thin and thick are used for platy types, while the terms fine and coarse are used for other structural types.

Table. 2. Class of soil structure of differentiated by size of soil peds (cm)

Class	Platy	Prismatic	Columnar	Blocky	S.A. Blocky	Granular	Crumb
V. fine	< 1	< 10	< 10	< 5	< 5	< 1	< 1
Fine	1-2	10-20	10-20	5-10	5-10	1-2	1-2
Medium	2-5	20-50	20-50	10-20	10-20	2-5	2-5
Coarse Thick	5-10	50-100	50-100	20-50	20-50	5-10	1-2

3. Grades of Structure- Durability of peds

Grades indicate the degree of distinctness of the individual peds. It is determined by the stability of the aggregates. Grade of structure is influenced by the moisture content of the soil. Grade also depends on organic matter, texture etc. Four terms commonly used to describe the grade of soil structure are:

1. **Structureless:** There is no noticeable aggregation, such as conditions exhibited by loose sand.
2. **Weak Structure:** Poorly formed, indistinct formation of peds, which are not durable and much unaggregated material.
3. **Moderate structure:** Moderately well-developed peds, which are fairly durable and distinct.
4. **Strong structure:** Very well formed peds, which are quite durable and distinct.

Importance of Soil Structure

1. **Water Infiltration and Drainage**
   - Well-structured soils (like granular) allow water to infiltrate easily, preventing surface runoff and improving water retention.
   - Platy and blocky structures can create barriers to water movement, leading to poor drainage or waterlogging.

2. **Root Penetration**
   - Good soil structure promotes easy root penetration and development, allowing plants to access water and nutrients more efficiently.
   - Poor structure, such as compacted or tightly bound aggregates, can restrict root growth, leading to weaker plants.

3. **Soil Aeration**
   - Properly structured soil provides enough pore space for oxygen to reach plant roots and soil organisms. Without adequate aeration, roots can suffocate, and beneficial microbial activity can decrease.
   - Granular and friable structures are ideal for maintaining good soil aeration.

4. **Nutrient and Microbial Activity**
   - Soil structure influences the availability of nutrients, as well-structured soils allow better movement of air, water, and nutrients.
   - Good soil structure supports a healthy population of soil microorganisms, which help break down organic material and release nutrients for plant uptake.

5. **Soil Erosion Resistance**
   - A well-aggregated soil is less prone to erosion by wind and water. Soils with poor structure, particularly those that are compacted, are more vulnerable to erosion.

Improving Soil Structure

- **Organic matter**: Adding compost, cover crops, or mulch can improve soil aggregation and structure.
- **Proper tillage**: Minimizing tillage and using no-till farming practices can preserve soil structure by reducing soil compaction.
- **Soil amendments**: For clay soils, adding gypsum or sand can help break up compacted layers and improve structure.

Soil structure is essential for maintaining soil health, supporting plant growth, and enhancing water and nutrient availability. Properly managing soil structure through the use of organic amendments, conservation practices, and appropriate tillage can significantly improve agricultural and horticultural productivity.

Determination of soil structure

1. Visual Inspection:

- **Field Assessment:** This involves observing the soil's appearance, including color, texture, and visible aggregates, to infer the soil structure.

- **Aggregate Size and Shape**: Observing the size, shape, and arrangement of soil particles and aggregates can provide insights into the soil's structure (e.g., granular, blocky, prismatic, etc.).

2. Aggregate analysis:

a) **Wet-Sieving Method**: A common method to determine aggregate stability, where soil is wet-sieved to separate aggregates based on their size and stability. The percentage of aggregates remaining intact after sieving indicates their stability.
b) **Dry-Sieving Method**: This method separates aggregates based on their size under dry conditions and is often used to evaluate the distribution of aggregate sizes.
c) **X-ray Computed Tomography (CT Scanning)**: This non-destructive method allows for the detailed 3D visualization of soil aggregates and pore spaces, providing insights into how aggregates evolve and interact within the soil matrix.

3. Soil Colour

Soil colour indicates many soil features. A change in soil colour from the adjacent soils indicates a difference in the soil`s mineral origin (parent material) or in the soil development. Soil colour varies among different kinds as well as within the soil profile of the same kind of soil. It is an important soil properties through which its description and classification can be made. Kinds of soil colour Soil colour is inherited from its parent material and that is referred to as lithochromic, e.g. red soils developed from red sandstone. Besides soil colour also develops during soil formation through different soil forming processes and that is referred to as acquired or pedochromic colour, e.g. red soils developed from granite or schist.

Determination of soil colour
The soil colours are best determined by the comparison with the Munsell colour. This colour chart is commonly used for this purpose the colour of the soil is a result of the light reflected from the soil.

Soil colour rotation is divided into three parts
Hue - it denotes the dominant spectral colour (red, yellow,blue and green).
Value - it denotes the lightness or darkness of a colour (the amount of reflected light).
Chroma - it represents the purity of the colour (strength of the colour). The Munsell colour notations are systematic numerical and letter designations of each of these three variables (Hue, Value and Chroma). For example, the numerical notation 2.5 YR6/6 suggests a hue of 2.5 YR, value of 5 and chroma of 6. The equivalent or parallel soil colour name for this Munsell notation is `red`.

Key Factors Influencing Soil Color

1. **Organic Matter:**
   - Soils with high organic matter content, such as humus, tend to be dark brown or black. Organic matter enhances soil fertility by increasing nutrient availability and moisture retention.
2. **Mineral Content**
   - Iron: Soils rich in iron often have red, yellow, or brown hues due to iron oxides. Well-drained soils are typically red or brown, while poorly drained soils can appear grayish or greenish.
   - Clay and Silica: Soils with high clay or silica content can exhibit a range of colors, from pale yellows to deeper browns.

3. **Moisture Content**
   - Wet soils may appear darker because water enhances the soil's ability to reflect light. As soils dry, they often lighten in color.

4. **pH Levels:**
   - Soils with low pH (acidic) may have more grayish or bluish hues, while soils with higher pH (alkaline) may have yellow or red colors due to the presence of minerals like iron.

Common Soil Colors

1. **Dark Brown to Black:**
   - Indicates high organic matter content, typical of fertile, well-developed soils, such as loams or muck soils. Common in forested areas or fertile agricultural land.
2. **Red, Yellow, or Brown**:
   - These colors suggest the presence of iron oxides. Red soils typically indicate well-drained, aerated conditions, while yellow soils can indicate slightly less aeration.
   - Brown colors may also indicate well-drained soils, often found in temperate climates.
3. **Gray or Blue:**
   - Soils with these colors are often poorly drained and may indicate low oxygen levels (anaerobic conditions), often found in wetlands or waterlogged areas. The color results from reduced iron compounds in the soil.

4. **White or Light Gray**:
   - Light-colored soils may indicate the presence of salt deposits or calcium carbonates, often found in arid regions or areas with high evaporation rates.
   - These soils can also be acidic or poorly developed.

Importance of Soil Color

1. **Drainage and Aeration**
   - Soils with red, brown, or yellow colors often suggest good drainage and aeration, which are essential for healthy root growth and microbial activity.
   - Gray or blue soils often indicate poor drainage and low oxygen levels, which can result in root damage or disease in plants.
2. **Soil Fertility**
   - Dark-colored soils typically have higher organic matter content, which increases soil fertility. Such soils are often more productive and capable of supporting a wider range of plants.
   - Lighter-colored soils with low organic matter may require additional fertilizers or organic amendments to enhance fertility.

3. **Soil Temperature**
   - Dark soils tend to absorb more sunlight and warm up faster in spring, which can be beneficial for early plant growth. In contrast, light-colored soils may stay cooler for longer periods, which could delay plant development in some cases.

4. **Soil pH and Composition**
   - Soil color can provide clues about the soil's pH and mineral composition. For example, reddish soils may indicate a neutral or slightly alkaline pH, while gray soils could signal an acidic or low pH environment.
   - Soil color is a useful indicator of soil health, fertility, drainage, and other critical conditions affecting plant growth. By observing soil color, farmers, gardeners, and horticulturists can gain insights into the soil's texture, organic matter content, and overall suitability for supporting different crops and plants.

5. **Soil Consistency**
   - Soil consistency refers to the soil's ability to resist deformation and maintain its shape under various conditions. It describes how easily the soil can be crumbled, compressed, or molded and is closely related to its moisture content. Soil consistency is influenced by factors like soil texture, organic matter content, and compaction.

   - Soil consistency is categorized by its behavior at different moisture levels: dry, moist, and wet. Understanding soil consistency is essential for managing soil structure, ensuring proper root growth, and optimizing soil management practices.

   - Consistency, plasticity and stickiness of soil directly proportionate to structural strength and relates soil water retention status.

Categories of Soil Consistency

1. **Dry Consistency:**
   - **Hard**: When the soil is dry, it may become very hard and compacted, making it difficult for roots to penetrate. This is typical of clay-rich soils that have low porosity and high compaction.
   - **Loose**: Sandy soils tend to be loose and easily crumble when dry. While they may not offer much resistance, they can also lack structure, making it difficult for them to retain moisture.

2. **Moist Consistency:**
   - **Friable**: Moist soils that crumble easily when disturbed are considered friable. This is ideal for planting, as it indicates good aggregation and root penetration. Loam soils are often described as friable.
   - **Plastic:** Soils that can be molded or shaped when moist, but are not sticky, have a plastic consistency. These soils are typically clay-based and retain enough moisture to hold shape but aren't excessively sticky.
   - **Sticky**: Clay soils with high moisture content can become sticky and form ribbons when squeezed between fingers. This behavior suggests high compaction and poor aeration, which can hinder root growth.

3. **Wet Consistency:**
   - **Very Soft**: Soils become soft and mushy when waterlogged, making them challenging to work with. Poorly drained soils with high organic matter can exhibit this consistency.
   - **Squishy**: Wet soils that are excessively waterlogged are squishy and may ooze water when pressed. This can lead to root suffocation and poor plant health, especially in clay or loamy soils.

Dry class	**Wet class**
Loose	Loose
Soft	Very Friable
Slightly Hard	Friable
Mod. Hard	Firm
Hard	Very Firm
Very Hard	Extremely firm

Plasticity

It is the degree to which puddled soil material is permanently deformed without rupturing by force applied in any direction.

Class	Code	Description
Non	SO	<6mm roll diameter
Slight	SP	6mm diameter roll supports
Moderate	MP	4mm diameter roll supports
Very	VP	2mm diameter roll supports

Stickiness

It is the capacity of soil to adhere with other object or hand.

Class	Code	Description
Non sticky	PO	Not adhere to fingers
Slight	SS	Little adhere to both fingers
Moderate	MS	Adhere to both fingers
Very	VS	Adhere firmly to both fingers

Measurement of Shrinkage (Linear extensibility)

It is the measure of change in clod dimension on going from a dry to moist state. It is expressed as coefficient of linear expansibility (COLE).

COLE = (Length of moist clod – Length of dry clod)/ Length of dry clod

For shrink & swelling soils (black soils), it is an essential parameter. The value exceeds 0.09 significant shrinkage and swelling is expected.

Determination of soil consistency

1. Feel and Visual Method

The "feel" method involves assessing soil consistency by hand at various moisture levels. This is often used in the field to get a rough idea of the soil's behavior. The soil is squeezed and worked between fingers to determine its texture and plasticity.

2. Atterberg Limits Test (Plasticity Tests)

The Atterberg limits method is the standard laboratory technique for determining the consistency of fine-grained soils (mainly clays) based on moisture content.

- **Upper plastic or Liquid Limit (LL):** The moisture content at which the soil changes from a plastic to a liquid state. It is determined using a Casagrande apparatus or a cone penetrometer.
- **Lower Plastic Limit (PL**): The moisture content at which the soil can no longer be rolled into threads without breaking. It is determined by rolling a soil sample into a thin thread (usually 3 mm in diameter) until it breaks.
- **Plasticity Index (PI):** The difference between the liquid limit and the plastic limit (PI = LL - PL). A higher PI indicates a soil that is more cohesive and plastic.
- **Shrinkage Limit (SL):** The moisture content at which further reduction in water content does not lead to a decrease in the volume of the soil. This test is typically conducted for fine-grained soils and can provide information about the shrinkage characteristics of the soil.

3. Penetrometer Method

- **Procedure**: A penetrometer is an instrument used to measure the resistance of soil to penetration by a sharp point or probe. The depth of penetration is a measure of soil consistency, with higher resistance indicating a more compact or firm soil.

Types of Penetrometers

a) **Pocket Penetrometer**: Used in the field to estimate soil consistency by measuring the pressure required to push a probe into the soil. It provides an estimate of the soil's consistency in terms of its resistance to penetration, typically for silt, clay, and loam soils.

b) **Cone Penetrometer (CP)**: Used for assessing the consistency of soil at greater depths. It measures soil resistance to penetration using a conical tip driven into the soil by a standardized weight.

Importance of Soil Consistency

1. Root Growth:

- Soils with **friable consistency** allow plant roots to penetrate easily and access water and nutrients, promoting healthy growth.
- **Sticky** or **compact** soils can restrict root development, leading to poor plant growth and waterlogging.

1. **Soil Management**:
   - Understanding soil consistency helps in choosing the right tillage methods. **Friable** soils are easy to work with, while **hard** or **sticky** soils may require additional amendments (like organic matter or gypsum) or different management practices.

2. **Water Infiltration and Drainage**:
   - Soils with the **right consistency** allow water to infiltrate evenly. Compact or sticky soils can hinder water flow, causing **surface runoff** or **water logging**, which may damage plant roots.
   - **Loose soils** (especially sandy ones) can cause water to drain too quickly, reducing the availability of water for plants.
3. **Soil Fertility**:
   - A **friable consistency** often indicates good aggregation and microbial activity, which are important for soil fertility. The right consistency promotes nutrient availability and improves soil's capacity to support plant growth.

4. **Tillage and Planting**:
   - Knowing soil consistency helps determine the best time for tillage. Soils that are too wet or too dry are difficult to work with and may lead to soil damage, while properly moistened soils are optimal for planting.

Improving Soil Consistency

- **Add organic matter** to improve soil structure and consistency, making it more friable and easier to work with.
- **Avoid over-tilling**, which can lead to soil compaction and degradation.
- **Proper irrigation management** prevents soils from becoming too wet or too dry, maintaining an ideal consistency for planting and growth.

Soil consistency is a vital physical property that affects root growth, water movement, nutrient availability, and soil management in both agricultural and horticultural settings. Understanding and managing soil consistency ensures optimal conditions for plant health and productivity.

5. Soil Density

Soil density refers to the mass of soil per unit volume and is a key physical property that influences soil porosity, water retention, aeration, and root growth. It can be categorized into two types:

1. **Bulk Density**: The mass of the soil per unit volume, including both solids and pore spaces (air and water).
2. **Particle Density**: The mass of the solid particles per unit volume, excluding the pore spaces.

Soil density is typically measured in grams per cubic centimeter (g/cm^3) or kilograms per liter (kg/L).

Types of Soil Density

1. **Bulk Density (BD)**:
   - Bulk density refers to the weight of soil particles and pore spaces combined. It is an indicator of soil compactness and its ability to store water and air.

- **Formula**: BD=Mass of Dry Soil/ Volume of Soil
- **Ideal Bulk Density**: For most agricultural soils, bulk density values range from 1.1 to 1.6 g/cm³. Values above 1.6 g/cm³ can indicate compaction, which restricts root growth and water infiltration.

2. **Particle Density (PD)**:
   - Particle density refers to the density of the soil's solid particles, excluding pore spaces. It usually ranges between 2.6 and 2.8 g/cm³ for most mineral soils.
   - **Formula**: PD=Mass of Soil Solids/Volume of Soil Solids
   - Particle density is influenced by the mineral composition, with heavier minerals (like iron and aluminum oxides) leading to higher values.

Importance of Soil Density

1. **Soil Compaction and Root Growth**:
   - Low **bulk density** (less compacted soil) allows better root penetration and air circulation, which is crucial for healthy root growth.
   - High bulk density can lead to soil compaction, restricting root growth, water infiltration, and microbial activity. This is particularly problematic for clay-heavy soils.

2. **Water and Nutrient Retention**
   - Soils with lower bulk density typically have more pore space, which helps retain water and nutrients. **Sandy soils**, which tend to have low bulk density, may have issues with poor water retention, requiring more frequent irrigation.
   - **Clay soils** with high density may retain too much water, leading to waterlogged conditions that are detrimental to plant roots.

3. **Soil Aeration**
   - Proper soil aeration is essential for root and microbial activity. Soils with low bulk density allow for better air exchange, ensuring that plant roots get sufficient oxygen.
   - High bulk density can lead to reduced air spaces in the soil, limiting oxygen availability and affecting root respiration and microbial processes.

4. **Soil Structure and Health**
   - Soils with ideal bulk density have a good balance between solid particles and pore spaces, contributing to a healthy soil structure that supports plant growth and soil fertility.
   - Over compaction or excessive density can disrupt soil structure, making it harder for water and roots to penetrate, thereby reducing soil fertility and plant health.

Soil density, particularly bulk density, is a critical property that influences soil fertility, water movement, root growth, and overall plant health. Understanding and managing soil density helps

in improving soil structure, preventing compaction, and ensuring optimal conditions for agricultural and horticultural practices. Balancing soil density with proper organic matter management and tillage practices enhances soil health and productivity.

6. Soil Water

Soil water refers to the water present in the soil, which is essential for plant growth, nutrient transport, and maintaining soil structure. It is a critical component of the soil-plant-atmosphere system and plays a key role in agriculture, horticulture, and environmental sustainability. Soil water can exist in different forms and is stored in the soil's pore spaces, moving between soil particles or being absorbed by plant roots.

Forms of Soil Water

1. **Gravitational Water**:
   - Water that moves through the soil under the influence of gravity.
   - This water is typically found in the larger pores of the soil and moves quickly downward, draining through the soil profile.
   - **Gravitational water** is not available to plants because it drains too rapidly below the root zone.

2. **Capillary Water**:
   - Water held in the soil by capillary forces (the attraction between water molecules and soil particles).
   - This is the form of water that is most available to plants, as it is held in the smaller pores of the soil.
   - **Capillary water** is essential for plant growth as it is readily absorbed by plant roots.

3. **Hygroscopic Water**:
   - Water that is tightly bound to soil particles and cannot be absorbed by plants.
   - Found in the smallest pores, this water is unavailable to plants because it is held too strongly by the soil particles.
   - **Hygroscopic water** is typically found in dry, sandy soils and is not significant for plant growth.

Soil Water Holding Capacity

The water-holding capacity of the soil refers to the ability of soil to retain water for plant use. It depends on the soil’s texture, structure, and organic matter content. Different soil types hold water differently:

- **Clay soils** have a high water-holding capacity due to their small particles and high surface area, but they can also retain too much water, leading to poor aeration and root damage.
- **Sandy soils** have a low water-holding capacity because of their larger particles and larger pores, which allow water to drain quickly, leaving little water available for plants.
- **Loamy soils** are ideal for plant growth as they have a balanced water-holding capacity, holding enough moisture while allowing excess water to drain away.

Water Movement in Soil

1. **Infiltration**:
   - The process by which water enters the soil from the surface, typically from precipitation or irrigation.
   - Infiltration is influenced by soil texture, structure, and moisture content. Sandy soils have high infiltration rates, while clayey soils tend to have low infiltration rates.

2. **Percolation**:
   - The downward movement of water through the soil profile due to gravity.
   - This process helps distribute water deeper into the soil, making it available for plant roots, and also helps flush out excess salts and chemicals.

3. **Evaporation and Transpiration (Evapo-transpiration)**

   - **Evaporation** is the loss of water from the soil surface due to heat.
   - **Transpiration** is the process by which plants lose water through small pores in their leaves (stomata).
   - Together, these processes, known as **evapo-transpiration**, affect the amount of water available to plants in the soil.

Soil Water Availability

- **Field Capacity**: The amount of water that remains in the soil after it has drained due to gravity. It is the optimal moisture level for plant roots, where water is readily available.
- **Wilting Point**: The point at which the soil has lost most of its water, and the remaining water is bound tightly to soil particles, making it unavailable to plants. Plants cannot extract water from the soil at or below this point.
- **Available Water**: The water that is available to plants, typically defined as the water held between field capacity and the wilting point. Plants can use this water for growth.

Importance of Soil Water

1. **Plant Growth and Development**
   - Soil water is vital for plant growth, as it provides necessary nutrients and supports biological processes like photosynthesis.
   - Insufficient soil water can lead to drought stress, wilting, and poor plant growth, while excess water can cause root rot and other diseases.
2. **Nutrient Transport**
   - Water in the soil serves as a medium for the transport of dissolved nutrients to plant roots. Plants absorb nutrients from the soil solution, which is a mixture of soil water and dissolved minerals.
3. **Soil Structure and Fertility**
   - Adequate moisture in the soil helps maintain good soil structure by preventing excessive compaction and erosion.
   - Moist soils support healthy microbial activity, which is essential for breaking down organic matter and releasing nutrients for plant uptake.

4. **Irrigation Management**
   - Understanding the soil's water-holding capacity and available water helps farmers and gardeners optimize irrigation schedules, reducing water wastage and preventing under- or over-watering.

Soil water is a critical factor in plant health, soil fertility, and overall agricultural productivity. Understanding how water behaves in the soil and its availability to plants allows farmers and horticulturists to manage water efficiently, ensuring optimal growth conditions for crops and reducing environmental impacts. Proper soil management, including improving water retention and drainage, is essential for sustainable land use and healthy plant ecosystems.

7. Soil temperature

Soil temperature refers to the warmth of the soil and plays a critical role in plant growth, seed germination, root development, and soil biological activity. It affects the rate of chemical and biological processes in the soil and influences the overall health and productivity of plants. Soil temperature is determined by various factors including climate, time of year, soil type, and moisture content.

Soil Temperature and its important

1. **Seed Germination**
   - Soil temperature is critical for the germination of seeds. Each plant species has an optimal soil temperature range for germination. Too cold or too hot conditions can hinder or prevent seed sprouting.

- For example, most cool-season crops like lettuce and peas prefer soil temperatures between 10°C to 20°C, while warm-season crops like tomatoes and corn require soil temperatures of 21°C to 30°C for optimal germination.

2. **Root Development**
   - Optimal soil temperatures are necessary for healthy root growth. In cold soil, roots grow slowly, and in excessively hot soil, roots may suffer damage or even die.
   - Cool soil (below 10°C) can limit root extension, while warm soil (20°C to 30°C) supports optimal root growth and nutrient uptake.

3. **Nutrient Availability**
   - The availability of nutrients is directly affected by soil temperature. At higher temperatures, soil microbes and enzymes become more active, accelerating nutrient mineralization. However, excessive heat can lead to nutrient leaching or reduced uptake by plant roots.
   - At low temperatures, microbial activity slows down, and nutrient availability decreases, leading to poor plant nutrition.

4. **Microbial Activity**
   - Soil microorganisms, including bacteria and fungi, are highly sensitive to soil temperature. Warmer soil temperatures accelerate microbial activity, which aids in the decomposition of organic matter and nutrient cycling.
   - However, extreme temperatures (either too hot or too cold) can suppress microbial activity, leading to reduced soil fertility and slower breakdown of organic matter.

5. **Soil Aeration**
   - Soil temperature influences air movement within the soil. Warmer soils have increased microbial respiration, which consumes oxygen and can lead to a decrease in soil aeration. Poor aeration can affect root health, especially in compacted soils.

Soil Temperature Management

1. **Tillage and Planting Timing:**
   - Farmers often use soil temperature to determine the best time for planting crops. For instance, planting may be delayed until soil temperatures rise to the optimal range for the crop. Using a soil thermometer helps assess whether the soil is warm enough for seeds to germinate.
   - In areas with colder climates, farmers might use row covers or greenhouses to raise soil temperatures and extend the growing season.

2. **Soil Mulching**
   - Mulch helps regulate soil temperature by insulating the soil, keeping it cooler during hot days and warmer during colder nights. Mulching reduces temperature extremes, which is beneficial for plant growth, especially in regions with fluctuating temperatures.

3. **Irrigation Management**
   - Excessive irrigation during the warmer months can lead to soil cooling, while insufficient irrigation in hot weather can raise soil temperature too high, stressing plants. Proper water management helps maintain a favorable soil temperature for plant growth.

4. **Soil Temperature Monitoring**
   - Regular monitoring of soil temperature is crucial in understanding seasonal changes and adapting to different crop requirements. Thermometers or temperature sensors can be used to track temperature fluctuations at various soil depths.

Ideal Soil Temperatures for Common Crops

- **Cool-Season Crops**: Such as lettuce, broccoli, peas, and spinach, grow best at temperatures between 10°C to 20°C.

- **Warm-Season Crops**: Like tomatoes, corn, beans, and peppers, thrive in soil temperatures ranging from 21°C to 30°C.

- **Root Crops**: Potatoes, carrots, and beets typically prefer slightly cooler soils, around 15°C to 20°C.

Soil temperature is a crucial factor that impacts many aspects of plant growth, from seed germination to nutrient availability and root development. By understanding and monitoring soil temperature, farmers, gardeners, and horticulturists can optimize planting times, improve crop yields, and enhance soil health. Proper soil temperature management, through practices like mulching, irrigation, and timing, ensures favorable conditions for plant growth throughout the growing season

8. Soil aeration

Soil aeration refers to the process of introducing air into the soil, allowing for the exchange of gases between the soil and the atmosphere. It is vital for maintaining adequate oxygen levels in the soil, which is necessary for the respiration of plant roots, soil organisms, and microorganisms. Good soil aeration helps create an environment conducive to plant growth by improving root development, nutrient uptake, and microbial activity.

Importance of Soil Aeration

1. **Root Respiration and Growth**
   - Oxygen is essential for root respiration, a process in which roots convert stored carbohydrates into energy for growth. Adequate aeration ensures that roots have access to enough oxygen to carry out this function.
   - Poor aeration can lead to root suffocation, restricting growth and causing plants to become weak and stressed.

2. **Microbial Activity**
   - Soil microorganisms, including bacteria, fungi, and earthworms, require oxygen to survive and perform essential functions such as decomposing organic matter and cycling nutrients.
   - Inadequate aeration can reduce microbial activity, slowing down nutrient mineralization and affecting soil fertility.

3. **Water Movement:**
   - Proper aeration allows water to move more easily through the soil. It ensures that the soil can absorb rainfall or irrigation and that excess water can drain properly.
   - Well-aerated soil helps prevent waterlogging, which can suffocate plant roots and create anaerobic conditions (lack of oxygen) that promote the growth of harmful pathogens.

4. **Nutrient Uptake**
   - Adequate oxygen is essential for the uptake of essential nutrients, especially nitrogen, by plant roots. Roots rely on oxygen for active transport mechanisms to absorb nutrients from the soil solution.
   - Poor aeration can limit nutrient uptake, leading to deficiencies and poor plant health.

5. **Soil Fertility**
   - Aeration supports the breakdown of organic material by soil organisms, which releases nutrients into the soil in forms that plants can absorb.
   - It also helps to prevent the accumulation of toxic substances like carbon dioxide and methane, which can occur in poorly aerated soils

Improving Soil Aeration

1. **Tillage**
   - **Tilling the soil** helps break up compacted layers and increase pore space, allowing air to penetrate deeper into the soil. However, excessive tillage can also lead to soil degradation and reduced soil structure over time.

- **No-till or reduced-till farming** practices can help maintain soil structure while reducing the disruption of soil aggregates and promoting long-term aeration.

2. **Organic Matter Addition**
   - Adding organic materials like compost, manure, or mulch can improve soil structure, increase pore space, and enhance aeration. Organic matter also supports beneficial microbial activity and enhances soil fertility.

3. **Use of Cover Crops**:
   - **Cover crops** such as clover or vetch help reduce soil compaction, improve soil structure, and enhance aeration. Their roots create channels in the soil that allow air to reach deeper layers.
   - They also add organic matter to the soil when they decompose, further improving aeration.

4. **Soil Amendments**:
   - The addition of soil amendments like **gypsum** or **perlite** can help improve soil structure, increase pore space, and enhance aeration, especially in clayey or compacted soils.

5. **Proper Irrigation**:
   - Avoid over-irrigating, which can lead to waterlogged conditions and poor aeration. Drip irrigation or sprinkler systems that allow for even moisture distribution are more effective in maintaining proper soil aeration.

6. **Avoiding Soil Compaction**
   - Avoid heavy machinery use during wet conditions, as this can lead to soil compaction and poor aeration. Also, limiting foot traffic or animal movement on sensitive soils can help maintain proper pore spaces.

Soil aeration is a critical factor in maintaining soil health and supporting plant growth. Proper aeration ensures sufficient oxygen supply to plant roots and soil microorganisms, promotes water infiltration, and enhances nutrient cycling. Practices such as tillage, organic matter addition, use of cover crops, and avoiding soil compaction can help improve and maintain soil aeration, contributing to better soil structure, plant productivity, and overall soil health. Managing aeration is especially important in intensive agricultural systems to optimize crop yields and prevent soil degradation.

Laboratory instruments used in soil and plant analysis

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pH meter

A pH meter is very commonly used for the measurement of the reaction of a solution or a medium. The pH determination with the help of a pH meter is based on the measurement of the electromotive force (e.m.f) of a pH cell consisting of an electrode sensitive to H^+ ions and a reference electrode. The pH cell can be represented as follows

H^+ sensitive electrode | Reference buffer || Salt bridge | Reference electrode

The conventional type of pH meters has a H^+ sensitive glass electrode and a calomel reference electrode. The other types of H^+ sensitive electrodes are hydrogen gas electrode, platinum electrode, quinhydrone electrode and antimony electrode.

Glass electrode

The electrode is a glass membrane electrode. It consists of a H^+ responsive thin-walled soft glass bulb sealed to a stem of non-H^+ responsive high resistance glass. The pH response is confined to the area of the glass membrane only and thus the effect of depth of immersion is eliminated during the pH measurement. Both the inner and outer surfaces of the bulb are sensitive to the changes in H^+ concentration. The inside of the bulb is filled with an electrolyte of high buffering capacity such as a 0.025M solution of HCl or H_2SO_4. An inner reference electrode also dips into this electrolyte. When the glass electrode bulb is dipped in a solution having H^+ concentration different from that inside the electrode, an electrical potential develops across the membrane and this potential is proportional to the difference in the pH between the two sides. Since the pH of the inner side remains unchanged, the difference denotes the H^+ concentration of the outer solution.

The glass electrode offers many advantages such as:

1. The dissolved CO_2 and other gases are not expelled from the system,
2. It is adaptable to thick fluids, pastes or gels,
3. There is no effect of oxidizing or reducing solutions,
4. No H_2 gas or catalytic surface or auxiliary materials are required,
5. It provides rapid and fairly accurate results, and
6. It is convenient for continuous working.

However, the glass membrane attains the equilibrium slowly and normally takes several seconds for it. Also, the glass surface is easily contaminated with adsorbed cations and suspended particulates, leading to delayed equilibrium. For an appropriate combination of chemical durability and electrical resistance the electrodes are designed for certain ranges of both temperature and pH. A general-purpose electrode is useful as it works satisfactorily for -5 to 60°C with negligible error up to pH 11. The error at higher pH is considerable and needs correction.

Calomel electrode

The reference calomel electrode consists of Hg in contact with KCl saturated with Hg_2Cl_2. Undissolved KCl salt in the saturated KCl solution is clearly visible. In a number of commercial makes, a paste of Hg and Hg2Cl2 is filled in the inner tube connected to the KCl solution in an outer tube. The lead wire is connected to the paste through the Hg column. The outer tube containing KCl ends in a fine capillary to act as a salt bridge through the test solution to the H^+ sensitive electrode.

Measurement of pH

The term pH was introduced by Sorensen and is defined as the negative logarithm of the H+ activity, which is expressed in gram ions per litre. The H^+ activity in a very dilute solution can be expressed as concentration in gram mole per litre. Thus, $pH = -\log_{10} H^+$ or $-\log_{10}[H+]$

The effective concentration of H^+ ions includes all sources e.g. H^+ obtained from dissociation of soluble acids and from soil particles.

Water dissociates into its components namely H^+ and OH^- ions but only slightly, so much so that the quantity of the undissociated water remains large enough to be treated as constant. Therefore, in the ionization equilibrium:

$H_2O \rightarrow H^+ + OH^-$

Dissociation Constant

- The dissociation constant K is expressed as:
  - $K = [H^+] \times [OH^-] / [H_2O]$
- The product of the two ions *i.e.* H^+ and OH^- is also constant at a given temperature.
- Thus, $[H^+] \times [OH^-] = 10^{-14}$ g mol L^{-1}
- At neutral pH (7.0), $[H^+] = [OH^-] = 10^{-7}$ g mol L^{-1}.
- Since the potential of glass electrode is directly proportional to pH, the scale is calibrated into pH units.

- The value of the potential at 25 °C is 0.059 volt for each pH unit.
- The activity of H^+ and OH- ions at different pH values on the scale are given below:

pH	$[H^+]$	$[OH^-]$
0	10^{0}	10^{-14}
1	10^{-1}	10^{-13}
2	10^{-2}	10^{-12}
3	10^{-3}	10^{-11}
4	10^{-4}	10^{-10}
5	10^{-5}	10^{-9}
6	10^{-6}	10^{-8}
7	10^{-7}	10^{-7}
8	10^{-8}	10^{-6}
9	10^{-9}	10^{-5}
10	10^{-10}	10^{-4}
11	10^{-11}	10^{-3}
12	10^{-12}	10^{-2}

The electromotive force (e.m.f.) measurement is done on a suitably calibrated galvanometer or ammeter and read directly in pH units. It is necessary to set the instrument at the temperature of the test solution.

Types of pH meters

A pH meter may be of any one of the following types

1. Potentiometric. In this type of glass electrode pH meter, the simple circuit incorporates an ordinary potentiometric circuit with single electron tube in a null-type amplifier circuit. A constant current from a battery is obtained through a slide wire and the off-balance currents as deflection are amplified electronically so that an ammeter can be used to detect the balance point. The electronic amplifier thus serves only as a null-point indicator. pH meters of this type are compact, portable and inexpensive. The scale extends from pH 2 to 12 with a ± 0.1 pH unit accuracy.
2. Vacuum tube voltmeter (VTVM) type: The VTVM with scale indicating pH values is calibrated in voltage units for a glass-calomel electrode pair on the basis of the relationship given below:

$$pH = pHs + (E - Es)/0.000198\ T$$

Where, pHs is the pH of standard reference solution, E and Es are the e.m.f. of the pH cell for unknown and standard solution, respectively, and T is the temperature in Kelvin. The assumption in the relationship is that the internal and external reference electrodes for the glass electrode assembly are of the same type and similar concentrations. Most of the pH meters used in the soil testing laboratories in India are VTVM type.

3. Direct reading type: The e.m.f. of the glass electrode assembly is impressed across a high resistance and the direct current flowing through the resistance amplified and then passed through an ammeter. The deflection indicates the pH directly. This is in fact a modification of VTVM type and is characterized by greater rapidity of reading and is adaptive to continuous working. The compensation for temperature variation can be provided by a flow of feedback current through a temperature-sensitive resistor either located in the input circuit or placed in the test solution.

Care in handling and maintenance

The most delicate part of a pH meter is the glass electrode. The thin-walled glass bulb very often breaks due to rough handling. It may also dry up when kept out of water for long. If dried, the electrode should be immersed in 0.1N HCl and then in distilled water for 1-2 days and checked again for its sensitivity. For general care, attention may be paid to the following:

1. For checking the defect in electrode, short circuit the electrode jacks with the special strap and provide the terminal connections with the instrument. Switch on the instrument and allow 15-20 minutes for warm up. If the galvanometer reads 7.0 or can be adjusted to pH 7.0, the defect lies in electrode. Replace the electrode in such a case.
2. Ensure there is always some solid KCl in the reference electrode.
3. Clean Electrode: Remove any clay gels on the electrode using cotton wool and distilled water.
4. Spare Electrode: Keep a pair of glass and calomel electrodes (or a combined electrode) as a spare for emergency use.

Conductivity meter

Principle

Salinity in soil and water is characterized as the total content of dissolved inorganic solutes. Electrical conductivity is measured to conventionally determine salinity. Electrical conductivity is a measure of the ability of a salt solution to carry electric current through the migration of ions under the influence of an electric field.Ions is the carriers of electricity. Solutions obey Ohm's law, like metallic conductors. Dissociation of salts is promoted by increased temperature, increasing conductivity at a rate of approximately 2% for every degree Celsius increase. The unit of specific conductance is the reciprocal of specific resistance in ohms cm^{-1}, i.e., mhos cm^{-1}.If Cs is the concentration of a solution in gram equivalents L^{-1}, then the volume of solution in mL per equivalent is 1000/Cs, where K is the cell constant. At infinite dilution, ions are theoretically independent of each other, and each ion has its contribution to the total conductance.

Thus,

$\lambda\alpha = \Sigma(\lambda^{+}) + \Sigma(\lambda^{-})$

where, $\lambda\alpha$ is the total conductance,

λ^{+} is the conductance of cations, and

λ^{-} is the conductance of anions at infinite dilution

The instrument used for measuring conductivity is also known as conductivity bridge. A typical system consists of an alternating current (AC) Wheatstone bridge, a primary element of conductivity cell and a null balance indicator (as in "Solubridge") or an electronic "eye" in the conductivity meter. The test solution is filled in a conductivity cell, which is usually made out from two platinum sheets embedded in glass so that the two surfaces facing each other remain exposed. The area and distance between these plates must remain constant. In order to increase the sensitivity of the measurement, one or two stages of amplification are provided before feeding the signal to the electronic eye.

Determination of cell constant

The cell constant, k, of a conductivity cell is determined by measuring the electrical conductance of a standard KCl solution at the same temperature according to the equation:

$k = L/C$

where, L and C are the known specific electrical conductance and the measured conductance of the standard solution (usually 0.02M KCl) in the given cell in dSm^{-1}. The specific conductance (L) of 0.02M KCl is 2.39 dSm^{-1}. at 18 °C and 2.77 dSm^{-1}at 25 °C. By using the temperature coefficient provided in the table given below, the specific conductance can be calculated at various temperatures.

Procedure

1. Switch on the instrument. Allow at least 15-20 minutes for warm up.
2. Wash the electrode with distilled water and wipe dry with tissue paper.
3. Use 0.02M KCl solution to calibrate the meter.
4. Wash and fill the cell with the KCl solution. Adjust the meter to read the standard conductivity at that temperature or adjust the cell constant with the help of the calibration knob.
5. Wash the electrode with distilled water, followed by the test solution.
6. Fill the electrode with the test solution.
7. Record the conductivity reading. Note the temperature of the solution and make the temperature correction (Table 4.1) to express results as dS m^{-1} at 25°C.

Precautions

1. Before using a new conductivity cell, place it in distilled water for 24 hours.
2. When not in use, keep the cell in distilled water.
3. Keep the cells perfectly clean for accurate readings.
4. Rinse the cell with the specimen before making the measurement.

Conversion factors for obtaining EC values at 25 °C

Observation temperature (°C)	Conversion factor	Observation temp. (°C)	Conversion factor
14.0	1.217	20.2	1.107
15.0	1.247	20.4	1.102
16.0	1.213	20.6	1.097
17.0	1.189	20.8	1.092
18.0	1.163	21.0	1.088
18.2	1.157	21.2	1.082
18.4	1.152	21.4	1.078
18.6	1.147	21.6	1.073
18.8	1.142	21.8	1.068
19.0	1.136	22.0	1.064
19.2	1.131	22.4	1.060
19.4	1.127	22.6	1.051

Colorimeter/ spectrophotometer

Principle

Colorimetry is the determination of the concentration of a substance by measuring the relative absorption, or transmission of light with respect to a known concentration.Colorimetric analysis is based on the measurement of intensity of radiant energy after it passes through a sample solution. A monochromatic light beam of known intensity is passed through the test solution and

the intensity of the transmitted beam is determined with the help of a photo-electric cell.Thus, colorimetry can be considered as the absorption spectrophotometry in the visible range.

It is based on Beer's law which states that the intensity of a monochromatic light beam decreases exponentially as the concentration of the absorbing substance increases arithmetically, as expressed below:

$$\log I/I_1 = kC$$

where, I and I_1 are the intensities of the incident radiation and transmitted radiation, respectively, C denotes the concentration in solution, and k is a constant.The above relationship holds good only when the light is of the wavelength at which its absorption is maximum by the sample. Therefore, monochromation of the incident light through a suitable filter or grating is an essential prerequisite for colorimetry or absorption spectrophotometry. The Beer-Lambert's law relates the concentration to the logarithm of the ratio of the intensities of incident and transmitted radiations. Hence the absolute intensities need not be determined. The colorimeter tube acts as a cylindrical lens, converging the light to a sharp line on the photo-cell. If the tube is not exactly circular in cross section, its focal length changes at different angles. This leads to a change in the intensity of the light falling on the photo-cell.A perfectly circular tube when filled with distilled water will not show any deflection of the galvanometer needle at any angle of tube rotation.

Types of colorimeters

Absorption photometers may be classified as visual comparators, filter photometers and spectrophotometers. On the basis of their construction, these could be either single beam or double beam type. Also, the instruments may be of direct-reading type or based on balanced circuit.Special features of some instruments are the double monochromation and dual wave-length monochromators, plus automatic recording. While selecting an instrument, one should consider the initial and maintenance costs, flexibility of operation and adaptability to varying situations.

Visual comparators

The simplest colour comparators use side-by-side viewing of light coming from a common source through a pair of matching, flat bottom tubes, one containing the test solution and the other the standard.On matching the two, the ratio of the vertical heights of the solutions would be inversely related to the ratio of their intensity.

Filter photometer

In a single beam, direct-reading photo-electric colorimeter, the optical path is from the light source, through the filter and sample holder, to the detector. The light passes through the solution and then strikes the surface of the barrier layer cell, the output of which is measured as deflection of the galvanometer.

Double beam colorimeters employ barrier layer matching photo-cells, and the incident filtered light is divided into two parallel beams, one passing through the solution in the tube/cuvette before falling on the photo-cell and the other passing directly on to the reference photo-cell through an adjustable slit.

A colorimeter essentially has i) a light source, usually a tungsten lamp, ii) a monochromator (filter or prism).

Spectrophotometer

There is no difference between the basic principles of ordinary filter colorimeter and spectrophotometer. In the spectrophotometers a more refined monochromator is employed and the measurement may be made slightly beyond the visible region of the electromagnetic spectrum. The wavelength ranges from 375 to 650 nm and can be extended to 950 nm by adding a red filter and exchanging the photo-tubes. The effective band width is 20 nm.

Care and maintenance

For a better service and maintenance of the instrument, follow the important tips given below:

1. Do not disturb the galvanometer assembly.
2. Protect the instrument from mechanical shocks. Keep it on a vibration-free surface.
3. Consult a competent engineer, if the instrument has developed some fault.
4. If the projection lamp fails to light and if there is a dangling wire it is sign of damaged bulb. Replace it with the same wattage bulb. If the bulb filament is intact, set right the loose connections, if any.
5. If the photo-cells fitted in the instrument lose their sensitivity on prolonged use or for any other reason, clean them or get them replaced. Never open them.
6. For replacement of photo-cell, contact any competent firm undertaking the jobs of repairs/service.
7. Use an automatic voltage stabilizer in the AC supply line.
8. Always place the colorimeter tube (absorption cell) gently in order to avoid scratches.
9. Ensure that the outer surface of the tube/cuvette is absolutely clean and no liquid is sticking to it before placing in the socket.

Flame emission spectrophotometer

Atomic emission spectrometry using flame photometers has been extensively used for the estimation of the alkali metals (Na & K) and alkaline earth metals (Ca & Mg) in soil, plant and water samples. The precision and accuracy for Na and K determination using flame photometer are better than those for Ca and Mg. The use of improved burner systems, high dispersion monochromators and nitrous oxide-acetylene flame has markedly improved the performance of this technique by improving precision and detection limit capabilities for many other elements, while at the same time minimizing certain types of interferences. The development of AAS, and ICP-AES instruments, despite their higher cost have completely replaced flame photometers in many laboratories in the advanced countries. But flame photometry has advantages of comparatively much less initial and maintenance/running costs because of its simple optical system, and the operation procedures are well suited to the laboratories that cannot afford costly equipment.

Principle

When a solution of a salt is sprayed into a flame, the salt breaks into the component atoms due to high temperature. The energy provided by the flame excites the orbital electrons to higher energy levels. When these electrons return to their ground state, they emit a characteristic radiation. Flame emission spectrophotometers are designed to measure the intensity of the characteristic line (resonance line) emitted from the excited atoms or ions of the element to be determined as opposed to AAS, which involves measurement of the absorption of radiant energy by excited atoms.

Each excited individual atom emits one quantum of radiation when it returns to the ground state. Therefore, the increase in the intensity of radiation emitted from steady and non-luminous flame will be proportional to the number of atoms of the particular element in the flame i.e. its concentration. This concentration is directly related to the content of the element in the test solution. Like most of the analytical techniques, this method is also not absolute but comparative, and concentration of the analyte in the sample is to be computed from the calibration curve.

The instrumental set-up consists of three parts:

- Atomization assembly, comprising a nebulizer (atomizer) to produce a fine mist from the solution and a burner which vaporizes the analyte (in atomized form).
- Monochromation system (filter, prism) that separates out the analytical wavelength from the other radiations.
- Photometric system for measuring the intensity of the emitted radiation.

Types of flame photometers

Flame photometers are of two types – single beam and double beam.

- Single-beam type: A single beam equipment commonly referred to as direct reading type, comprises only one set of optics. Light emitted from the core of the flame just above the inner cone is collected by a reflector and focused by a lens of heat-resistant glass through interchangeable optical filters (interference type filter) on to a single photo-detector. Alternatively, light from the burner passes into a monochromator and radiation leaving the exit slit is focused on to the photo-detector unit.
- Double-beam type: In the double-beam type instrument, a second light path is provided for the radiation emitted by the internal standard element (e.g. lithium) that is added in a fixed amount to each test solution as well as calibration standard. The wavelengths of internal standard and analytical materials are isolated by means of special filters in a dual optical system and each beam is focussed on separate photoelectric cell.

Operation of flame photometer

While the ordinary type of manual flame photometers can be operated with great ease, modern flame photometers are operated with the help of computer software and necessary operational parameters and can be set through keyboard commands. The actual steps involved may vary with the type of the instrument. Therefore, the users are advised to consult the manual provided by the manufacturer. However, the common steps required are given below:

1. Select the desired optical filter (K, Na or Ca).
2. Switch on the instrument.
3. Switch on the compressor to get air supply.
4. Adjust the air control knob to give a pressure as prescribed in the operation manual.
5. Leave the instrument for about five minutes to get stabilized.
6. Turn on the gas supply and light the flame.
7. Adjust the gas control until formation of separate, stable, blue colour cones in the flame without sound.
8. Set the galvanometer to zero by means of the control knob against a reagent blank solution (medium).
9. Set the galvanometer to 100 with the highest concentration of standard solution.
10. Repeat the last two steps till the above setting is obtained without further adjustment.
11. Proceed with the determination of the remaining standards and samples.
12. For switching off the instrument close the gas supply first, run distilled water for about 2 minutes more and then switch off the compressor. Turn off all the knobs and switches.

Precautions

1. Keep the standards and samples free from any suspended material to prevent clogging of the nebulizer and the capillary.
2. Do not feed highly concentrated acid and salt solution.
3. Maintain a constant supply of air-gas mixture to the burner.
4. Do not leave the flame unattended.
5. Periodically replace the pressure tubing of the fuel gas.

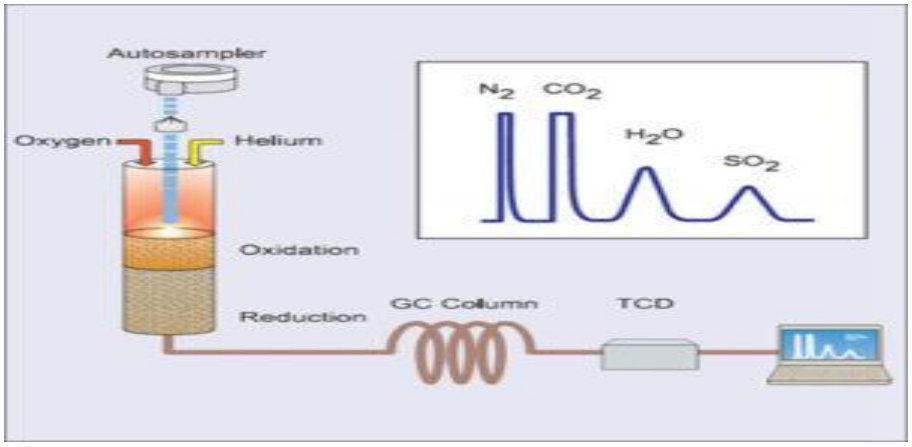
CHNS elemental analyzer

CHNS elemental analyzers provide a means for the rapid determination of carbon, hydrogen, nitrogen and sulphur inorganic matrices and other types of materials. They are capable of handling a wide variety of sample types, including solids, liquids, volatile and viscous samples, in the fields of pharmaceuticals, polymers, chemicals, environment, food and energy.

Combustion elemental analyzers are manufactured in a variety of configurations to suit specific applications, and the choice will depend on the elements of interest, the sample type and size, and the concentration of the analyte.

All instruments require two gas supplies: (i) an inert carrier gas (helium recommended); and (ii) high purity oxygen (minimum 99.9995%). The strict specification for oxygen is associated with the need to reduce the nitrogen 'blank' contribution to an inconsequential level. Additionally, GC-type gas filters are also usually fitted to prevent trace organic species and water entering the combustion system.

The choice of sample introduction systems will depend on the application and the sample type. For solids or viscous liquids, samples are weighed out into tin capsules; for liquids, samples can be sealed in individual aluminium vials or introduced via a liquid auto-sampler. Both capsules and vials are pre-cleaned and dried to avoid trace contamination from oils and water acquired during their manufacture. Instruments are marketed with either simple 'one shot' introduction interfaces or a carousel type auto sampler. In some instances a microbalance is directly interfaced with the analyser to allow the automatic recording of the weight of each test portion.



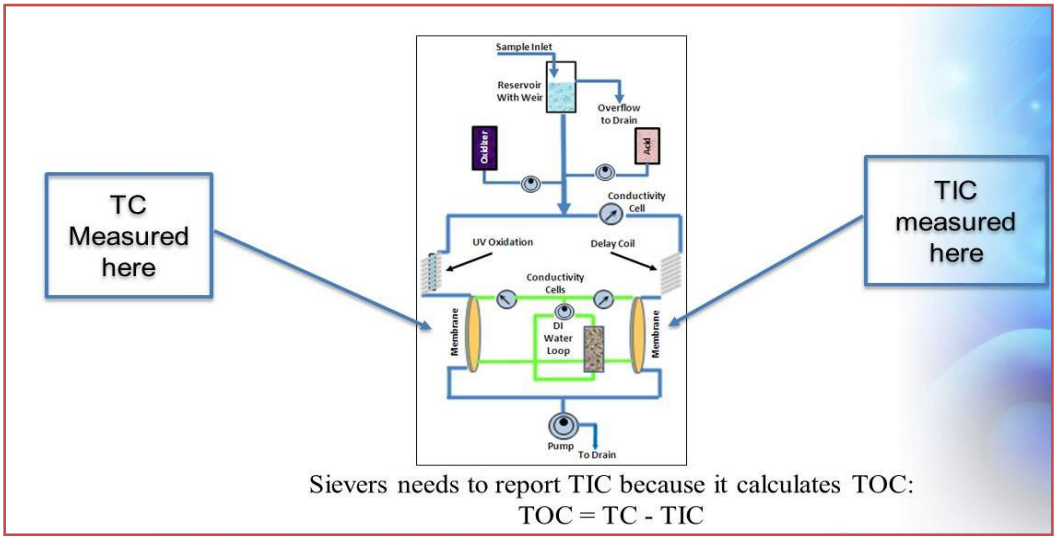
The combustion section of the analyser is designed to achieve both complete combustion of the sample and conversion of oxides of nitrogen to nitrogen gas (N2). Although different approaches have been chosen by different manufacturers, the use of high purity copper is universal for the reduction stage. In some instruments, the combustion and reduction stages are housed in separate furnaces. In others, the reactions are combined in a single two-tier furnace. Catalysts are usually added to the combustion section to aid complete combustion and absorbents to remove potential contaminants. Both the catalysts/absorbents and copper metal are packed into readily exchangeable tubes made of ceramic material or high quality silica.

Instruments are classified as either 'static' or 'dynamic' in terms of their combustion characteristics. In the 'static' type, a pre-set volume of oxygen is added to the combustion tube before the sample is introduced. In the 'dynamic' type, the oxygen is added to the tube at the same time as the sample introduction and continues to flow for a set time. In the majority of applications, either method is applicable. For slow burning materials such as coals and cokes, where multiple additions of oxygen are required for complete combustion, the 'static' system is preferred.

The detection system within the analyser can take several forms depending on the combustion mode and sample size. With small test portions, the combustion gases can be separated on a GC column and quantified using a thermal conductivity detector. If larger test portions are required, an instrument employing 'frontal' chromatography can be chosen. The latter approach employs a GC column with thermal conductivity detection but provides a step-wise profile for integration. Yet other detection approaches require no separation step but use separate infra-red and thermal conductivity cells to respond to individual elements.

Control of the instrument is established through a computer module, which is used to set up the program of work, report instrument diagnostics, and manage the calibration procedures.

Total organic carbon (TOC) analyzer



The TOC analyser is used for the measurement organic carbon pollution in water samples from municipal and industrial sources. TOC is a popular analytical technique that forms the basis of many industry standard analytical methods. Carbon can be present in water samples from organic and inorganic sources. Total Organic Carbon (TOC) consists of living organisms, decaying matter and synthetic/organic products such as petrol, coal, plastics, etc. However, water can also contain carbon from inorganic sources. Inorganic Carbon (IC) is comprised of carbonates and bicarbonates, dissolved CO_2 elemental carbon, cyanides etc. Carbon is analysed in the TOC analyser by first oxidising it to form carbon dioxide, which is then detected using a non-dispersive infrared (NDIR) detector. There are two types of TOC analyser which use either high temperature catalytic combustion oxidation or UV-persulphate oxidation methods.

High temperature catalytic combustion oxidation TOC analyser

The sample is injected into a furnace operating at 680°C -1000°C. The combustion tube contains a bed of a proprietary platinum are often used to promote better oxidation. This is the preferred method for the analysis of waste water, drinking and surface water, ground water, sea water, and other hard to oxidize matrices. It offers excellent oxidation of all organics, the ability to analyse salt samples and works well with particulate samples. The method does tend to have relatively high background levels making it less effective at low parts per billion (ppb) levels.

UV-Persulfate oxidation TOC analyser

In UV/Persulphate methods, UV light is the main oxidiser but the oxidation power of the reaction is enhanced by the addition of a persulphate compound. The UV/ Persulphate oxidation method is generally best suited for the pharmaceutical and biotechnological industries. This is primarily due to low instrument background and the large sample volumes that may be tested for TOC content. This method offers excellent precision at low ppb levels.

Measurement options

The TOC analyser is a versatile instrument that offers a number of measurement options.

- Total carbon can be measured by placing the sample directly into the analyser without pre-treatment.
- TOC can be measured directly by first removing inorganic carbon by acidification and sparging. The remaining carbon is then measured as TOC. This method, however, also removes purgeable organic carbon (volatile and semi volatile organic materials), but since this generally represents 1% or less of total carbon in a sample, it is considered negligible.
- IC can be analysed in liquid samples by acidifying with an inorganic acid to pH 3 or lower, and then sparging with a stream of inert gas. The acidification converts carbonates and bicarbonates to carbon dioxide, which is then removed along with dissolved CO_2 by the gas stream, and measured to provide an IC value.

TOC can also be measured by difference or by sum. TOC measurement by Difference measures TC and IC individually and the difference between these two measurements is rigorously TOC. TOC measurement by Sum measures nonpurgeable organic carbon and purgeable organic carbon independently. The sum of these measurements is rigorously TOC.

Atomic absorption spectrophotometer (AAS)

Atoms are excited by thermal means to higher energy states → emit radiation by dropping down to less energetic states or to the ground state

$M + h\nu \rightarrow M^* \rightarrow M + h\nu$

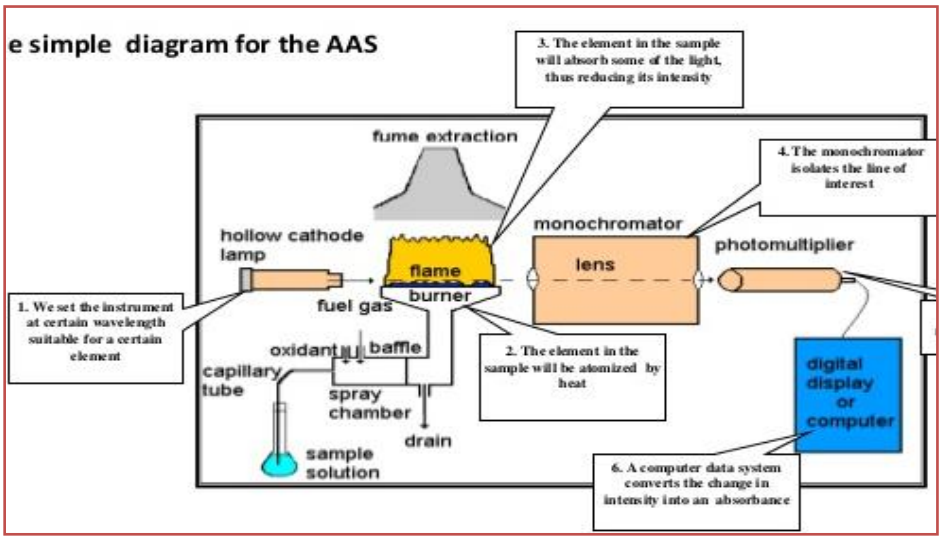
Absorption Emission

The number of atoms in a flame in a particular excited energy state *(n* *) and the number of atoms in the ground or unexcited state *(n)* are related by the following familiar boltzman relationship: $n^*/n = A \exp(-\Delta E/KT)$

n^*/n values for most elements in flames of about 3,000°K are in the 10^{-10} to 10^{-4} range.

AAS - Instrument Features

- A light source that emits resonance line radiation
- A sampling cell, usually a flame, into which the sample is fed as an aerosol
- A monochromator that is used to isolate the absorbing resonance line from other non absorbing lines
- A detector that measures the amount of absorption
- Electronic amplification of the absorption signal;
- A readout system that normally is a strip chart recorder, a digital display, a meter, or a printer.



AAS – Principle of operation

- The sample aerosol is aspirated
- Mixed with the gases before combustion
- During combustion, the element is reduced to the atomic state and then can absorb radiation
- Absorption of radiation is directly proportional to no. of atoms present in ground state
- Two types of flames:
    - air- acetylene (air-C_2H_2 and
    - nitrous oxide-acetylene (N_2O-C_2H_2)
- Air-C_2H_2 flame (2,100-2,400°C) $\rightarrow$ used for elements with low ionization potentials that don't form refractory compounds
- Nitrous oxide-acetylene is a hotter flame (2,600-2,800°C) $\rightarrow$ used for Al, As, Cr, Si, Ti

Atomic absorption instrument types

- Single-beam
- Double- beam
- Dual-channel double-beam
    - simultaneous determination of conc. & ratios of two elements using identical atomization and flame parameters
- Double-beam sequential multi-element
    - Upto 6 elements can be determined sequentially
- Double beam: compensates for
    - changes in lamp intensity
    - variations in electronic noise
    - detector sensitivity
- Double-beam instrument sends only half of the source lights' intensity through the sample chamber
- Single-beam instrument will give better detection limits especially if the electronics are stable.

Good practice for operation precautions

- Alignment of hollow cathode lamp
- Alignment of burner: horizontal and vertical
- Alignment of capillary in spray chamber: Speed of suction of solution to be optimized
- Quality control check: Measure concentration of blank and a standard solution

Inductively coupled plasma –optical emission spectrophotommetry (ICP-OES)

- ICP-OES gained a strong foothold in environmental laboratories in the 1980s and 1990s
- Advantages over flame atomic absorption spectroscopy:
    - Multi-element analysis capability,

- large dynamic linear range
- reduction of matrix interferences,
- improved detection limits for refractory elements and
- enhancement of productivity.

ICP-OES: Principle

- Sample constituents are vapourized→ atomized → excitation of atoms or ions.
- The excited atoms or ions will emit their specific line spectra.
- The intensities of these lines depend on the concentrations of their respective elements in the sample
- Emitted spectra are analyzed by suitable detector
- Plasma is used for vaporization, atomization, ionization and excitation elements
- Electrons and ions passing through the oscillating electromagnetic field flow at high acceleration rates inside the quartz tube space
- Collisions between accelerated electrons (and ions) and ensuing unionized Ar gas cause further ionization
- The collisions cause ohmic heating and give temperatures ranging from 6,000 to 10,000°K

ICP-OES: Major components

- Sample introduction system
- Nebulizer
- Plasma generation assembly
- RF generator
- Detector

Classification of ICP-OES

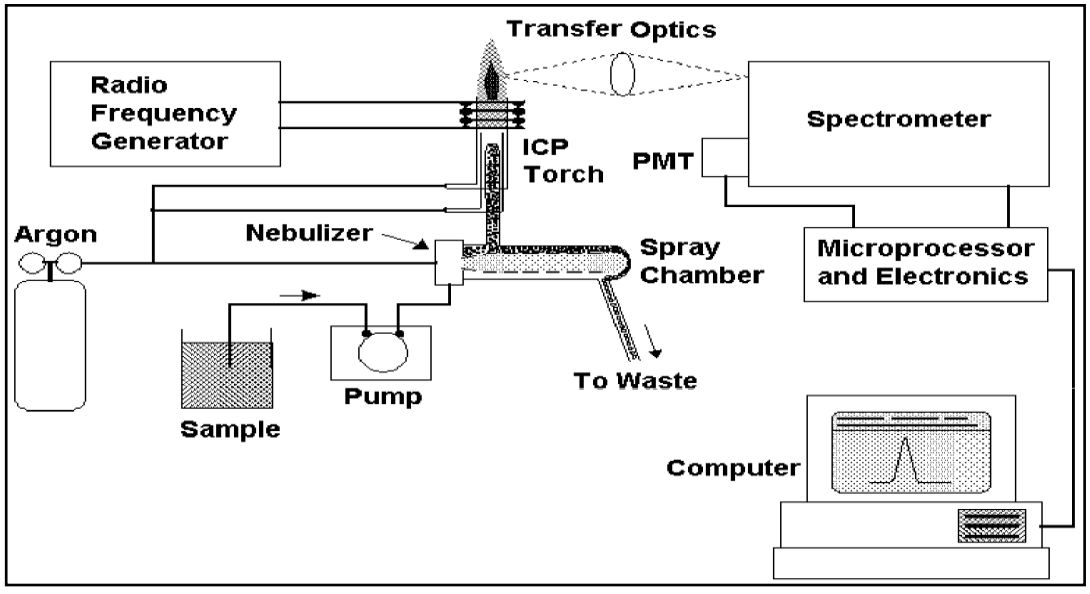
- Method of measurement
  - Simultaneous
  - Sequential
- Viewing of plasma
  - Axial view
  - Radial view
- Detector
  - Photomultiplier tube
  - Solid state detector

Precautions

- Filter soil extracts, and soil and plant tissue digests with Whatman No. 42 filter paper to prevent clogging of the nebulizer.
- To prevent clogging of the nebulizer tip, either use high salt nebulizer (Babington type) or standards and samples having very low salt content.
- Avoid mixing of chemicals that cause precipitation during the preparation of multi-element working standard solution.

Limitation in ICP

- ICP technique is applicable to the determination of a large number of elements. The detection limits for these elements are generally in the µg/L (ppb) range. As in many techniques, the detection limit is regarded as the lowest concentration at which the analyst can be relatively certain that an element is present in a sample. Measurements made at or near the detection limit, however, are not considered to be quantitative. For purposes of rough quantitation (±10%), it is recommended that an element's concentration should be at least five times higher than the detection limit. For accurate quantitation (± 2%), the concentration should be greater than 100 times the detection limit. While most of the over 70 elements that can be determined by ICP have low detection limits, it is worthwhile to discuss the elements that are usually not determined at trace levels by ICP. These elements fall into three basic categories. The first category includes those elements that are naturally entrained into the plasma from sources other than the original sample. For example, in argon ICP, it would be hopeless to try to determine traces of argon in a sample. A similar limitation might be encountered because of the CO_2 contamination often found in argon gas. When water is used as a solvent, H and O would be inappropriate elements, as would C if organic solvents were used. Entrainment of air into the plasma makes H, N, O and C determinations quite difficult.



Component of ICP-OES

- Another category of elements generally not determined at trace levels by ICP includes those elements whose atoms have very high excitation energy requirements such as the halogens, Cl, Br and I. Though these elements may be determined, the detection limits are quite poor compared to most ICP elements. The remaining category includes the man-made elements which are typically so radioactive or short-lived that gamma ray spectrometry is preferable for their determination.

Interference

- Interference is anything that causes the signal from an analyte in a sample to be different from the signal for the same concentration of that analyte in a calibration solution. Despite the fact that the presence of interference can be devastating to the accuracy of a determination, there is no analytical technique that is completely free from interferences. However, modern trace elemental analysis instruments have been designed to minimize the interferences.
- When ICP was first introduced to the analytical community, the claim was often made that the technique was nearly free from interferences. This claim was made because the classic chemical interferences that were found in flame atomic absorption spectrometry were not observed in ICP. Soon after analysts began measuring trace element concentrations in a wide variety of samples, however, the reality of the existence of some interference became apparent. The interferences that we know about today in the ICP are spectral in origin. Other interferences are often the result of high concentrations of certain elements or compounds in the sample matrix and are not too severe for most samples.
- The best way to guard against inaccurate results due to unexpected interferences with ICP is an adequate quality control program. The components of quality control will vary with the sample type, the degree of precision and accuracy required, and the penalty anticipated if errors exceed acceptable levels. The most generally applicable quality control procedure is to analyze samples of known composition along with the unknowns. These reference materials should match the sample matrix and the concentration range of the analyte elements.
- Reference materials representing many different types of matrices with numerous certified trace element concentrations can be purchased from the U. S. National Institute of Standards and Technology (formerly the National Bureau of Standards).

Methods of analysis of soils and plants (Practicals)

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Determination of pH of soil

Potentiometric method

The activity of hydrogenis calculated from the measured potential of a half cell involving this ion and the known standard potential of the half cell.

Principle

A pH meter is an instrument which measures the voltage developed by the combination of a glass electrode and a reference electrode. The scale is graduated in terms of both pH and milli volts (mV). In a pH meter, this small current is amplified through electronic tubes so that it can be measured easily.

Reagents

1. Buffer solution (pH 4.0): Dissolve 10.21 g of potassium hydrogen phthalate (0.05 M) in distilled water and dilute it to 1 L. This solution should not to be used after 5-6 weeks.
2. Buffer solution (pH 7.0): Dissolve 0.948 g of KH_2PO_4 and 1.57 g Na_2HPO_4 in distilled water and dilute it to 1 L.
3. Buffer solution **(**pH 9.2) (Borax, 0.01 M): Dissolve 3.81 g of $Na_2B_4O_7.10H_2O$ in carbon dioxide free water and dilute to 1 L. The solution should be protected from atmospheric carbon dioxide.

The buffer tablets or powder are available commercially for pH 4.0, 7.0 and 9.2. These buffer solutions can be prepared by dissolving the powder/ tablet in 100 mL of boiled cooled distilled water.

Procedure

1. Take 20 g of soil in 100 mL beaker
2. Add 50 mL of distilled water and stir the contents for atleast 5 times over a 30 minute to reach equilibrium.
3. In the mean time, switch on the instrument, set temperature knob to room temperature and set range selector to zero.
4. Set the galvanometer to zero with zero knob after 15 minutes.
5. Dip the electrodes into a buffer of known pH, turn the range selector and adjust the pH meter to pH of the buffer solution by set buffer knob.
6. Turn the selector to zero, press the key stand by hand and take out the electrode. Wash

the electrode with distilled water and dry it with a piece of filter paper.

7. Shake the soil suspension, and insert the electrodes into it. Turn the selector to the proper pH range and read the pH on the dial of the pH meter. Turn back the selector to zero and take out the electrode.
8. Rinse the electrode with distilled water and lower it back into a beaker containing distilled water.

Precautions in the use of pH meter

1. The electrodes should not be allowed to remain in suspension or test solution longer than necessary.
2. The electrode should be washed with a gentle stream of distilled water immediately after use.
3. The electrodes should be suspended in distilled water when it is not in use. Drying of the electrodes should be avoided.
4. If soil has more soluble salts, soil suspension may be prepared, using either 0.1 M $CaCl_2$ or KCl solution instead of water to overcome the effect of soluble salts on pH.

Interpretations

Sl. No.	pH	pH classes	Management required
1.	< 6.5	Acidic	Lime addition for reclamation
2.	6.5-8.5	Neutral	No amendments required, optimum for crops
3.	> 8.5	Alkaline	Gypsum addition for reclamation

Determination of electrical conductivity of soil

Principle

The EC of a soil is measured with a conductivity meter known as “solute bridge”. It is based on the principle of Wheat-Stone Bridge in which an alternating current is used instead of direct current in order to eliminate the polarization of electrodes. The balance point is indicated by a “magic eye”. A conductivity cell consists of two platinum electrodes in the form of rectangular pieces fused on glass on one side and covered with black spongy platinum on the other. Two wire heads connect it to proper terminals on the solute bridge. A figure known as cell constant is marked on the cell.

Procedure

1. Take 10 g of soil into a beaker and add 25 mL of distilled water.

2. Stir the suspension intermittently and leave it overnight to get clear supernatant solution.
3. Switch on the instrument and stabilize for 15 min prior to recording reading.
4. Dip the conductivity cell into the supernatant solution.
5. Move the pointer on the dial to get maximum area in shade in the magic eye.
6. Note the reading on the solute bridge and calculate EC as given below

Interpretations

Sl. No.	EC (dS m^{-1})	Salinity classes	Nature of soil
1	< 0.8	Low	Normal
2	0.8 -1.6	Medium	Critical for sensitive crops
3	1.6 - 2.5	High	Critical for salt tolerant crops
4	> 2.5	Very high	Injurious for many crops

Determination of organic matter in soil

Principle

A known weight of the soil is treated with an excess volume of standard potassium dichromate solution in the presence of concentrated sulphuric acid. The soil is digested by the heat of dilution of sulphuric acid and organic carbon in the soil is thus oxidized to carbon dioxide. The excess of potassium dichromate, unused in oxidation is titrated back against a standard solution of ferrous ammonium sulfate $\{FeSO_4(NH_4)_2SO_4\}$ in the presence of flouride or phosphoric acid and diphenylamine solution (indicator). The organic carbon content of soil is calculated using the relationship of of 1 mL of 1 N K_2Cr_2O7 = 0.003 g of organic carbon.

Reagents

1. $K_2Cr_2O_7$ (1 N) solution: Dissolve 49.04 g of potassium dichromate in distilled water and make up to 1 L.
2. FAS (0.5 N) (Mohr's salt): Dissolve 196 g of FAS in distilled water, add 50 mL Conc. H_2SO_4 and make up the volume to 1 L.
3. Diphenyl amine: Dissolve 0.5 g of diphenylamine in a mixture of 100 mL of Conc. H_2SO_4 and 20 mL of distilled water.
4. Concentrated H_2SO_4
5. Sodium fluoride (NaF) or Orthophosphoric acid (85 %)

Procedure

1. Weigh 0.2-0.4 g of 0.2 mm sieved soil (powdered and then sieved) into a 500 mL conical flask.
2. Add 10 mL of 1 N $K_2Cr_2O_7$ solution and shake to mix.
3. Add 20 mL of conc. H_2SO_4 from the sides of the flask.
4. Keep the contents of the flask undisturbed for 30 minutes.
5. Add 3 g of NaF or 10 mL of H_3PO_4 and 100 mL of distilled water and shake vigorously.
6. Add 10 drops of diphenyl amine indicator which gives violet colour.
7. Titrate against 0.5 N FAS solution till the colour changes from violet to bright green and note down the volume of solution used.
8. Carry out blank titration in a similar manner without soil.

(If ferrion is used as indicator, there is no need to use H_3PO_4 and NaF)

Observations and Calculations

Vol. of FAS used in blank = X mL

Vol. of FAS used to oxidize soil organic carbon = Y mL

1 mL of 1N $K_2Cr_2O_7$ = 0.003 g of organic carbon

Organic carbon (%) (A) = $[\{(X-Y) / 2\} \times (0.003) \times 100] / S$

Organic matter (%) = $A \times 1.724$

Determination of available nitrogen in soil

Reagents

1. $KMnO_4$ (0.32 %): Dissolve 3.2 g of $KMnO_4$ in distilled water and make up the volume to 1 L
2. NaOH (2.5 %): Dissolve 25 g of NaOH flakes in distilled water and make up the volume to 1 L
3. H_2SO_4 (0.02 N): Dilute 0.6 mL of conc. H_2SO_4 to 1 L with distilled water
4. NaOH (0.02 N): Dissolve 0.8 g of NaOH in distilled water and make up to 1 L
5. Methyl red indicator (0.
6. 15 %): Dissolve 0.15 g of methyl red powder in 100 mL alcohol.

Procedure

1. Weigh 20 g of soil on to a filter paper, prepare a packet and place it into the Kjeldahl distillation flask and secure the flask in the Kjeldahl assembly.
2. Add 100 mL of 0.32 % $KMnO_4$ solution and 100 mL of 2.5 % NaOH solution and secure the cork immediately. Pipette out 25 mL of 0.02 N H_2SO_4 in a conical flask and add 3-4

drops of methyl red indicator and dip the end of the delivery tube into it.

3. Distill the ammonia gas from the distillation flask with the help of a burner and collect about 30 mL of the distillate (till no ammonia is liberated).
4. Titrate the excess sulphuric acid in the conical flask against 0.02 NaOH till the color changes from pink to yellow and note down the volume of the NaOH used.

Precautions

1. Before adding NaOH solution to the distillation flask, the delivery tube must be dipped into the dilute acid contained in the receiver.
2. Immediately after the addition of NaOH the mouth of the flask should be closed, so as to avoid loss of ammonia produced as a result of the alkaline reaction.
3. The indicator should be added before starting distillation to ensure that the receiver contains enough of acid.
4. The connections should be air tight so that liberated NH_3 is not lost.
5. Before putting off the burners, the delivery tube end must be removed from the receiver to avoid "back suction" after the distillation is over.
6. Titration should be done carefully not to cross the end point.

Observations

1. Weight of soil taken = 20 g
2. Vol. of 0.02 N H_2SO_4 taken = 25 mL
3. Vol. of 0.02 NaOH used = X mL
4. Vol. of 0.02 N acid used for NH_3 = (25 - X) mL

Calculations

1 mL of 1 N H_2SO_4 = 0.014 g of N

$$\text{Avail. Nitrogen (\%)} = \frac{(25 - X) \times N \times 0.014 \times 100}{20}$$

Avail. N (ppm) = % × 10,000

Avail. N (kg/ha) = % × 22,400

Determination of available phosphorus in soil

I. Bray's No. 1 method (for acid soil)

Principle

The combination of HCl and NH_4F is designed to extract easily acid soluble forms of phosphorus, largely Ca-phosphates and Al and Fe phosphates. The NH_4F dissolves Al, Fe and Mn-phosphates by forming complex ion with these metal ions in acid solution (in soluble compounds of Al, Fe and Mn fluoride are formed) and thereby releases phosphate ion into the solution. In presence of chloromolybdic acid in an acidic medium, the phosphate ion forms a heteropoly complex compound of phosphorus, on reduction, imparts blue colour to the solution. The intensity of blue colour can be measured at 660 nm, using a spectrophotometer.

Reagents

1. Bray's No. 1 (0.03 N NH_4F + 0.025 N HCl): Dissolve 1.11 g NH_4F in about 250 mL distilled water and add 2 mL of conc. HCl and make up the volume to 1 L.
2. Ammonium molybdate (1.5 %) (Dickman & Bray's reagent): Dissolve 15g of ammo. Molybdae in 300 mL of hot distilled water (50-60^oC) filter if there are any sediments. Cool and add 350 mL of 10 N HCl slowly with rapid stirring. Cool and make upto 1 L and store in an amber coloured bottle (If HCl is cone, add calculated amount of HCl equivalent to 350 mL of 10 N HCl).
3. Std. phosphorus solution (5 ppm): Dissolve 21.95 mg of KH_2PO_4 in distiller water, add 25 mL of approx. 7 N H_2SO_4 and make up to 1 L of water
4. Stannous chloride stock solution (40 %): Dissolve 10 g of $SnCl_2$ in 25 mL of conc. HCl by heating. Add a piece of pure metallic tin and store in an amber coloured glass stoppered bottle. Its working solution is prepared by diluting 0.5 mL of the stock solution to 66 mL with distilled water, just before use. Prepare fresh working solution every day.

Procedure

1. Weigh 5 g of soil into a 250 mL conical flask.
2. Add 50 mL of Bray's extractant, mix and shake the contents for 5 min and filter.
3. Take 5 mL of the filtrate into 25 mL volumetric flask and add 5 mL of ammonium molybdate solution. Mix well until the evolution of CO_2 ceases. If more aliquot has to be taken for analysis (for low P soils) fluoride interference has to be eliminated by adding 75 mL of 5 % boric acid to 5 mL extract.
4. Add about 10 mL of distilled water washing the neck of the flask to remove the adhering molybdate.
5. Add about 1 mL of working stannous chloride solution and make up the volume to the mark with distilled water.
6. In the meantime switch on the colorimeter and adjust the wave length to 660 nm Allow to warm up for about 10-15 minutes.
7. Adjust the pointer on the galvanometer to read '0' transmission by keeping blank,
8. Rinse the colorimeter tube (cuvette) with the blank solution then pour a suitable volume. Place the tube in the cuvette and turn the 100 set knob to read 100.

9. Pour the test solution into another colorimeter tube and read the percentage transmission or the absorbance.

Preparation of standard curve

1. Pipette out 0, 0.5, 1, 2, 3, 4 and 5 mL of 5 ppm of P solution in different 25 mL volumetric flasks.
2. Then proceed to develop colour as done for the test sample and record the absorbance or transmittance.
3. Plot the absorbance values on Y-axis and concentration on X-axis and draw a line to pass through maximum number of points.
4. From the graph, calculate the concentration 'C' at OD of 1.0 and is used in further quantification of soil phosphorus.

II. Olsen's method (for neutral, alkaline and calcareous soil)

The phosphorus in neutral, alkaline and calcareous soil is extracted with sodium bicarbonate which id designated to largely calcium phosphates. In presence of chloromolybdic acid in an acidic medium, the phosphate ion forms a heteropoly complex compound of phosphorus, on reduction, imparts blue colour to the solution. The intensity of blue colour can be measured at 660 nm, using a spectrophotometer.

Reagents

1. Sodium bicarbonate (0.5 N) (pH 8.5): Dissolve 42 g of sodium bicarbonate in about 900 mL distilled water and adjust the pH to 8.5 using NaOH or HCl and make up the volume to 1000 mL. Store in a poly propylene reagent bottle.
2. Ammonium molybdate (1.5 %): Dissolve 15 g of ammonium molybdate in 300 mL of hot distilled water (50 - 60 °C), filter if there are any sediments. Add 400 mL of 10 N HCl and make up the volume to 1 L. Store in an amber coloured bottle.
3. Darco-G 60 (P free activated charcoal powder): If it is not available, P-free activated charcoal can be prepared. Take 80 g charcoal and obtain a slurry with Distilled water. Leach this slurry overnight with 1 L of 6 M HCl in 60 mm diameter columns. Then leach with deionised water till the leachate is free of chloride. Dry the material at 110°C (Sariullah*et al*, 1990).
4. Stannous chloride stock solution (40 %): Same as for Brays No. 1 method

Procedure

1. Weigh 5 g of soil into a 250 mL conical flask.
2. Add a pinch of P free Darco-G 60 and 50 mL of 0.5 N $NaHCO_3$ solution (soil: solution: 1:10 or 1:20).
3. Shake and filter the contents using whatman No. 1 filter paper (shake the solution before

pouring suspension in to funnel).

4. Take 5 mL of the filtrate into 25 mL volumetric flask and add 5 mL of ammonium molybdate solution. Mix well until the evolution of CO_2 ceases.
5. Add about 10 mL of distilled water washing the neck of the flask to remove the adhering molybdate.
6. Add about 1 mL of working stannous chloride solution and make up the volume to the mark with distilled water.

Ascorbic acid method for developing colour

Ascorbic acid reagent can be used for developing the colour in phosphorus estimation in place stannous chloride.

Reagents

1. Reagent A:Dissolve 12 g of ammonium molybdate in 250 mL distilled water and of antimony potassium tartrate in 250 mL distilled water separately. Add both reagents 1000 mL of 5 N H_2SO_4. Mix thoroughly and make up to 2 L. Store in pyrex glass bottle in a cool dark place.
2. Reagent B: Dissolve 1.056 g of ascorbic acid in 200 mL of Reagent A and mix. This reagent should be prepared fresh as and when required.

Procedure

1. Pipette out 5 mL aliquot (Bray's or Olsen's extract) in a 25 mL volumetric flask.
2. Acidify with 5 N H_2SO_4 to pH 5.
3. Determine the volume of acid required to bring the solution to pH by using P-nitrophenol (gives yellow colour at pH 5.0).
4. Add 20 mLof distilled water and 4 mL of reagent B.
5. Read the intensity of blue colour at 730 nm after 10 minutes.

Observations

1. Weight of the sample: 5.0 g
2. Vol. of the extractant: 50 mL
3. Vol. of aliquot (filtrate) taken: 5 mL
4. Final vol. after development of colour: 25 mL
5. Transmittance of the test solution: T
6. Conc. of P read from the Std. Curve: ‘X’ ppm
7. Avail. P (ppm): X x 50
8. Avail. P (kg ha^{-1}): ppm x 2.24
9.

$$\text{Avail. } P_2O_5 \text{ (kg/ha)} = \frac{\text{Graph ppm x Vol. of extractant x Vol. made x 2 x}10^6 \text{ x 2.29}}{10^6 \text{ x Weight of soil x Aliquot taken}}$$

Determination of available potassium in soil

Principle

The ammonium ions in ammonium acetate (Schollenberger& Simon, 1945 and Merwin and Peach, 1951) exchange with the exchangeable potassium ions of the soil. In addition, NH_4^+ holds highly charged layers together just as potassium the release of non-exchangeable potassium in an exchangeable form is retarded during extraction with ammonium acetate. The extracted potassium ions are estimated by flame photometry.

Reagents

1. Neutral Normal Ammonium acetate solution: Dissolve 77.09 g of ammonium acetate in distilled water and make up to 1 L. Adjust the pH of the solution using a pH meter.
   If ammonium acetate salt is not available, add 57 mL of 99.5 % glacial acetic acid to 700 mL distilled water and then add 69 mL of conc. ammonium hydroxide. Dilute to about 900 mL and adjust the pH to 7.0 by the addition of 3 N ammonia solution or 3 N acetic acid solution and make up to 1 L. Store in pyrex or polypropylene bottle.

2. Std. K Solution (1000 ppm): Dissolve 1.91 g of KCl (AR grade) in 1000 mL of distilled water.

Procedure

1. Weigh 5 g of soil into a 250 mL conical flask.
2. Add 25 mL of neutral normal ammonium acetate solution.
3. Shake the contents of the flask on the electric shaker for 5 minutes and filter through Whatsman No.1 paper. First few mL of filtrate may be rejected.
4. Feed the filtrate in to the atomizer of the flamephotometre which has been adjusted to 100 with 40 ppm (in case of Systronics Flame Photometer) or 10 ppm (in case of Elico flame photometer) standard solution of K and note down the reading.
5. Locate this reading on the standard curve and calculate the amount of K in the soil as shown below.

Observations and calculations:

1. Weight of the sample : 5 g
2. Volume of NH_4OAc added : 25 mL
3. Flame photometer reading for the sample : X
4. ppm as read from standard curve : Y
5. ppm of avail. K in soil =Y x total dilution = A

$$\text{Avail. } K_2O \text{ (kg/ ha)} = \frac{\text{Graph ppm} \times \text{Vol. of extractant} \times 2 \times 10^6 \times 1.20}{10^6 \times \text{Wt. of soil}}$$

Determination of exchangeable calcium and magnesium in soil

Principle

A complexometric titration using EDTA is a classical method for determining calcium and magnesium simultaneously or individually. Analytical success is based on (a) Eliminating the interfering ions (b) Achieving the required pH, and (c) Employing the appropriate indicator.

A known weight of soil is extracted with a known volume of neutral normal ammonium acetate. The calcium and magnesium ions in the extract at high pH is titrated against standard ethylene diamine tetra acetic acid using appropriate indicator, either Eriochrome Black T/ Mureoxide/ Patton & Reeders reagent.

Reagents

1. Buffer solution: Dissolve 67.5 g of NH_4Cl in 200 mL distilled water. Add 570 mL of conc. NH4OH and dilute to 1 L with distilled water.
2. Std. EDTA solution: Dissolve 1.86 g of disodium EDTA (ethylene diamine tetra acetic acid) in distilled water and make upto 1 L to get approximately 0.01 N solution.
3. Std. Ca solution: Dissolve 0.50 g of reagent grade $CaCO_3$ (dried at 150°C for 6 hrs) in 5 mL of approx. 6 N HCl and dilute the solution to 1 L to get 0.01 N solution.
4. Eriochrome Black - T (EB-T) indicator:Dissolve 0.2 g of EBT in 50 mL of methanol (This solution should not be used after 3 weeks of preparation).
5. Murexide indicator: Mix 0.2 g of ammonium purpurate with 40 g of finely ground-potassium sulphate and grind again in an agate/glass pestle and mortar.
6. NaOH solution (10%): Dissolve 10 g of NaOH in distilled water and make upto 100 mL.
7. Buffer complex: Mix 800 mL of buffer solution with 50 mL each of 1 % KCN solution, 5 % hydroxyl amine hydrochloride solution, 4 % potassium ferrocyanide solution and triethanolamine.
8. Patton & Reeders reagent: Mixture of 0.5 g of the pure Patton-Reeder indicator [2-hydroxy-1-(2-hydroxy-4-sulfo-1-naphthylazo)-3-naphthoic acid] and 50 g of sodium sulfate ground together to a fine powder.

Procedure

A. Calcium + Magnesium

1. Transfer 5-10 mL of ammonium acetate extract into a porcelain basin.
2. Add 5-10 mL of buffer complex to the contents to attain the pH to 10.
3. Add 10 drops of EBT indicator.
4. Titrate with Std. EDTA till colour changes frompink to blue.

B. Calcium

1. Transfer 5-10 mL of ammonium acetate extract into a porcelain basin
2. Add 5 mL of 10 % NaOH solution to attain a pH of 12 or more.
3. Add a pinch of murexide indicator
4. Titrate against Std. EDTA solution till the colour changes from pink to violet.

Calculations

$$\text{Exch. Ca + Mg (m. eq per 100 g)} = \frac{\text{TV1} \times \text{N of EDTA} \times \text{Vol. Made} \times 100}{\text{Weight of soil x Aliquot taken}}$$

$$\text{Exch. Ca (m.eq per 100 g)} = \frac{\text{TV2} \times \text{N of EDTA} \times \text{Vol. Made} \times 100}{\text{Weight of soil x Aliquot taken}}$$

Exch. Mg (m.eq/ 100) = m.eq of (Ca + Mg) - m.eq of Ca

Determination of available sulphur in soil

The most commonly used methods for extracting available sulphur in soils are

1. Heat soluble sulphur method
2. 0.15 % $CaCl_2$ extractable S method
3. Sodium acetate - acetic acid buffer method.

Calcium chloride extractable Sulphur (Williams and Steinberg (1959)

Principle

The sulphur in soil is extracted with $CaCl_2$ (0.15 %) solution and the extracted sulphate is treated with barium chloride to convert into barium sulphate in the presence of conditioning/ stabilising agent. The turbidity formed is estimated using a spectrophotometer at 420 nm.

Reagents

1. $CaCl_2$ solution (0.15 %): Dissolve 1.5 g of calcium chloride in 1 L of distilled water.
2. $BaCl_2$ crystals of 20-30 mesh
3. Conditioning agent: Dissolve 15 g sodium chloride in 300 mL distilled water, add 30 mL conc. HCl and 100 mL 95 % ethyl alcohol and 500 mL glycerol and mix well.
4. Standard sulphur solution: Dissolve 147.9 mg of anhydrous sodium sulphate in distilled water and make up to 1000 mL (1.0 mL = 100 µg SO_4^{2-}).

Preparation of standard curve

1. Measure into 50 mL volumetric flask 0, 2.5, 5, 10, 15 and 20 mL standard sulphate solution.
2. Add 1 mL of seed solution and 1 mL conditioning reagent and mix well.
3. Add 0.5 g barium chloride crystals and continue to stir for one minute.
4. Immediately after one minute pour some solution into absorption cell of spectrophotometer and measure optical density at 420 nm.
5. Prepare standard graph between optical density v/s concentration of sulphate.

Procedure

1. Transfer 5 g of soil into a 250 mL conical flask add 25 mL of 0.15 % $CaCl_2$ solution and shake for 30 minutes
2. Filter using Whatman No. 42 filter paper.
3. Take 10-20 mL extract and follow same as in standard curve preparation of sulphate.

Some suggestions

1. Instead of $CaCl_2$ solution, extraction with 500 ppm P mono-calcium phosphate solution is preferred, as $CaCl_2$ extracts only soluble sulphur. The phosphate solution helps in extraction of adsorbed sulphate. The calcium phosphate is preferred, over sodium and potassium, as it helps in flocculation and gives clear filtrate.
2. As $CaCl_2$ gives a clear extract, treatment with H_2O_2 is not necessary.
3. Field moist samples should be used as air drying increases the amount of SO_4 extracted by $CaCl_2$.

Determination of available micronutrient cations in soil

There are two methods employed for the determination of available micronutrient status of soil.

1. Colorimetric method
2. Atomic absorption spectroscopy method (AAS)

The colorimetric method is quite tedious method and for each element, separate method of extraction and estimation has to be followed. Use of AAS is quite convenient for rapid method of estimation. Irrespective of the method followed for estimation, extraction of only the available quantity of nutrients is important. The extractant used should extract all of the available forms of a nutrient from soils with variable properties. The amount extracted should correlate with the crops response to that nutrient under various conditions.

Principle

Diethylene triamine penta acetic acid (DTPA) is a chelating agent which extracts the available forms of iron, manganese, zinc and copper when buffered at pH 7.3. The simultaneous extraction

of these elements is done by shaking the soil with DTPA for two hours. The concentration of these elements in solution can be determined by using Atomic Absorption Spectrophotometer (AAS).

Reagents

1. DTPA extractant(0.005 M DTPA, 0.01 M $CaCl_2$ and 0.1 M Tri ethanol amine [TEA] with pH 7.3)**:** Dissolve 149.2 g of reagent grade TEA, 19.67 DTPA and in approx. 200 mL glass distilled water. Dilute to about 9 L and adjust the pH to 7.3 using dilute HCl or NaOH and make up to 10 L. This solution is stable for several months.

2. **Standard solutions of micronutrient cations**

   The standard solutions are prepared using the extractant used for extraction of soil.

a. Iron standard (100 ppm Fe): Dissolve 0.7022 g of fresh FAS (ferrous ammonium sulphate) in glass distilled water and dilute to 1 L. Prepare working standards ranging from 0 to10 ppm.
b. Manganese standard (100 ppm Mn): Dissolve 0.406 g of $MnSO_4.4H_2O$ in glass distilled water containing 1 mL of conc. H_2SO_4 and dilute to 1 L. Prepare the standards ranging from 0 to 10 ppm.
c. Zinc standard (1000 ppm Zn): Dissolve 0.4398 g of $ZnSO_4.7H_2O$ in glass distilled water and dilute to 1 L. Dilute this to get 100 ppm and prepare working standards ranging from 0 to 5 ppm.
d. Copper standard (100 ppm): Dissolve 0.393 g of $CuSO_4.5H_2O$ in glass distilled water and make up to 1 L. Prepare working standards ranging from 0 to 5 ppm.

Standard curve preparation

1. Prepare the appropriate standards as mentioned in the standard solution preparation
2. Adjust the instrument to read zero after feeding blank solution.
3. Feed different concentrations of a particular element and obtain the readings
4. Plot the values on a graph sheet and construct the standard graph.

Procedure

1. Weigh 10 g of soil into a 150 mL conical flask, add 20 mL of DTPA extractant and shake the contents on a horizontal shaker for 2 hrs.
2. Filter the suspension through Whatman No. 40 filter paper.
3. Feed the clear sample to the instrument having an appropriate hallow cathode lamp and record the readings.

Calculation

$$\text{Micro nutrient conc. (ppm)} = \frac{\text{Graph value} \times \text{volume of the extractant}}{\text{Weight of the soil}}$$

Determination of available boron in soil

The boron is present in soil in anionic form and the amount extracted by hot water is considered as available to plants. This method was first developed by Burger and Trough (1939) and then modified by Wear (1965). Another method is also available for boron estimation (Keren and Bingham, 1985; Sippola and Ervco, 1987).

1. The Carmine method
2. Curcumine method
3. Azomethine-H reagent method

Among these, Azomethine-H reagent method is commonly followed as it is simple and accurate.

Azomethine-H method

Principle

Boron in solution (within a concentration range of 0.5 - 10.0 ppm) forms a stable colour complex with azomethine-H reagent at pH 5.1. The intensity of the colour, proportional to boron concentration, is measured at 420 nm wavelength.

Reagents

1. Buffer mask solution: Dissolve 250 g of ammonium acetate and 15 g of EDTA-Na salt in 400 mL of distilled water and slowly add 125 mL of glacial acetic acid and mix.
2. Azomethine-H reagent:Dissolve 0.45 g of azomethine-H in 100 mL of 1 % L-ascorbic acid solution. Fresh reagent should be prepared each week and stored in refrigerator.

Preparation of standard curve

1. To a series of 25 mL volumetric flask, pipette out 0, 0.25, 0.5, 1, 2 and 4 mL of 5 ppm Boron solution to get 0, 0.05, 0.1, 0.2, 0.4 and 0.8 ppm of Boron.
2. To each of the flask, add 2 mL of buffer solution and mix, add 2 mL of Azomethine reagent, stir thoroughly and allow to stand at room temperature for 30 minutes.
3. Make up the volume with distilled water and measure the absorbance at 420 nm.

Procedure

1. Weigh 20 g soil into a reflux condenser.
2. Add 40 mL distilled water and 0.5 g activated charcoal. Boil for 5 minutes.
3. Filter immediately, through whatman 40 filter paper.

4. Pipette out 5 mL of the extract in a 25 mL vol. flask, add 5 mL of buffer solution and 4 mL of azomethine reagent.
5. Keep for 1 hr for development of colour and make up the volume
6. Measure the intensity of the colour at 420 nm.

Calculations

$$\text{Boron Conc. (ppm)} = \frac{\text{Graph ppm} \times \text{Vol. of Water added}}{\text{Aliquot taken} \times \text{Wt. of soil}}$$

Digestion of plant sample

For nutrients other than N, the plant material can be digested in a di-acid mixture or a tri-acid mixture or dry ashed and dissolved in acid.

The di-acid digestion is used for the determination of P, K, Ca, Mg, S, Fe, Mn, Zn and Cu. It must be followed for the determination of Ca and Mg. the tri-acid digestion is recommended only when p and K are to be estimated. Sulphur cannot be estimated from tri-acid extract. Similarly, Ca will also be underestimated. Since H_2SO_4 can contribute some micronutrients and heavy metals, di-acid digestion is normally recommended for plant analysis. Wet digestion is normally not used for the estimation of B and Mo.

Dry ashing can be used for sample preparation for the determination of Na, K, Ca, Mg, Cu, Fe, Mn, Zn, B and Mo in plant tissue. It is the preferred technique for B and Mo particularly. Dry ashing provides good precision and is an easy, rapid method requiring minimal analyst attention. It is also relatively free from reagent contamination. The main disadvantage of this procedure is that it cannot be used for elements such as N, P and S which are volatile at the ashing temperature.

Di-acid digestion: It is carried out using a 9:4 mixture of HNO_3:$HClO_4$. If the sample is high in fats/oils, pre-digestion using 25 mL HNO_3/g sample is recommended to avoid explosion. Detailed procedure is as follows:

Place 1 g ground plant material in 100 mL conical flask. Add, 10 mL of di-acid mixture and mix the content of the flask by swirling. Placed the flask on low heat hot plate in a digestion chamber. Then, heat the flask at higher temperature until the production of red NO_2 fumes ceases, continue digestion until the volume is reduced to about 3 to 5 mL but not to dryness. The completion of digestion is confirmed by the snow white residue or when the liquid become colorless.

After cooling make up the volume with glass distilled water deionized water and filter solution through Whatman No.1 filter paper. Use aliquots of this solution for the determination of P, K, Ca, Mg, S, Fe, Mn, Zn and Cu. If acid digest cannot be subjected to analysis immediately then the volume should be made using 6 N HCl.

Tri-acid digestion: It is carried out using a mixture of HNO_3: $HClO_4$: H_2SO_4 in the ratio of 9:4:1. The sample digestion is carried out as described under the di-acid digestion.

Dry Ashing: The organic matter destruction can also be accomplished by high temperature oxidation. The critical requirements here are: (i) nature of the ashing vessel (ii) Placement in the muffle furnace (iii) ashing temperature and (iv)time.

The vessels used for ashing range from silica to platinum crucible or dishes. The sample size can vary from 0.5 to 2 g, depending on expected concentration of elements to be determined. The temperature used for ashing ranges from 475 to 600^o C and time varies from 4 to 12hr depending on sample weight and sample type. The ash residue is usually dissolved in a HNO_3or HCl solution and diluted to volume with deionized water. When dertermining Ca and Mg the final sample dilution should contain 1% Lanthanum to overcome potential anionic interferences.

Procedure

1. Place 1g of dried ground plant sample in a silica crucible.
2. Place the crucible in a cool muffle furnace and ash at 550^{o}C for 5 hr.
3. Cool and dissolve in 5 mL of 20 % HCl the solution if necessary to dissolve the residue. Care should be taken to see that the crucibles are away by atleast 2 cm from walls and bottom of the furnace to avoid localized over heating.
4. Filter the solution through an acid washed filter paper into a 50 mL volumetric flask.
5. Wash the filter and dilute with deionised water and mixed well.

Determination of phosphorus in plant sample

The nutrients (except nitrogen) in plant samples is digested either with diacid/ tri acid on sand bath till digested material turns to either colourless or whitish. The phosphorus in the aliquot of the digested material in presence of vanadium (V^{5+}) and molybdenum (Mo^{6+}), orthophosphates forms a yellow colouredphosphovanado molybdate complex which can be read using spectrophotometer 430 nm.

Reagents

1. Phosphate standard (50 ppm): Dissolve 0.2195 g of dried (40^{0}C potassium dihydrogen phosphate in about 400 mL of distilled water. Then add 25 mL of 7 N H_2SO_4 and make up the volume to 1 L with distilled water.
2. Solution A: Dissolve 25 g of ammonium molybdate in 400 mL of hot distilled water.
3. Solution B: Dissolve 1.25 g of ammonium metavanadate in 300 mL of boiling distilled water. Cool the content's and add 250 mL of Conc. HNO_3.
4. Vanadomolybdate reagent: By mixing the solution A and solution B and make up the volume to 1 L

Procedure

Preparation of the standard curve

1. Pipette out 50 ppm P solution to a series of 50 mL volumetric flasks to get a concentration of 0, 5, 10, 15 and 20 ppm P solution.
2. Add 10 mL of vanadomolybdate reagent, mix and make up the volume.
3. Read colour intensity at 430 nm after 30 minutes.
4. Plot the absorbance against concentration and draw the standard curve.

Plant sample

1. Pipette out 5 mL of digested sample into a 50 mL volumetric flask
2. Add 10 mL of vanadomolybdate reagent and make up the volume to 50 mL
3. Read colour intensity at 430 nm after 30 minutes.
4. Compare the unknown sample absorbance with standard curve

Calculations

$$\text{P (\%)} = \frac{\text{Graph ppm} \times \text{Vol. of digested sample} \times \text{Vol. made up}}{10^6 \times \text{weight of sample} \times \text{Aliquot taken}} \times 100$$

Determination of potassium in plant sample

Principle

In Flame photometry, also known as Flame emission or Flame atomic emission, the sample in solution, is sprayed into a flame to vaporize, atomize, and excite the sample. The excited atoms of the element of interest emit light at certain discreet wavelengths, which characteristic of that element. Light of the wave length of interest is separated from remainder of emitted radiations and its intensity is measure. The intensity measurement can be related directly to the concentration of the element of interest usually by comparing with the measured intensities of a standard or series of standards.

Reagents

1. Std. potassium (100 ppm): Dissolve 0.191 g of KCl in some volume of distilled water and then make up the volume to 1 L.
2. Prepare the working standards from 0 to 40 ppm of potassium

Procedure

Sample

Feed the digested sample solution to the Flame photometer and record the reading (if dilution is required, it should be done before feeding to the instrument). Compare the unknown sample readings with standard curve to determine the % K in plant sample.

Calculations

$$K\ (\%) = \frac{\text{Graph ppm} \times \text{Vol. of digested sample} \times \text{Vol. made up}}{10^6 \times \text{weight of sample} \times \text{Aliquot taken for dilution}} \times 100$$

Determination of calcium and magnesium in plant sample

Reagents

1. Standard EDTA solution (0.01 N): Dissolve 1.861 gm of EDTA in 900 mL distilled water and make up the volume to 1000 mL.
2. Std. Ca solution: Dissolve 0.6005 g portion of pure dried $CaCO_3$ in 0.2 N HCl. Solution is boiled to expel the CO_2 and dilute to 1 L.
3. 10 % NaOH solution: Dissolve 10 g portion of NaOH in about 90 mL distilled water and dilute to the 100 mL.
4. Murexide indicator: Mix 0.2 g of murexide with 40 g of powdered K_2SO_4.
5. Buffer solution (pH 10): Add 142 mL of NH_4OH to 17.5 g of NH_4Cl and dilute to 250 mL with distilled water.
6. Erichrome Black T indicator: Dissolve 0.2 g of the EBT powder 15 mL of triethanolamine and 5 mL of absolute ethanol.

Procedure

a) Determination of calcium

1. Take 5 mL of digested sample in a porcelain basin and dilute with 10 mL distilled water.
2. Add 5 mL of 10 % NaOH (pH of sample solution would reach more than 12).
3. Add about 0.5 g of murexide indicator.
4. Titrate the contents against std. EDTA with stirring until it becomes violet in colour. Note down the burette reading.

b) Determination of calcium + magnesium

1. Take another 5 mL of digested sample in a porcelain basin and dilute with 25 mL of distilled water.
2. Add 5 mL buffer solution. Add 3-5 drops of EBT - indicator and
3. Then titrate the contents against std. EDTA by stirring until it becomes sky blue colour. Note down the burette reading.
4. The titre value Ca alone is subtracted from titre value of Ca + Mg, to get the value for Mg.

$$Ca\ (\%) = \frac{\text{T.V. for Ca} \times \text{N of EDTA} \times 0.02 \times \text{Vol. of digested sample}}{\text{Aliquot taken} \times \text{weight of sample}} \times 100$$

$$\text{Mg (\%)} = \frac{\text{T.V. for Ca + Mg} - \text{T.V. for Ca} \times \text{N of EDTA} \times 0.012 \times \text{Vol. of digested sample}}{\text{Aliquot taken} \times \text{weight of sample}} \times 100$$

Note: If the concentrations of interfering ions are more in the sample, then 1 or 2 drops of 1 % KCN or NaCN should be added to the sample before titration.

Determination of sulfur in plant sample

Principle

The plant sulphur is released into solution after digestion with diacid mixture (HNO_3 + $HClO_4$). The released 'S' in the solution is precipitated by Ba^{2+} ions as $BaSO_4$. This turbidity developed by $BaSO_4$ is then determined by turbidimeter. Turbidimetric analysis is based on measuring the weakening intensity of a luminous flux when it passes through a solution containing particles in suspension.

Reagents

1. Acid seed solution (20 ppm 'S' in 6 N HCl): Dissolve 0.109 g of K_2SO_4 in some volume of 6 N HCl and make up the volume to 1000 mL with 6 N HCl.
2. $BaCl_2$ crystals (20-60 mesh size)
3. Stabilizing reagent: Dissolve 0.25 g gum acacia in 100 mL of water or mix 20 mL of glycerol with 80 mL of alcohol.
4. Standard 'S' solution (100 ppm S): Dissolve 0.544 g of K_2SO_4 in 1 L of distilled water.

Procedure

Standard curve

1. Take 0, 2.5, 5, 10, 15 and 20 mL of 100 ppm S solution in separate 50 mL volumetric flasks.
2. Add to each 1 mL acid seed solution and 1 mL stabilizing agent.
3. Dilute the contents to about 40 mL
4. Add to each, 1 g of $BaCl_2$ crystals and make up the volume to 50 mL.
5. Mix well and record the turbidity of these solutions at 420 nm within 20 min.
6. Plot the turbidance against the concentration of solutions and draw the curve.

Plant sample

1. Take 10 mL of digested sample in a 50 mL volumetric flask.
2. Follow as in the standard curve preparation

3. Record the turbidity or % transmission at 420 nm within 20 min.

Calculation

$$S\ (\%) = \frac{\text{Graph ppm} \times \text{Vol. of digested sample} \times \text{Vol. made up}}{10^6 \times \text{Weight of sample} \times \text{aliquot taken}} \times 100$$

Determination of micronutrients content in plant sample

I. Determination of Fe, Mn, Zn and Cu

Make suitable dilutions of tri/ di acid extract and feed standard/ sample to AAS having appropriate hallow cathode lamps. Record values on plot on graph paper.

Calculation

$$\text{Micronutrient conc. (ppm)} = \frac{\text{Graph ppm} \times \text{Vol. of digested sample}}{\text{Weight of sample}} \times 100$$

II. Boron

Pipette out suitable aliquot of tri/di acid extract and develop color using curcumine/carmine Azomethine H reagent method and measure OD using a spectrophotometer.

Calculation

$$\text{Boron conc. (ppm)} = \frac{\text{Graph ppm} \times \text{Vol. of digested sample} \times \text{Vol. made up}}{\text{Weight of sample} \times \text{aliquot taken}} \times 100$$

Analysis of soil biological health parameters

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Soil organisms improve soil fertility by performing a number of functions that are beneficial for plants and also for their own growth and reproduction. In addition, they produce organic matter, consume organic matter, and decompose them. Some of them burrow in the soil, make spaces for their accommodation and movement, and mix surface and subsoil materials together. The changes that are caused by soil organisms have their impact on soil fertility and productivity. Although soil biota, which includes living roots and soil organisms, occupies a very small fraction of the total soil volume (<0.5 %), it has tremendous influences on soil properties and soil processes. However, soil organisms are usually the most active in the surface soil zone of 0–15 cm, because this zone has accumulation of organic residues and available nutrients.

Soil biological properties unlike chemical and physical properties are difficult to define, it includes macro and micro groups of organisms. Soil biological properties have immense role in agricultural and horticultural crop production since ancient time and now it attracted attention to study the soil biological properties especially soil microbes. There are many different types of creatures that live in the topsoil. Each has a role to play. These organisms will work for the farmer's benefit if simply managed for their survival. An acre of living top soil contains approximately 900 pounds of earthworms, 2,400 pounds of fungi, 1,500 pounds of bacteria, 133 pounds of protozoa, 890 pounds of arthropods and algae, and even small mammals in some cases. (Pimentel, D. 1995). While a great variety of organisms contribute to soil fertility, earthworms, arthropods and the various microorganism's merit particular attention.

Soil biota can be grouped according to size in micro, meso and macrobiota. Microbiota are less than 0.2 mm and consist of bacteria, actinomycetes, fungi, algae and protozoa. Mesobiota range from 0.2 to 10 mm in size and consist of nematodes, enchytraeids, collembola or springtails, mites, rotifers and small insects (arthropods). Macrobiota are organisms larger than 10mm and consist of earthworms, molluscs and larger arthropods. Microbiota are the dominating group, both according to numbers and total biomass.

Biological indicators of Soils

Bio-indicators of soil health are measurable properties that define the biotic components in soil and could potentially be used as a metric in determining soil functionality over a wide range of ecological conditions. Soil biota also respond rapidly to soil management and land use changes and can be candidates for soil quality indicators. There are, however, limitations in directly measuring soil organisms as indicators of soil quality. Because of this, biological dynamic properties (respiration, POM, PMN, and enzymes) are often selected as surrogates for

measurement of processes mediated by soil biota. Phospholipid fatty acids and DNA are also gaining popularity in academic and research laboratories. Earthworms, which are not often diverse and are easy to count, are the only biota that have been considered usable as biological indicators by personnel regardless of special training and that are presently measured in the field by determination of their abundance. Biological indicators may reflect the overall number, type, and activity of microorganisms and the diversity of the living organisms in soil, particularly the microbial population. Some biological indicators are linked to the organic matter fractions (POM, β-glucosidase), nitrogen pools (PMN), or soil biota (respiration). The following are the biological indicators of soils:

1. **Population of soil organisms**

Earthworm populations reflect the general health and fertility of soils. Higher earthworm abundance and diversity typically signify healthier soil conditions with good organic matter content and nutrient availability. Earthworms can indicate soil quality by (1) the abundance and species composition of the earthworm fauna at a particular site (2) the behaviour of individual earthworms in contact with a soil substrate (preference/avoidance/activity) (3) the accumulation of chemicals from the soil into the body, and (4) the biochemical/ cytological stress-biomarkers in the earthworm.

Protozoa are unicellular – population ranges from 10,000 to 100,000 per g of soil. Most of the soil forms are flagellates, amoebae or ciliates. Abundant in upper larger of the soil. They are regulating the biological equilibrium in soil. Most of protozoans derive their nutrition by feeding or ingesting soil bacteria belonging to the genera *Enterobacter, Agrobacterium, Bacillus,Escherichia, Micrococcus,* and *Pseudomonas* and thus, they play important role in maintaining microbial/bacterial equilibrium in the soil. Some protozoa have been recently used as biological control agents against phytopathogens. Species of the bacterial genera *viz., Enterobacter* and *Aerobacter* are commonly used as the food base for isolation and enumeration of soil protozoans. Several soil protozoa cause diseases in human beings which are carried through water and other vectors, e.g. Amoebic dysentery caused by *Entomobea histolytica.*

Nematodes are used as biological indicators of soil health because the number and types present in a soil reflect changes in the microbes they consume, and the soil's physical and chemical environment. The ratio of bacterial- to fungal-feeding nematodes indicates the rate of nutrient cycling. Although there are a few pest nematodes species, there are over 95 non-pest species.

Bacteria are the most diverse group in the soil, and the most abundant cell type and equal to one half of the microbial biomass in soil. Bacteria bring about a number of changes and biochemical transformations in the soil and thereby directly or indirectly help in the nutrition of higher plants growing in the soil. The important transformations and processes in which soil bacteria play vital role are: decomposition of cellulose and other carbohydrates, ammonification (proteins ammonia), nitrification (ammonia-nitrites-nitrates), denitrification (release of free elemental

nitrogen), biological fixation of atmospheric nitrogen (symbiotic and non-symbiotic), phosphate solubilisation, oxidation and reduction of sulphur and iron compounds. All these processes play a significant role in plant nutrition.

Actinomycetes are bacteria, but due to their mycelial morphology and production of spore bodies, they have traditionally been considered as an intermediate group between bacteria and fungi. Abundance is next to bacteria. Actinomycetes in soil are particularly specialized towards decomposition of organic matter, including more complex substrates as chitin and hemicellulose, particularly under adverse conditions as high pH, temperatures and water stress. 70% of soil actinomycetes are *Streptomyces*. Many of them are known to produce antibiotics.

Fungi are more numerous in surface layers of well-aerated and cultivated soils dominant in acid soils. Common genera in soil are *Aspergillus, Mucor, Penicillium Trichoderma, Alternaria, Rhizopus.* Number of soil fungi forms mycorrhizal association with the roots of higher plants (symbiotic association of a fungus with the roots of a higher plant) and helps in mobilization of soil phosphorus and nitrogen e.g. *Glomus, Gigaspora, Aculospora,* (Endomycorrhiza) and *Amanita, Boletus, Entoloma, Lactarius* (Ectomycorrhiza). Algae found in most of the soils in number ranges from 100 to 10,000 per g soil, plays important role in the maintenance of soil fertility. Most of soil algae (especially BGA) act as cementing agent in binding soil particles and thereby reduce/prevent soil erosion. Soil algae like Blue green algae (BGA) act as cementing agent in binding soil particles and prevent soil erosion.Mucilage secreted by the BGA is hygroscopic in nature and thus helps in increasing water retention capacity of soil for longer time/period.Soil algae through the process of photosynthesis liberate large quantity of oxygen in the soil environment and thus facilitate the aeration in submerged soils or oxygenate the soil environment. They help in checking the loss of nitrates through leaching and drainage especially in un-cropped soils.

Microbial population in soils can be enumerated by employing serial dilution technique using different culture media for enumeration of soil bacteria, fungi, Actinobacteria; quantification of different Functional microbial groups by Most probable number (MPN) method, microbes involved in nutrient cycling like phosphate solubilizer, nitrogen fixers, zinc solubilizers on specific media, mycorrhiza spores by wet sieving and decanting method. Counts of earthworms, protozoa, nematodes, arthropods *etc.*, helps in judging the status of soil health.

Abundance of soil organisms

Organism	Number per gram soil	Biomass (kg/ha)
Earthworms	-	100 - 1,500
Mites	1-10	5-150
Nematodes	10-100	10-150
Protozoa	up to 100 thousand	20-200

Algae	up to 100 thousand	10-500
Fungi	up to 1 million	1,000-15,000
Actinomycetes	up to 100 million	400-5,000
Bacteria	up to 1 billion	400-5,000

2. Microbial biomass

Microbial biomass is a measure of the weight of microorganisms in soil, which mostly consists of bacteria, fungi and other microbes called archaea. Measures of microbial biomass measure either the weight/mass of carbon or nitrogen in soil microorganisms. The size of the soil microbial biomass (measured as mg C per kg) is affected by climate and many soil properties. Microbial biomass is the powerhouse of almost all biological processes in soil. The microbial biomass consists of bacteria and fungi, which decompose crop residues and organic matter in soil. This process releases nutrients, such as nitrogen (N), into the soil that are available for plant uptake. About half the microbial biomass is located in the surface 10 cm of a soil profile and most of the nutrient release also occurs here. Generally, up to 5% of the total organic carbon and N in soil is contained in the microbial biomass at any one time. When microorganisms die, these nutrients are released in forms that can be taken up by plants. Soil microorganisms are responsible for most of the nutrient release from organic matter. When microorganisms decompose organic matter, they use the carbon and nutrients in the organic matter for their own growth. They release excess nutrients into the soil where they can be taken up by plants. If the organic matter has a low nutrient content, micro-organisms will take nutrients from the soil to meet their requirements.

3. Soil respiration

The rate of respiration can be used as an index of the biological activity of soil as it reflects the physiological efficiency of the organisms.

Microbial activity can be determined by trapping carbon dioxide (CO_2) evolved from soil as the microbial biomass actively decompose soil organic matter and fresh plant residues. Activity is dependent on many factors including soil moisture (in dry soils the microbial biomass is not active), temperature (when soil moisture is present microbial activity increases as temperature increases within the range of values experienced through the agricultural zone), organic carbon (as a food source) and pH (around neutral). Decomposition of soil organic matter is controlled by the active microbial biomass and leads to the release of nitrogen and other nutrients that can become plant available. Management practices influence microbial activity by altering organic carbon availability, pH and other soil conditions and therefore reflect rapid changes in the biological function of soil. Although microbial activity can be influenced by management factors, these changes will only be expressed where sufficient moisture is present in the soil profile – a dry soil is not active.

4. Soil enzymes

Soil enzymes increase the reaction rate at which plant residues decompose and release plant available nutrients. The substance acted upon by a soil enzyme is called the substrate.

For example, glucosidase (soil enzyme) cleaves glucose from glucoside (substrate), a compound common in plants. Enzymes are specific to a substrate and have active sites that bind with the substrate to form a temporary complex. The enzymatic reaction releases a product, which can be a nutrient contained in the substrate. Sources of soil enzymes include living and dead microbes, plant roots and residues, and soil animals. Enzymes stabilized in the soil matrix accumulate or form complexes with organic matter (humus), clay and humus-clay complexes, but are no longer associated with viable cells. It is thought that 40 to 60% of enzyme activity can come from stabilized enzymes, so activity does not necessarily correlate highly with microbial biomass or respiration. Therefore, enzyme activity is the cumulative effect of long term microbial activity and activity of the viable population at sampling. However, an example of an enzyme that only reflects activity of viable cells is dehydrogenase, which in theory can only occur in viable cells and not in stabilized soil complexes. Monitoring of dehydrogenases, which are respiratory enzymes and integral part of all soil organisms will give a measure of biological activity of soil at a given time.

Enzymes respond to soil management changes long before other soil quality indicator changes are detectable. Soil enzymes play an important role in organic matter decomposition and nutrient cycling. Some enzymes only facilitate the breakdown of organic matter (e.g. hydrolase, glucosidase), while others are involved in nutrient mineralization (e.g. amidase, urease, phosphatase, sulfates).

Soil enzymes as indicators of soil health

Soil enzymes	**Enzyme reaction**	**Indicator of**
Dehydrogenase	Electron transport system	Microbial activity
B glucosidase	Cellobiose hydrolysis	C-cycling
Cellulase	Cellulose hydrolysis	C-cycling
Phenol oxidase	Lignin hydrolysis	C-cycling
Urease	Urea hydrolysis	N-cycling
Phosphatase	Release of PO_4	P-cycling
Arylsulphatase	Release of SO_4	S-cycling
Protease	Protein breakdown	N-cycling

Collection of representative rhizosphere soil samples for microbiological parameters

- Select a composite rhizosphere soil sample from each uniform area in a growing season since the microbial life will be more active in warm and moist conditions. All sampling

tools and container used for soil samples must be sterilized in advance (wrapped in tin foil, sterilized with high pressure steam and left overnight in an oven at 120^{o} C) or wipe with an alcohol to prevent interference from exogenous substances.

- Remove the surface soil litter including plants, visible roots and soil animals, fallen leaves. For standing fruit crops or perennial crops collect the rhizosphere sample from the active root zone or from the boundary of the tree canopy.
- For vegetables, flowers and medicinal crops, uproot the plant and shake the plant roots to remove loose soil and excess dirt, put the plant in a cover and shake it or use sterile brush to collect the rhizosphere soil which is adhered to the roots.
- Avoid taking samples when the soil is recently fertilized.
- Mix the rhizosphere soil samples collected from multiple points within the same uniform area and label. Transport the soil back to the laboratory.
- Sieve the soil using 2 mm sieve based on its condition, if the soil is too sticky or has high moisture content, sieving can be avoided.
- Soil samples used for characterization of microbial numbers and activities of organisms should be used as quickly as possible after collection. Soil samples can be stored for long term at -20^{o} C, and for short term upto 3 days if refrigerated at 0-4^{o} C.

1. Enumeration of Rhizospheric microorganisms

Materials required

Rhizosphere soil samples, Nutrient agar, Martin's Rose Bengal agar and Kusters agar,Waksman No77 medium, Pikovskayas medium, Water blanks 9.0 ml and 90 ml, Pippettes and petriplates.

Procedure

1. Transfer 10 g rhizosphere soil to 90 ml sterile water blank, shake it well.
2. Prepare serial dilutions of the sample up to 10^{-8} dilution.
3. Plate out 1 ml dilutions of 10^{-7} and 10^{-8} into triplicate plates for enumeration of bacteria,

each from 10^{-4} and 10^{-5} into three sets of triplicate plates each for Actinomycetes and fungi. 10^{-5} and 10^{-6} to the petriplates for enumeration of phosphate solubilizers and 10^{-2} and 10^{-3} for free nitrogen fixers.

4. Pour the respective melted and cooled medium (about 15-20 ml per plate) - Nutrient agar for bacteria, Rose Bengal agar for fungi, Kusters agar for Actinomycetes, Waksman No. 77 medium for free nitrogen fixers, Pikovskayas medium for phosphate solubilizers.

5. Gently rotate clockwise and anticlockwise directions to ensure proper distribution of soil suspension in the medium.

6. Incubate the plates at 30°C for 3-4 days.

7. Observe the colonies appeared on respective medium and count the number of colonies and calculate colony forming units (CFU)/g of soil using following formula.

$$\text{CFU/g soil} = \frac{\text{Colony count xdilution factor}}{\text{Dry weight of soil sample}}$$

2. Enumeration of mycorrhiza spores by wet sieving and decantation method

Arbuscular mycorrhizal fungal spores which are present in the soil can be separated by sedimentation and decanting technique.

Materials required: Rhizosphere soil, sieve set of 2 mm, 450 µm, 250 µm, 150 µm and 40 µm. to collect AM spores, measuring cylinder and beaker.

Procedure:

1**.** Uproot a plant along with the soil around the roots. Cut off the shoot portion and collect the soil around root zone.

2. Weigh a known amount of rhizosphere soil (100 g) and mix with 3-4 volumes of water with continuous stirring in a beaker.

3. Pour the soil-water mixture through a set of sieves stacked one above in the order from top 2 mm, 450 µm, 250 µm, 150 µm and 40 µm.

4. Wash the soil sample using a small jet of water through these sieves kept in a sink.

5. Discard the soil particles which concentrate on top sieves and collect the finer soil particles along with the AM spores which will collected in 150 and 40 µm sieves.

6. Using a jet of tap water wash the spores and finer soil particles through these sieves and the process is repeated until the water washing through the bottom sieve become colorless. Transfer the contents from 150µm sieve to 40µm sieve

(**Note:** The water drains slowly through the lower sieve; hence, the 40 µm sieve must be continuously checked for the height of the water. If the water over flow the lower sieve, spores are lost)

7. The contents of 40µm sieve are collected by washing them into a beaker using a small stream of water from a wash bottle.

8. The supernatant that contains the spores are poured over the clean 40µm nylon mesh placed on sieveand the nylon mesh is transferred on to a glass plate.

9. The nylon mesh containing spores is observed under stereo light microscope, count the spores and expressed as number of spores per gram of soil

2. Enumeration of soil Protozoa

Soil protozoa directly feed (predate) on host bacteria. When eaten up by protozoa, it will result in removal of growth of the bacterium. A series of replicated soil dilutions are plated on petri dishes with growth of host bacterium. Removal of growth of host bacterium due to predation shows presence of at least one protozoa which is counted as positive (+). Those in which host bacterium is not affected shows absence of protozoa (predator) and is counted as negative (-). By counting both (+) and (-) growth in each of dilution and their replicates, the number of protozoa can be calculated from the total number of negative responses using Fisher's method of negative plates (Fisher and Yates, 1943).

Materials required

Soil sample, Pipettes and 1 ml tips, sterile test tubes, glass rings (2cm internal diameter and 1cm depth; 1-2mm thickness), *Aerobacter aerogenes* host culture, sterilized petri plates.

Reagents

- **Sterile normal saline solution:** Dissolve 58.45g sodium chloride in 1000ml distilled water. Sterilize for 15min at 15kg cm^{-2} pressure.

Procedure

1. Take 10g soil and shake for 4min with 50ml sterile normal saline solution.
2. From the soil suspension (step-1) make a series of two fold dilutions by adding 1ml of each dilution to 1ml sterile normal saline solution in each tube. Make a series of 15 dilutions.
3. Pour about 15ml of molten agar containing $5gL^{-1}$ NaCl into each of the sterilized petri plates of 10cm diameter.
4. Place eight sterile glass rings to each petri plate quickly before the agar solidifies.
5. Make thick suspension of *Aerobacter aerogenes* from a week-old growth slants. Pour one drop of this suspension to each dilution in the eight rings.
6. Place 0.5ml of suspension of each dilution in the eight rings in one petri plate. You will thus have 15 such plates with 8 rings in each.
7. Incubate plates for 15 days at $28\pm1^{o}C$ in an incubator.
8. Examine each ring for bacterial growth. Count rings showing bacterial growth as (-) and those without bacterial growth as (+) for the presence of protozoa. (Annexure I).

4. Determination of Microbial Biomass C

Fumigation-extraction method:

A more easily applicable, non-subjective and replicable method is described for total microbial biomass determination in soil samples at a particular point of time. In thefumigation-extraction method, a direct measurement of C and other nutrients contained therein in microbial biomass is carried out. Overnight fumigation of chloroform is carried out to kill all the organisms in soil samples. The microbial biomass constituents released by $CHCl_3$ fumigation treatment can be extracted directly through chemical extractants. The readily oxidisable C contained in the extractant can be measured through standard chemical procedures.

Materials required:

Moisture box, separating funnel, glass beads and other glassware, moisture box, Whatsman No.1 filter paper

Instruments

Vacuum pump and vacuum desiccators, Rotary shaker, Hot plate

Reagents

(i) Distilled Chloroform
(ii) Conc. H_2SO_4
(iii) 0.5M K_2SO_4: Dissolve 43.563 g of K_2 SO_4 in distilled water and dilute to 500 ml.
(iv) 0.2 M $K_2Cr_2O_7$: Dissolve 0.9808 g $K_2Cr_2O_7$ to 100 ml distilled water
(v) Orthophosphoric Acid.
(vi) 0.005M Ferrous ammonium sulphate (FAS): Dissolve 3.92 g FAS and 0.15 ml of H_2SO_4 in distilled water and dilute to 2 liter.
(vii) Ferroin/diphenyleamine indicator: Dissolve 0.695g of $FeSO_4.7H_2O$ and 1.485g of orthopheananthroline monohydrate in 100 ml of distilled water. Alternatively, use ready-made ferroin indicator. Diphenylamine indicator can also be used instead of ferroin (Dissolve 1g Diphelamine in100 ml H_2SO_4).

Procedure

I. Put soil sample in plastic bag to prevent drying due to evaporation. Sieve the soil through 2 mm mesh. Do not dry the sample, soil samples are to be analyzed the same day they are received in the laboratory.
II. Weight five sets of 10g of moist soil for each sample. Keep one set in the moisture box after taking weight of the empty box. Keep the box in the oven at 105^0C for 24 hrs until a constant oven dry weight is achieved. Calculate the moisture content of the soil.
III. Out of the four sets of the soil, keep two sets in 50ml beakers for fumigation. Remaining two sets are packed and keep in refrigerator for extraction next day.

IV. Take 20 ml chloroform for each 10 g soil in a separating funnel. Wash the chloroform with Conc. H_2SO_4 (each with half the volume of chloroform) and discard the acid (bottom phase) carefully after phase separation. Take precaution to open the stop-cock after each shaking to release the pressure inside.

V. Wash two times more with the same volume of distilled water similarly and collect the bottom whitish phase. All these washings are given to make the chloroform free ethanol.

VI. Keep the ethanol free chloroform in 100 ml beakers. Do not keep more than 40 ml in each beaker to provide space for boiling. Place some glass beads in the beaker to reduce bumping.

VII. Place all the beakers containing soil and chloroform in a vacuumdesiccator. Line the inner surface of the desiccator with moistened filter paper. Do not use plastic desiccator. Use high density vacuum grease at the lid-joint to ensure proper sealing. Use a rubber tube to direct the exhaust through water.

VIII. Put on the vacuum pump and keep it on until the chloroform boils for about five minutes. Close the outlet and put the desiccator in dark for 24 h.

IX. After 24 h release the vacuum, take out the beaker containing chloroform and the inner paper lining. Perform back suction for five to six times to ensure removal of any excess/adhered chloroform vapour.

X. Take the non-fumigated soil samples from fridge and thaw it.

XI. Transfer both the fumigated and non-fumigated soil in 250 ml conical flasks. Add 25ml of 0.5M K_2SO_4 and shake for 30 minutes. After shaking the suspension through Whatman No.1 filter paper.

XII. Transfer 10 ml of the filtrate in 500 ml conical flask. Add 2 ml of $K_2Cr_2O_7$ (0.2 M), 10 ml of conc. H_2SO_4 and 5 ml of orthophosphoric acid to each flask. Run at least two blanks with 10 ml distilled water each along with the acids mentioned above.

XIII. Keep the flasks on hot plate at 100^oC for 30 minutes under refluxing condition. Take out the flasks and add about 250 ml of distilled water immediately. Allow the contents to cool down to room temperature.

XIV. Add two to three drops of ferroin indicator and titrate the contents against 0.005 M ferrous ammonium sulphate to get brick red end point. Alternatively use diphenylamine indicator.

Calculation

- Soil water content (WS):

$$WS\ (\%) = \frac{\text{Wt. of wet soil (g) - Wt. of oven dry soil (g)}}{\text{Weight of oven dry soil (g)}} \times 100$$

- Weight of soil sample (oven dry weight equivalent) takes for microbial biomass measurement (MS):

$$MS\ (g) = \frac{\text{Wt. of wet soil (g)}}{\{100+WS\ (\%)\}} \times 100$$

- Total volume of solution in the extracted soil (VS)
  VS (ml) = Wt. of wet soil (g) - Wt. of oven dry soil (g) + Extractant volume (ml)

- Determination of extractable carbon (EC in µg ml^{-1}):

  a) Standardization of FAS solution:

  $$\text{Normality of FAS (XN)} = \frac{\text{Volume of } K_2Cr_2O_7 \text{(2 ml) x Strength of } K_2Cr_2O_7 \text{(0.2N)}}{\text{Average titer value for the blank (ml)}}$$

  b) Determination of volume of $K_2Cr_2O_7$ solution consumed by FAS in any sample (Y) ml:

  $$Y = \frac{\text{Normality of FAS (XN) x Titer value (ml)}}{\text{Normality of } K_2Cr_2O_7 \text{ (0.2 M)}}$$

  c) Volume of $K_2Cr_2O_7$ consumed for oxidizing easily mineralizable C in 10 ml of extractant = 2-Y ml

  d) Extractable C (EC) in µg ml^{-1}:

  1mL of 1N $K_2Cr_2O_7$ oxidizes 0.003 g of C
  1mL of 0.2 N $K_2Cr_2O_7$ oxidizes 0.0006 g of C *i.e.*, 600 µg of C ml
  (2-Y) mL of 0.2 N $K_2Cr_2O_7$ oxidizes 600 x (2-Y) µg of C

  So, the amount of extractable C (EC)

  $$EC\ (\mu g\ mL^{-1}) = \frac{600x(2-Y)}{10}$$

- Total weight of extractable C in the fumigated (EC_F) and non-fumigated (EC_{NF}) in soil samples:

  $$EC_F \text{ or } ECNF\ (\mu g\ g^{-1}\ soil) = EC\ (\mu g\ ml^{-1}) \times \frac{VS\ (ml)}{MS\ (g)}$$

- Microbial biomass carbon in soil (MB-C):

  $$MB\text{-}C\ (\mu g\ g^{-1}\ soil) = \frac{(EC_F - EC_{NF})}{K_{EC}}$$

Where = 0.25± 0.05 and it represents the efficiency of extraction of microbial biomass carbon.

5 Assessing nematode population in soil by Cobb Decanting and Sieving Method

Nematodes are soil fauna which are of specific interest as they cause some plant diseases and often are needed to be examined for their general population. Besides, they also help in enhancing soil quality through.

1. Release nutrients stored in microbial biomass for plant use.
2. Increase decomposition rates and soil aggregation by stimulating bacterial activity.
3. Prevent some pathogens from establishing on plants.
4. Provide prey for larger soil organisms, such as nematodes. As nematodes are filamentous, they can be separated from finer components through a series of sieving decanting techniques. Their gregarious nature is utilized in separating them from the soil debris of equal size fraction.

Materials required

Two plastic pans (I & II), A range of sieves-20, 60, 100, 200 and 325 mesh size, 250ml and 400 ml beakers, 100ml petri dishes, aluminum gauge, tissue paper, graduated counting dish.

Procedure

1. Collect soil samples from periphery of the patch where the plants show gradual decline in growth. For perennial crops, collect samples from feeder root zone. For annual crops samples from rhizosphere zone gives better assessment.
2. Keep samples moist and store under shade. If necessary, samples to be stored at 10-15^{o}C without allowing the soil to dry.
3. Keep 250 ml of soil in pan I and soak in one liter of water for 5 minutes.
4. Break soil crumbs by hand. Discard big stones or granules separated by hand to discard, and the suspension is mixed thoroughly. Tilt pan and wait for 10 seconds for settling of heavier particles. Then the muddy mixture is poured through 20 mesh sieve into pan II.
5. To obtain optimum yield of nematodes, more water is added to the residue in part I, and the process is repeated thrice. To ensure that even long nematodes pass through the sieve, materials on sieve are either rinsed with gentle jet of water or are partly immersed in pan II with gentle shaking.
6. Discard residue in pan I and on 20 mesh sieve and mix contents in pan II thoroughly and pour in the same way through 60 mesh sieve back to pan I. The process is repeated for two to three times and the sieve is rinsed as before.
7. Wash residue on the sieve into a 250ml beaker to observe for nematode cysts.

8. Repeat the process of decanting and sieving with the rest three sieves with the only additional precaution to keep the sieve at 45^0C angle with ground while sieving. This will prevent the filamentous nematodes to pass easily through the sieve.
9. Collect residues on each sieve separately through backwash. If the suspension of the residue is cloudy due to presence of colloidal clay, it should be returned to the respective sieve and rinsed again before proceeding to the next stage.
10. Discard material coming through the 325 mesh. This is supposed not to carry any nematode.
11. Allow contents of the beakers to settle for 2 hours and excess supernatant water is poured out. Pool contents of all the beakers (except those collected over 60 mesh sieve) in 100ml beaker and again allow to settle for reduction of the volume.
12. Keep a slightly depressed circle of aluminum wire gauge in the petri dish in such a way that there is a gap between the bottom of the petri dish and the gauge. Two layers of moist tissue papers are spread on the wire gauge and water is kept inside the petri dish just to touch the bottom of the gauge.
13. Pour suspension on the tissue paper and leave for 24 to 48 hours to allow the nematodes to storm across the tissue paper in the water below leaving behind the other debris. This helps in separating the nematodes from suspension.
14. Measure the volume of contents in the pertidish. Spread 5 to 10 per cent of it over a graduated dish for counting by observation under microscope at 40-60x magnification.

Calculation

Express nematode population in numbers per unit volume of moist soil. Moreover, by measuring the initial moisture content and the weight of the soil taken for measurement, the result can also be expressed on the basis of per unit weight of oven dry soil.

6. Monitoring Organic Matter Decomposition in Soil through Carbon Dioxide Evolution: Alkali Trap Method

The volume of NaOH that absorbs by CO_2 is taken for calculation for amount of CO_2 evolved. This technique is simple and easily adaptable where resources are limited. Improved dynamic chamber technique and micrometeorological methods are also available for more accurate observation of CO_2 evolution.

Materials required

Conical flasks (500 mL), test tubes, rubber stoppers, burettes and pipettes, asbestos sheets, soil samples.

Reagents

- Standard NaOH solution (0.5 N): Dissolve 20 g NaOH in distilled water and make volume to 1 L.

- Standard H_2SO_4 solution (0.5 N): Dilute 1.4 mL conc. H_2SO_4, to 1 L.
- Saturated solution of $BaCl_2$
- Saturated solution of Phenolphthalein indicator

Procedure

1. Take 100 g soil in 500 mL conical flask.
2. Determine moisture content gravimetrically.
3. Add water to bring its moisture content to field capacity, unless you intend to study the effect of moisture content.
4. Take 20 mL of 0.5N NaOH in test tubes.
5. Hang the tubes with the help of thread inside the conical flask without touching the soil.
6. Make the flasks air tight by rubber stoppers. Keep the flask in the incubator at 28 °C or 37 °C (as required).
7. After different specific time intervals (eg. 1-day, 2-days, 7-days *etc*.) of incubation, take out the flask from the incubator.
8. Transfer the 0.5N NaOH solution from the test tubes to the beakers. Give several washings of the tubes for complete transfer.
9. Add few drops of saturated $BaCl_2$ solution and few drops of Phenolphthalein indicator. Titrate with standard 0.5N H_2SO_4, slowly until the pink color just disappears. Approach the end point with caution and record the exact amount of acid required.
10. Repeat the above steps 3 to 9 if measurement has to be continued for longer duration.

Calculation

One mL IN NaOH= 22 mg CO_2. Accordingly, calculate the amount of CO_2, evolved from the soil samples. Express the results as mg CO_2 produced per 100 g soil per unit time. Give the data in a tabular form

Weight (g) CO_2 of evolved = Volume of NaOH converted (to Na_2CO_3) X 0.022

8. Soil enzymes activities

Dehydrogenase activity (µg TPF/g soil/day)

Dehydrogenase activity (DHA) is widely used as a generalized index of microbial activity. The DHA of the soil samples can be determined by following the triphenyl tetrazolium reduction test (Casida *et al.,* 1964). Place one gram of air-dried soil in an air-tight screw capped test tube (15 ml capacity) to which add 0.2 ml of 3% triphenyl tetrazolium chloride (TTC) solution and 0.5 ml of 1% glucose. Gently tap the bottom of the tube to drive out all the trapped oxygen creating a water seal above the soil. Incubate tubes at 28 ± 0.5 ^{0}C for 24 h. After incubation, add 10 ml methanol and shake vigorously to extract the pink colored formazan formed by the reduction of TTC and after 6 hours filter the clear pink coloured supernatant and take the absorbance of the supernatant in a spectrophotometer at a wave length of 485 nm (blue filter). Determine the concentration of formazan in soil samples with reference to a standard curve prepared by using

graded concentrations of formazan (10 µg to 90 µg TPF ml^{-1}). Express the results as µg of triphenyl formazan (TPF) formed g^{-1} soil per day.

Fluorescein diacetate (FDA) hydrolysis (µg fluorescein/g soil/hr)

Fluorescein diacetate (FDA) hydrolysis is widely accepted as an accurate and simple method for measuring total microbial activity in the soil samples. Colorless fluorescein diacetate is hydrolysed by both free and membrane bound enzymes, releasing a coloured end product fluorescein which can be measured by spectrophotometry. FDA of soil samples can be determined by following the procedure of Adam and Duncan (2001). Place two grams of fresh sieved soil (2 mm) in a 50 ml conical flask and add 15 ml of 60 mM potassium phosphate buffer pH 7.6 followed by addition of stock solution (0.2 ml 1000 µg FDA ml^{-1}) to start the reaction. Prepare blanks without the addition of the FDA substrate.

Shake the content of the flasks with the help of a stopper. Then place the flasks on an orbital incubator shaker at 30^0C for 20 min. After incubation, add 15 ml of chloroform/methanol (2:1 v/v) to terminate the reaction. Shake the content of the flasks. The contents of the conical flasks were then transfer to 50 ml centrifuge tubes and centrifuge at 2000 rpm for 3 min. Filter the supernatant from each sample using (Whatman No 2 filter paper) into 50 ml conical flasks and use the filtrate samples for measuring absorbance at 490 nm on a spectrophotometer. The concentration of fluorescein released during the assay can be calculated using the calibration graph produced from 0 to 5 µg fluorescein ml^{-1} standards prepared by using 20 µg fluorescein ml^{-1} standard solution. Use the reaction mixture containing no added fluorescein as a blank to set the spectrophotometer at zero before taking the readings.

Annexure I: Fisher's table for negative plate

No. of negative cultures	Organisms per gram	No.of negative cultures	Organisms per gram	No.of negative cultures	Organisms per gram	No.of negative cultures	Organisms per gram	No.of negative cultures	Organisms per gram
4	1,690,000	27	232, 000	50	17,300	73	2,330	96	317
5	1,430, 000	28	121, 000	51	15,800	74	2,140	97	290
6	1,230, 000	29	110, 000	52	14,500	75	1,960	98	265
7	1,000, 000	30	101, 000	53	13,300	76	1,800	99	243
8	934, 000	31	92, 000	54	12,200	77	1,650	100	223
9	824, 000	32	84, 000	55	11,100	78	1,510	101	203
10	729, 000	33	77, 000	56	10,200	79	1,390	102	185
11	650, 000	34	70, 000	57	9,380	80	1,270	103	169
12	581, 000	35	64, 000	58	8,570	81	1,170	104	154
13	520, 000	36	59, 000	59	7,860	82	1,070	105	140
14	467, 000	37	54, 000	60	7,210	83	979	106	126
15	421, 000	38	49, 000	61	6,600	84	898	107	113
16	380, 000	39	45, 000	62	6,040	85	823	108	101
17	344, 000	40	44,400	63	5,540	86	755	109	90.2
18	311, 000	41	37,900	64	5,080	87	693	110	79.4

19	282, 000	42	34,700	65	4,670	88	635	111	69.5
20	256, 000	43	31,800	66	4,280	89	582	112	60.2
21	232, 000	44	29,200	67	3,920	90	534	113	51.3
22	211, 000	45	26,700	68	3,600	91	490	114	42.9
23	192, 000	46	24,500	69	3,300	92	450	115	34.8
24	175, 000	47	22,400	70	3,020	93	412	116	27.4
25	159, 000	48	20,500	71	2,770	94	377		
26	145, 000	49	18,800	72	2,540	95	346		

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Salt affected soils and their management

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Salt affected soils are categorized as saline soils, saline-sodic soils and sodic soils based on pH and electrical conductivity of the saturation soil extract and exchangeable sodium percentage.

Saline soils: Saline soils contain sufficient neutral soluble salts to adversely affect the growth of most crop plants. They are defined as soils which have an electrical conductivity of the saturation soil extract of more than 4 dS/m at 25°C.The pH value of saturated soil paste is always less than 8.2 and more often near neutrality. In saline soils, soluble salts most commonly present are the chlorides and sulphates of sodium, calcium and magnesium.

Presence of excess salts in saline soils keep the clay in flocculated state resulting in good physical properties. Soil tillage characteristics and permeability to water are even better than those of non-saline soils. In field conditions, saline soils can be recognized by the spotty growth of crops and often by the presence of white salt crusts on the surface. If the salinity level is not sufficiently high to cause barren spots, the crop appearance may be irregular in vegetative vigour. Leaves of plants growing in salt infested areas may be smaller and darker blue-green in colour than the normal leaves.

Effect of salinity on plants

The primary effect of excess salinity is that it renders less water available to plants although some water is still present in the root zone. This is because the osmotic pressure of the soil solution increases as the salt concentration increases. Apart from the osmotic effect of salts in the soil solution, excessive concentration and absorption of individual ions like chloride, sodium ions and boron may prove toxic to the plants and/or may retard the absorption of other essential plant nutrients.

Management of soil salinity

Leaching

Leaching with good quality irrigation water is the key factor in reducing the soluble salts concentration in crop root zone. When the build-up of soluble salts in the soil becomes excessive, the salts can be leached by applying more water than that needed by the crop during the growing season. Leaching removes considerable portion of the salts below the root zone by deep percolation. It is important to know that leaching is not needed until accumulating salinity is expected to exceed crop tolerance and reduce yield.

Measures to increase the efficiency of leaching

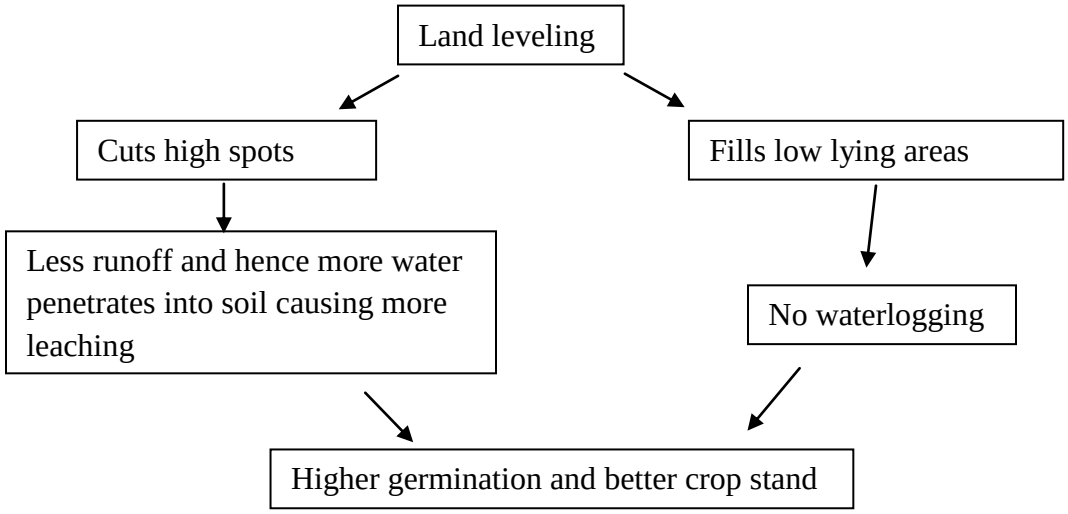
- Leaching during the cool hours of the day instead of the warm increases the efficiency since the evapotranspiration losses are lower during cool hours.

- While leaching, alternate ponding and drying is more beneficial instead of continuous ponding.

- Avoid leaching during hot summers where rapid secondary soil salinization from high water tables can occur and leads to higher soil salinity.

Land leveling

Salinity control is difficult if a field is not sufficiently graded to permit uniform water distribution. Salts accumulate in the high spots which have too little infiltration while water accumulates in low-lying areas resulting in poor germination and poor crop stand. Leveling the land also helps in achieving uniform water distribution and good crop stand as depicted below.



- Scraping of salts accumulated on soil surface is often an important practice to reduce soil salinity.

Irrigation management

Frequency of irrigation can be increased to maintain higher soil-water availability between irrigations. Providing pre-plant leaching irrigation will reduces surface salt concentrations which otherwise inhibit germination.

Placement of seed

It is important to adjust planting procedures to ensure that the soil around germinating seeds is sufficiently low in salinity. Salinity reduces germination and it is often difficult to obtain a satisfactory crop stand with furrow irrigation in saline soils**.**

Tolerance of crops to salinity

Response of crops to salinity is not uniform. Some crops have the potential to produce acceptable yields at higher levels of salinity than others. High salt tolerance of some crops could be due to their better ability to make the necessary osmotic adjustments which enables them to extract

more water from a saline root zone. Knowledge about salt tolerating ability of crops is very useful in adopting appropriate management practices. When the salt accumulation in soil cannot be controlled at an acceptable concentration for the crop currently being grown, switching for an alternate crop that is more tolerant to existing level of soil salinity will be an economically viable option.

Crop groups based on response to soil salinity

Sl. No.	Sensitive group		Resistant group	
	Highly sensitive	Medium sensitive	Medium tolerant	Highly tolerant
1	Beans	Radish	Spinach	Sugar beet
2	Peas	Cow pea	Guava	Turnip
3	Carrot	Cabbage	Pomegranate	Date palm
4	Onion	Broad bean		Ber
5	Lemon	Cauliflower		
6	Orange	Cucumber		
7	Grape	Gourds		
8	Peach	Tomato		
9	Plum	Sweet potato		
10	Apple			
11	Pear			

Sodic soils and their management

Sodic soils contain higher exchangeable sodium to adversely affect the growth of most crop plants. Sodic soils are those which have an exchangeable sodium percentage (ESP) of more than 15. In sodic soils, the electrical conductivity of saturation soil extracts is less than 4 dS/m at 25 °C and pH of saturated soil pastes is 8.2 or more and in extreme cases may be above 10.5.

Effect of high sodium in soil on plant growth

High sodium concentration in sodic soils poses problems due to its adverse effect on physical condition of soil. As the proportion of exchangeable sodium increases, the soil tends to become more dispersed which results in the breakdown of soil aggregates and lowers the permeability of the soil to air and water. Dispersion also results in the formation of dense, impermeable surface crusts that hinder the emergence of seedlings.

Another effect of excess exchangeable sodium on plant growth is through its effect on soil pH. High pH of sodic soils reduces the availability of some essential plant nutrients. Concentration of calcium and magnesium in the soil solution reduces as the pH increasesdue to formation of relatively insoluble calcium and magnesium carbonates by reaction with soluble carbonate of sodium. This results in deficiency of calcium and magnesium for plant growth.Similarly, solubility in soil and availability to plants of other essential nutrient elements viz., phosphorous, iron, manganese and zinc are affected in sodic soils. Also, accumulation ofsodium, boron and molybdenum in plants at toxic levelsmay result in plant injury or reduced growth.

Management of sodicity hazard and low infiltration rate in sodic soils

Application of gypsum

For reclamation of sodic soils, granular gypsum can be broadcasted at rates ranging from 5 to 40 t/ha and should be incorporated into the soil to shallow depth. Small and repeated soil applications of gypsum (5-10 t/ha) may be more effective for water-related surface infiltration problems. Annual rates of gypsum application in excess of 10 t/ha are usually uneconomical.

Cultivation and Deep Tillage

Where infiltration problems are severe due to sodicity, ploughing is helpful as it roughens the soil surface and slows the flow of water, increasing the time during which infiltration can take place.Deep tillage (chiselling, subsoiling) also allows sufficient water to enter soil and makes an appreciable difference in stored water and on the crop yield.

Application of organic residues

Incorporation of crop residues or other organic matter into the surface layer (< 10 cm) of soil improves water infiltration. Slowly degradable crop residues of barley, rice, wheat, maize and sorghum are known to improve water penetration than leguminous crop residues. It is one of the easiest methods to improve water infiltration especially for small farmers who do not have the resources to implement more costly corrective measures.

Green manuring: Cultivation and incorporation of green manure crops like sesbania, dhaincha etc. increases organic matter content and on degradation there will be release of carbonic acid. This lowers the pH and enhances solubility of native calcium carbonate and adds a considerable amount of plant nutrients in the soil.

Irrigation management

Irrigation management methods should be used in complement with the application of gypsum, organic residues and cultivation practices to make the water infiltration problem easier to manage.

Following are few irrigation management practices that can help in managing sodic soilsPre-plant irrigation

- Irrigating the land to fill the rooting depth to field capacity before planting is an effective method for wetting soils with a very slow infiltration rate.

Changing irrigation method

- Changing from surface irrigation method to micro irrigation methods (sprinklers for sandy soils and drip irrigation for heavier clayey soils) helps in achieving higher water infiltration rate in crop root zone.

Sodium toxicity

Since sodium is the most dominant ion on the exchangeable sites of sodic soils, crops tend to absorb sodium at higher amounts. This can result in sodium toxicity in plants.Typical toxicity symptoms are leaf burn, scorch and dead tissue along the outside edges of leaves. Symptoms appear first on the older leaves, starting at the outer edges and, as the severity increases, move progressively inward between the veins toward the leaf center. Leaf tissue analysis is commonly used to confirm sodium toxicity. Management practice like addition of gypsum reduces sodium concentration in soil and thereby reduces excess sodium absorption by plants. If amendments cannot control the sodium toxicity problem, a change to a more tolerant crop may be advisable.

Tolerance of crops to alkalinity

Sl. No.	Characteristics	ESP range	Crops
1	Sensitive	10-15	Safflower, peas, lentil, pigeon pea, black gram
		16-20	Chickpea, soybean
		20-25	Groundnut, cowpea, onion, pearl millet
2	Semi tolerant	25-30	Linseed, garlic, guar
		30-50	Indian mustard, wheat, sunflower
3	Tolerant	50-60	Barley, Sesbania
		60-70	Rice (Transplanted)

Plant sampling guidelines and methodology for plant analysis

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I) Plant tissue sampling guidelines

Soil tests, although useful in predicting fertilizer and soil amendment needs, are not the final measure of what nutrients a plant will absorb. Because temperature, moisture regimes, soil acidity and other soil conditions may modify the uptake of different nutrients by plants, it is sometimes necessary to determine nutrient content in the plants to evaluate the actual soil nutrient availability status. Total plant analysis and green tissue analysis the most important diagnostic techniques for determining deficient, sufficient or excessive amounts of essential elements in plant tissue. Tissue tests are of immense help to farmers in overcoming many problems and are the better approaches for nutrient management of horticultural crops. Plant analysis plays a key role in nutrient management in fruit crops as a guide for fertilizer application if reliable nutrient norms are available. Plant analysis as an aid to soil testing has its limitation also. Significant error in the plant analysis may arise due to wrong sampling alone, especially when the plant analysis is aimed at diagnosis of nutrient deficiency in standing crops. The success of this approach depends mainly on selecting the right plant part, stage of growth and time of sampling. The sampling guide and the optimum nutrient levels developed for different horticultural crops are given in Table 1 and Table 2 respectively. The visual recognition of nutrient deficiency caused by sub-optimal nutrition has also been used for diagnosis nutrient deficiency. Such diagnosis however is reliable only when symptoms of nutrient imbalance are characteristic.

Table 1. Plant tissue sampling guidelines for horticultural crops

Crop	Plant part	Growth Stage/ Time
Fruit Crops		
Banana	Petiole of 3rd open leaf from apex	Bud differentiation stage.
Cashew	4th leaf from tip of matured branch	At beginning of flowering
Custard Apple	5th leaf from apex	2 months after new growth
Fig	Fully expanded leaves, mid shoot current growth	July-August
Grapes	5th petiole from base	Bud differentiation stage for yield forecast. Petiole opposite to bloom time for quality
Citrus	3 to 5 month old leaf from new flush. 1st leaf of the shoot	June

Guava	3rd pair of recently matured leaves	Bloom stage (August or December)
Mango	Leaves + Petiole	4 to 7 months old leaves from middle of shoot
Papaya	6th petiole from apex	6 months after planting
Passion Fruit	Matured leaf opposite to last open flower	Bloom
Pineapple	Middle 1/3rd portion of white basal portion of 4th leaf from apex	4 to 6 months
Pomegranate	8th leaf from apex	Bud differentiation. In April for February crop and August for June Crop
Sapota	10th leaf from apex	September
Phalsa	4th leaf from apex	One month after pruning
Ber	6th leaf from apex from secondary or tertiary shoot	Two months after pruning
Vegetable Crops		
Bean	Upper most recent fully developed trifoliate leaves	
Cabbage	Wrapper leaf	2-3 months old
Carrot	Most recent fully matured leaf	Mid-grown
Cauliflower	Most recent fully matured leaf	At heading
Peas	Most recent fully developed leaflet	First bloom
Cluster bean	1st fully developed leaf	
Cucumber	5th leaf from tip	Flower bud start to small fruit
Brinjal	Leaf blades with midribs minus petioles from most recent fully developed leaf	
Garlic	Most recent fully matured leaf	Pre-bulb
Onion	Top-no white portions	1/3 to ½ grown
Tomato	Leaves adjacent to inflorescence	Mid bloom
Plantation Crops		
Coconut	Pinnal leaf from each side of 4th leaf	
Oil palm	Middle 1/3rd minus midrib of 3 upper and 3 lower leaflets from 17 frond of mature trees and 3rd frond of young trees	
Coffee	3rd or 4th pair of leaf from apex of lateral shoots	
Tea	Third leaf from tip of young shoots	
Clove	10th to 12th leaves from tip of non-fruiting shoot	End of blooming period
Ornamental crops		

Jasmine	Most recent fully developed leaf	
Chrysanthemum	4th leaf from tip, omit unfurled	Bud burst
Hibiscus	Most recent fully developed whole leaves	
Lilly	Most recent fully developed leaf	
Rose	Most recent fully developed compound 5th leaflet leaf	Flower bud pea size

Table 2. Optimum nutrient norms for fruit crops

Nutrient	Unit	Grape		Mango		Acid Lime	Pome-granate	Banana	
		Anab-e-Shahi	Thompson Seedless	Alphonso	Totapuri			Robusta	Elakki
Nitrogen	%	0.50-1.25	0.87-1.61	0.78-1.65	0.84-1.53	1.53-2.10	0.91-1.66	1.67-3.43	2.23-3.35
Phosphorous	%	0.46-0.68	0.29-0.65	0.02-0.33	0.064-0.147	0.10-0.15	0.12-0.18	0.12-0.21	0.12-0.23
Potassium	%	1.16-2.42	2.00-3.02	0.77-1.73	0.52-1.10	0.96-1.66	0.61-1.59	2.28-4.14	2.68-4.78
Calcium	%	1.40-2.07	0.98-1.36	0.76-1.63	1.97-3.20	3.05-3.43	0.77-2.00	0.48-1.70	0.40-1.28
Magnesium	%	0.24-0.58	0.63-1.10	0.40-0.65	0.40-0.65	0.40-0.60	0.16-0.42	0.33-0.58	0.14-0.65
Sulphur	%	0.08-0.18	0.09-0.13	0.035-0.131	0.0147-0.215	0.25-0.29	0.16-0.26	0.03-0.18	0.06-0.13
Iron	ppm	38-107	54-80	657-963	48-86	117-194	71-214	53-196	58-189
Manganese	ppm	18-86	42-209	13-408	57-174	21-63	29-89	112-417	142-516
Zinc	ppm	25-94	30-88	7.8-18.3	25-33	25-50	14-72	8-38	14-37
Copper	ppm	10-30	5-10	14.3-17.8	3.10-8.00	8.7-14.8	29-72	10.-32	11-33
Yield Limit	--	40 t/ha	25 t/ha	6 t/ha	10 t/ha	15 t/ha	15 t/ha	30 kg/plant	12 kg/plant

II) Methodology for plant analysis

Processing of plant sample

Washing

The fresh plant samples brought to the laboratory should be immediately washed in order to make them free from dust or any other adhering substances. Samples should be washed under the running tap water. Wash the samples with 0.2% detergent solution to remove waxy / greasy coatings. Subsequently, these samples should be washed with acidified distilled water (1 ml concentrated HCl / Litre) followed by thorough rinsing twice with distilled water. For micronutrient estimation, it is suggested to wash finally with double distilled water.

Drying

After washing, the excess water in the sample may be removed by spreading the plant samples on the blotting paper. The samples should be dried as rapidly as possible in order to reduce the chemical and biological degradation. Sample must be dried in hot air oven at 60-70^0 C. The

material to be dried should be loosely packed for proper drying. Plant samples are to be dried generally for 24 to 36 hours. Plant samples may also be dried in a microwave oven. This procedure is rapid and can dry individual samples to a brittle state in 5 minutes.

Grinding and storage

Grind the samples in an electric stainless steel mill using 0.5 mm sieve. Clean the cup and blades of grinding mill before each sample. Put back the samples in oven and dry again for few hours more for constant weight. Store in well stoppered plastic or glass bottles or paper bags for analysis.

i) Determination of total N in plant and manure extracts

Reagents:

1. Concentrated sulphuric acid ($H_2SO_{4)}$.
2. Catalyst mixture: Mix with 250 g potassium sulphate (K_2SO_4), 50 g cupric sulphate ($CuSO_4$. 5 H_2O) and 5 g metallic selenium powder in the ratio of 50:10:1.
3. 40 % sodium hydroxide (NaOH).
4. 4 % boric acid containing 20 - 25 ml mixed indicator /litre.
5. Mixed indicator: 0.066 g methyl red + 0.099 g bromocresol green dissolve in 100 ml of 95% alcohol.
6. 0.02N sulphuric acid ($H_2SO_{4)}$.

Procedure

(a) Digestion

- Weigh 0.5 g of prepared plant sample or manure sample and transfer it to the digestion tube.
- Add 10 ml of concentrated sulphuric acid and 5 g of catalyst mixture to the sample.
- Load the digestion tubes into the digester and heat the digestion block.
- Switch on the digestion unit and set the initial temperature 100 ^{0}C till frothing is over.
- Then block temperature is raised to 400 ^{0}C. The effective digestion starts only at 360 ^{0}C and beyond 410 ^{0}C.
- The sample turns light green colour or colourless at the end of the digestion process.

(b) Distillation

- After cooling the digestion tube, load the tube in distillation unit. Take 25 ml of 4% boric acid containing mixed indicator in 250 ml conical flask and place it in ammonia receiving tube of the distillation assembly.
- 40 ml NaOH (40%) is automatically added by distillation unit programme.

- The digested sample is heated by passing steam at a steady rate and the liberated ammonia absorbed in 25 ml of 4% boric acid containing mixed indicator solution kept in a 250 ml conical flask.
- With the absorption of ammonia, the pinkish colour turns to green.
- Nearly 150 ml of distillate is collected in about 8 minutes.
- Simultaneously, blank sample (without plant/soil) is to be run.

(c) Titration

- The green colour distillate is to be titrated with 0.02N sulphuric acid and the colour changes to original shade (pinkish colour).
- Note the titer value of blank and sample (ml) and calculate the total nitrogen content present in plant/manure samples.

(d) Calculations

$$\text{Nitrogen content in plant or manure (\%)} = \frac{R\ (\text{sample titer value} - \text{blank titer value}) \times \text{Normality of acid} \times \text{Atomic weight of nitrogen} \times 100}{\text{Sample weight (g)} \times 1000}$$

$$= \frac{R \times 0.1 \times 14 \times 100}{0.5 \times 1000}$$

$$\text{Factor} = R \times 0.28$$

ii) Determination of total P in Plant and manure extracts

Reagents

Ammonium molybdate-ammonium vanadate (in NHO_3) solution: Dissolve 25 g of ammonium molybdate in 400 ml of warm distilled water. Dissolve 1.25 g of ammonium metavanadate in 300 ml of boiling water, cool it, and add 250 ml of con. HNO_3. Cool again at room temperature. Now add ammonium molybdate solution to ammonium metavanadate and dilute to one litre.

Standard P solution: Prepare solution containing 50mg P/Litreby dissolving 0.219 g of dried KH_2PO_4 in water, acidifying with 7 N H_2SO_4 and make up the volume to one litre.

Procedure

Preparation of standard curve: Transfer 0, 1, 2, 3, 4and 5 ml of 50ppm P solution to 50 ml volumetric flasks in order to get 0, 50, 100, 150, 200 and 250 ppm P.

Add 10 ml vanado-molybdate reagent and make up the volume and mix content thoroughly, read absorbance at 420nm.

Sample analysis:

1. Take 5 ml aliquot
2. Add 10 ml vanado-molybdate
3. Make up the volume to 25 ml
4. Take readings after 30 min in 420 nm wavelength

iii) Determination of total K in plant and manure extracts

Total potassium in the acid digest of plant and manure samples can be determined using flame photometer using red filter and calculate the amount of K in the plant sample on the oven dry matter basis.

iv) Determination of total S in Plant and manure extracts

Reagents

1. Gum acacia-acetic acid solution: Dissolve 5 g of chemically pure gum acacia powder in 500 mL of hot water and filtered in hot condition through Whatman No. 42 filter paper. Cool and dilute to one litre with dilute acetic acid.
2. Barium chloride: Pass AR grade $BaCl_2$ salt through 1 mm sieve and store for use
3. Standard stock solution (2000 mg SL^{-1}): Dissolve 1.809 g of oven dried AR grade potassium sulphate per 100 mL.
4. Working standard solution (10 mg S L^{-1}): Measure exactly 2.5mL of the stock solution and dilute to 500 mL.
5. Barium sulphate seed suspension: Dissolve 18 g of AR grade $BaCl_2$ in 44 mL of hot water and add 0.5 mL of the standard stock solution (given above). Heat the contents to boiling and then cool quickly. Add 4 mL of gum acacia-acetic acid solution to it. Prepare a fresh seed suspension for each estimation every day.
6. Dilute nitric acid (approx 25%): Dilute 250mL of AR grade conc. HNO_3 to one litre.
7. Acetic-phosphoric acid: Mix 900 mL of AR grade glacial acetic acid with 300 mL of H_3PO_4 (AR grade).

Procedure

1. Measure 10 mL of the clear filtrate into a 25 mL volumetric flask.
2. Add 2.5 mL of 25% HNO_3 and 2 mL of acetic-phosphoric acid. Dilute to about 22 mL stopper the flask and shake well.
3. Shake the $BaSO_4$ seed suspension and then add 0.5 mL of it and 0.2 g of $BaCl_2$ crystals. Stopper the flask and invert three times and keep.
4. After 10 minutes, invert 10 times and keep. After another 5 minutes, invert 5 times.
5. Allow to stand for 15 minutes and then add 1 mL of gum acacia-acetic acid solution.
6. Make up the volume, invert three times and keep aside for 90 minutes.

7. Invert 10 times and measure the colour intensity at 440 nm (blue filter).
8. Run a blank side by side.

Preparation of standard curve for S

1. Place 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0 mL of the working standard solution (10 mg SL^{-1}) into a series of 25 mL volumetric flasks to obtain 25, 50, 75, 100, 125 and 150 µg S.
2. Proceed to develop turbidity as described above for sample aliquots.
3. Read the colour intensity and prepare the curve by plotting readings against sulphur concentration (in µg in the final volume of 25 mL).

Calculation:

5µg = R
1R = R/5 µg (factor)

$$\text{Total S (\%)} = \frac{\text{Factor x Sample R x 1000 x 100 x 100}}{\text{1000 x 10 x 1}}$$

v) Determination of total Ca, Mg, Fe, Mn, Zn and Cu in Plant and manure extracts

Calcium and Magnesium can be determined in the di-acid digest of plant sample either using AAS or versenate titration. Read for micronutrient content using atomic absorption spectro photometer.

vi) Determination of total B in Plant and manure extracts

Reagents

Azomethine-H reagent: dissolve 0.45 g azomethine-H in 100 ml of 1% L- ascorbic acid solution in polypropylene reagent bottle. Fresh reagent should be prepared weekly and stored in refrigerator.

Buffer solution: Dissolve 250 g of ammonium acetate (NH_4OAC) and 15 g of ethylene diamine tetra acetic acid (EDTA disodium) in 400 ml of distilled water. Slowly add 125 ml of glacial acetic acid and mix.

0.6 M $CaCl_2$ solution: Dissolve 1.47 g of $CaCl_2.2H_2O$ in distilled water and adjust the volume to 1 Litre.

Boron standard solution: Dissolve 0.114 g of boric acid (H_3BO_3) in distilled water and adjust the volume to 1000 ml. Each ml contains 20 µg B. Dilute 10, 20, 30, 40 and 50 ml of the stock solution to 100 ml with distilled water to have solution with B concentration of 2, 4, 6, 8 and 10 µg of B/ml respectively. Include a distilled water sample for the 0.0 µg of B/ml standard solution.

Procedure

1. Transfer 1 ml aliquot of blank, diluted B standard or sample solution into 10 or 15 ml polypropylene tube.
2. Add 2 ml of buffer and mix.
3. Add 2 ml of azomethine-H reagent, mix and after 30 minutes, read absorbance at 420 nm.
4. Refer these readings to that standard curve prepared with 0, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 2.0, 4.0, 6.0, 8.0, 10.0 mg of Boron per litre solutions for converting readings to B concentrations in soil extracts.

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Foliar nutrition in horticultural crops

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Introduction

In order to achieve "Zero hunger," one of the essential Sustainable Development Goals (SDGs) of the UN, is agricultural sustainabilit. An exponentially growing world population raises concerns about sustainable food production, which is made even more challenging by climate change-induced increases in the frequency and severity of heat and drought events. The soil-plant-atmosphere continuum is negatively impacted by the occurrence of such unexpected stresses.

By 2050, it is anticipated that there will be more than 10 billion people on the planet, which means that food production must rise by 50% to feed an additional 2 billion people at the cost of consuming 187 million tons of fertilizer and 4 million tons of pesticides. The net recoverable efficiency of applied nutrients may be decreased by such high resource input farming practices, which could also raise other environmental issues. These requirements encourage resource-efficient and coordinated approaches to address the growing socioeconomic difficulties posed by climate change.

Foliar application of mineral fertilizers has emerged as a necessary agricultural technique for global crop production under current conditions. Any dissolved mineral fertilizer applied directly to plant foliage is referred to as "foliar nutrition." Foliar fertilization receives interest as a rapid, targeted, and eco-friendly solution to increase crop yields in both favorable and adverse growth environments.

Foliar nutrition is a holistic approach that can be used extensively to address micronutrient deficiency and reduce nutritional deficits in agricultural plants throughout important growth phases. It can also be used for biofortification. In order to maximize crop production, produce quality, and minimize environmental concerns—particularly those related to nutrient leaching and volatilization losses—it is also beneficial to eliminate soil barriers for increased fertilizer usage efficiency.

How it works?

Nutrients are applied to the leaves, which have specialized structures like stomata and cuticles that allow for rapid absorption. The absorbed nutrients enter the plant's vascular system and are distributed to where they are needed, promoting growth and development. Foliar feeding can even improve the plant's ability to absorb nutrients from the soil, creating a synergistic effect

Why foliar nutrition is better for micronutrients?

Low quantity needed: Plants require micronutrients in very small quantities, making precise application difficult through soil methods. Foliar spray delivers small, concentrated amounts directly where needed.

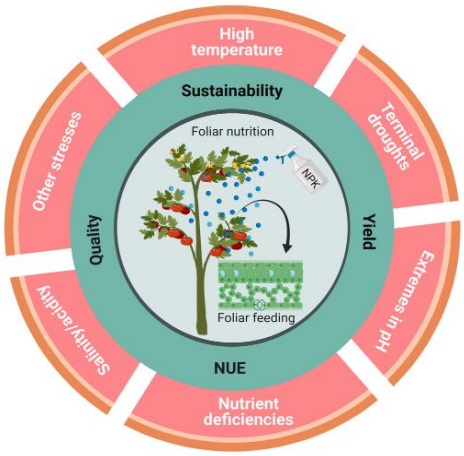

Figure 1. Diagrammatic representation of the role of foliar fertilization plays in bridging gaps in agriculture to attain food and nutrition security

Soil availability issues: Micronutrients are often unavailable in soil, making them hard for roots to absorb. Foliar application bypasses the soil and delivers nutrients to the leaves, where they can be directly absorbed.

Quick correction: Foliar feeding allows for immediate and rapid absorption of nutrients into the plant, providing a faster response to deficiencies compared to slow uptake from the soil.

Improved efficiency: For deficient micronutrients, foliar application is a more effective method to get the nutrient into the plant than soil application, as it requires less time for absorption and assimilation

Why macronutrients are typically soil applied?

Large quantities required: Plants need macronutrients (like Nitrogen, Phosphorus, and Potassium) in much larger amounts for energy and growth. Soil application is more practical for delivering these substantial quantities.

Root absorption: Roots are designed to absorb these larger nutrient quantities from the soil solution.

Lower energy cost: For the plant, absorbing large amounts of macronutrients from the soil is more energy-efficient than absorbing them through the leaves. Conversely, macronutrients are applied to the soil because plants require them in large quantities for growth and energy, and soil application ensures they are available for root absorption

Key benefits of foliar nutrition in horticultural crops

Rapid nutrient uptake: Nutrients are absorbed directly through the leaves, bypassing root absorption and providing a quick response to deficiencies.

Improved crop yield and quality: Foliar application can lead to higher yields, larger fruits, better color, and extended shelf life.

Correction of deficiencies: It's highly effective for correcting widespread micronutrient deficiencies that are difficult to address through soil application.

Enhanced stress tolerance: Plants can better withstand periods of drought or other stresses when receiving foliar nutrition, especially during critical growth stages.

Increased pest and disease resistance: Healthy plants with adequate nutrition are more resistant to pests and diseases.

Efficient nutrient use: Foliar application increases nutrient use efficiency and minimizes losses associated with soil fertilization, such as leaching.

Delivery of other compounds: Besides nutrients, foliar sprays can also deliver plant growth regulators and protestants.

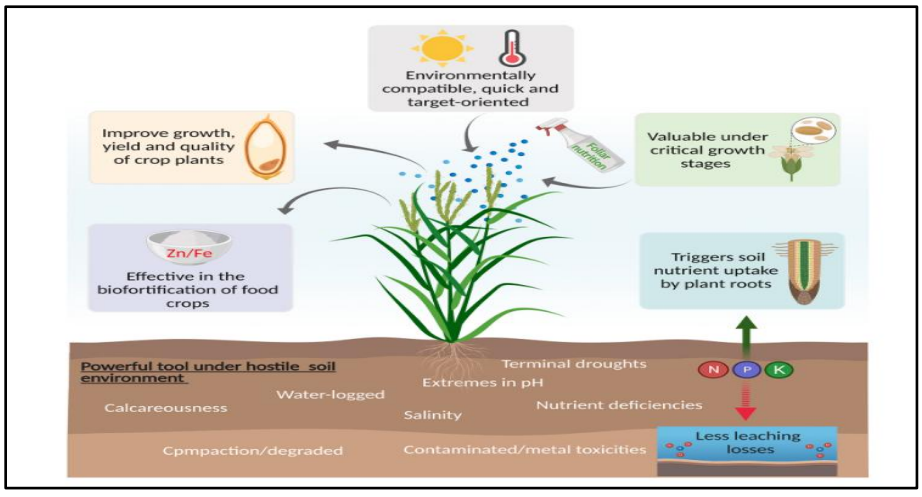

Fig. 2. Potential of applying foliar nutrition in agricultural production

Why it is important for horticultural crops?

Overcoming soil limitations: In many horticultural systems, poor soil structure or nutrient immobilization makes it hard for roots to function effectively. Foliar feeding provides a solution by supplying nutrients directly to the plant.

Meeting high-demand periods: During critical stages like flowering and fruit development, plants have high nutrient demands that foliar sprays can effectively meet.

Improving produce appearance: For horticultural crops, visual quality is as important as yield. Foliar nutrition improves fruit color, size, and overall appearance.

Ecological and economic advantages: By improving nutrient use efficiency and reducing potential nutrient runoff, foliar feeding contributes to more sustainable agricultural practices.

Conditions for application of foliar nutrition

Foliar spraying should be in the early morning and late afternoon because the humidity is higher, and the leaves of plants are in a full turgor condition with their cells full of water.

- Foliar spraying should be avoided during the warm hours of the day; plants can only absorb nutrients in a limited amount at high temperatures.
- Foliar spraying should be applied under minimum wind conditions.
- It should be sprayed at a time of sufficient soil moisture condition when leaves will be turgid and become less water-stressed, so irrigation is better before spraying.
- Spraying should be avoided before rainfall.
- The optimum pH of foliar spray is slightly acidic (5 ± 0.5).
- A suitable wetting agent or surfactant for minimizing the surface tension of the spray droplets should be used, which ultimately maintain the proper distribution of the droplet, increase the wetted surface area, decrease the burning of the leaves as well as improve nutrient uptake by plants.
- It should be ensured that the fertilizer is in a fully soluble condition

When to use foliar nutrition

To correct deficiencies: It's ideal for quickly addressing identified nutrient deficiencies in microelements like zinc, manganese, and boron, as well as macronutrients like magnesium.

During critical growth stages: Applying nutrients at specific times, such as during flowering, fruiting, or the emergence of winter, ensures optimal development and yield.

In adverse soil or environmental conditions: It's particularly useful in soils that limit nutrient availability or during periods of stress, such as drought, cold weather, or calcareous soils.

For specific plant responses: It can be used to induce dormancy breaking in some fruit trees or to stimulate flowering in others.

In conclusion, foliar fertilization emerges as an essential strategy in the farm management of extensive crops. Complementing soil fertilization, this practice offers rapid responses, efficiency in nutrient use and the ability to overcome soil constraints, contributing to healthy and productive crop growth on large areas of farmland. As agriculture seeks more sustainable and efficient methods, foliar fertilization stands as an invaluable tool in the modern farmer kit.

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Diagnosis of nutrient deficiency and toxicity symptoms

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Essential nutrients are classified as primary nutrients, secondary nutrients and micronutrientsbased on their relative abundance in plants. Nitrogen, phosphorus and potassium are primary plant nutrients; calcium, magnesium and sulphur are secondary nutrients; iron manganese, copper, zinc, boron, molybdenum and chlorine aremicronutrients. Micronutrients are required in small concentrations, but they are as important as primary nutrients in plant nutrition.

Identification of nutrient deficiency symptoms is an important management tool in crop production. Location of occurrence of nutrient deficiency symptoms depends on mobility of nutrients in plant. Mobile elements show early deficiency symptoms in older/matured leaves and as deficiency progresses symptoms spread throughout the plant. Deficiency symptoms of immobile elements first appear in upper leaves and young growing regions of plant**.**

Mobile elements: N, P, K, Mg - Early deficiency symptoms appear in lower part of plant

Immobile elements: Ca, S, Fe, Mn, Zn, Cu, B - Deficiency symptoms appear in upper part of plant

Nitrogen deficiency symptoms: The plant becomes lighter colour as a whole. Larger leaves in the lower part of the plant turn light green.Leaves in the lower part of the plant turn more yellow and then become white. Further yellowing and whitening occur in the top and middle parts of the plant. In crops like mango or tomato, there might be some red coloration to the petioles and leaf veins. If the problem persists, lower leaves will drop from the plant.

Phosphorous deficiency symptoms: At first, the leaves become dark green/blueish green. After 2 to 3 weeks, dark purple/black necrotic spots appear on the old and medium-old leaves, making the leaves malformed. Plants remains rather small with purple/black necrotic leaf parts, which later on become malformed and shriveled. In plants exposed to sufficient sun light, purple coloration in older leaves can be observed.

Potassium deficiency symptoms: Tips of the younger leaves show grey edges.Leaves turn yellow from the edge in the direction of the veins and rusty-colored dead spots appear in the leaves. The tips of the leaves curl up radically and whole sections of the leaves begin to rot. An extreme shortage produces meagre, unhealthy-looking plants with strongly reduced flowering. Potassium deficiency lead to improper fruit shape, colour and size, blotchy ripening where fruits fail to produce normal colour in some areas on the fruit.

Calcium deficiency symptoms: Yellow/brown spots occur, which are often surrounded by a sharp brown outlined edge in leaves. Growth is curbed and in serious cases the tops are smaller than normal. Examples of this are tip burn of lettuce and cole crops. Blossom-end rot of tomato also is a calcium-deficiency related disorder. Cells of the tomato fruit deprived of Ca break down causing the well-known dark area on the tomato fruit tips. Sometimes this breakdown can occur just inside the skin so that small darkened hard spots form on the inside of the tomato while the outside appears normal. On other occasions, the lesion on the outside of the fruit is sunken or simply consists of a darkening of tissue around the blossom area.Since Ca movement in the plant is related to transpiration, environmental conditions that affect transpiration also affect Ca movement. Periods of high humidity can lead to tip burn of lettuce because the leaves are not transpiring rapidly enough to move adequate Ca to the leaf extremities. In banana the lower leaf lamina becomes week and the leaves starts drooping one after the other. In mango it may be responsible for spongy tissue and mango malformation, in pomegranate fruit cracking may occur and in citrus leaf curling is common.

Magnesium deficiency symptoms: Small, rusty brown spots and/or yellow flecks appear in the middle-aged leaves between the veins. Interveinal chlorosis occurs at severe deficiency.

Sulphur deficiency symptoms: Earliest symptoms would first appear as a light green colouring and yellowing in the young leaves. Strong purple coloration in the leaf stems. More leaves change colour and the light green colour changes in places to deep yellow. Plants can generally tolerate quite high concentrations of sulphur in the growing media/soil and therefore its deficiency is not very common in horticultural crops. This is also one of the reasons for wide use of sulphur containing materials to supply nutrients such as magnesium and micronutrients.

Iron deficiency symptoms: Chlorosis from inside to the outside in the younger leaves and shoots. The veins remain mostly green. The continued yellowing of the leaves to sometimes almost white. In serious cases the leaves show necrosis, and the plant's growth and flowering are inhibited.

Zinc deficiency symptoms: Yellowing of leaves, often with main leaf veins remain green. Over time yellow spots turn bronze and necrotic spots start developing from leaf margins. Occurrence of shortened internodes and leaves clustered on stem giving resetting appearance.

Boron deficiency symptoms: Stunting and distortion of the growing tip that can lead to tip death, brittle foliage. Flowering and fruiting are reduced and developing fruit is often distorted.

Copper deficiency symptoms: Copper deficiency on young leaves leads to chlorosis and some elongation of the leaves. In most of the cases the leaf twigs bend down giving a succulent appearance and both twig and leaves droop down. Copper is not highly mobile in plants but some amount of copper can be translocated from older to newer leaves. Fruit may crack as is common in pomegranate and tomato. Excess Cu, especially in acidic soil may be toxic to plants.

Manganese deficiency symptoms: Manganese deficiency symptoms exhibit as reddish-brown spots on the leaf lamina, interveinal chlorosis. The chlorosis is more speckled in appearance. Manganese deficiency symptoms slightly resemble iron deficiency. However, manganese deficiency appears as chlorotic speckling over most of the leaf.

Molybdenum deficiency symptoms: Deficiency symptoms of molybdenum first appear on leaves that are intermediate and older in age. The leaves become chlorotic and the margins roll. Unlike other micronutrients, molybdenum deficiency occurs in acidic soil conditions.

Correction of nutrient deficiency symptoms

Deficiencies may occur either because of soil related problems or due to lack of nutrients in the soil. If the deficiencies are due to lack of nutrients then these must be corrected in time to avoid reduced yield and quality. It is best to avoid deficiencies by applying the required nutrients as per the recommendations for the respective crops.

For most macronutrients (N, P, K, Ca, Mg, S), a topdressing of 15 to 20 kg/ha of element (P and K are in oxide form) will correct a deficiency. These deficiencies are more effectively corrected by soil application in the root zone and maintaining sufficient moisture for their solubilisation, movement and uptake by the crops.

Foliar application of the deficient micronutrient can be an effective means of correction if adequate leaf coverage is obtained. Micronutrients can be toxic in large amounts so care must be exercised to apply the recommended rates. For crops with waxy leaves, coverage can be improved by use of a spreader-sticker adjuvant in the spray tank. IIHR has developed crop specific foliar nutrient formulations that supply all secondary and micronutrients in right proportion to the given crops. Currently formulations are available for grapes, mango, pomegranate, papaya, citrus and vegetables.

Nutrient Toxicities

Excessive application of nutrients may be toxic to some plants. Nutrient toxicity occurs when plants absorb more nutrients than they can effectively use or safely store. Soil pH, poor soil drainage, over fertilization or imbalanced fertilizer applications could be the reasons for excessive absorption of some nutrients by the plants. Nutrient toxicity symptoms are usually expressed as marginal or tip chlorosis, necrosis, growth abnormalities like stunted or excessive growth and root damage.

Nitrogen toxicity symptoms: Excessive nitrogen application can result in "luxury consumption" wherein plants keep absorbing nitrogen even when they don't need it. Plants produce lush, dark green foliage and plants become tender and succulent. Excess nitrogen delays flowering and fruit development.

Phosphorus toxicity symptoms: The most important issue with phosphorus toxicity is its interference with micronutrient uptake. High levels of soil phosphorus make it difficult for plants to absorb iron, zinc and manganese resulting in deficiency of these micronutrients.

Iron toxicity: Commonly seen in in acidic soils or growing media where iron becomes highly available. Toxicity symptoms include bronze or reddish-brown spots on leaves, starting with older leaves and progressing to younger ones. In severe cases, entire leaves turn brown and die.

Manganese and copper toxicity symptoms: Manganese toxicity causes similar symptoms to iron toxicity, with brown spots and leaf damage. Copper toxicity is less common but can occur when copper-based fungicides are used excessively or in hydroponic systems with copper components. Micronutrient toxicity symptoms appear similar to that of disease symptoms or other stress factors. Therefore, soil and tissue testing is required for accurate diagnosis.

Managing nutrient toxicities

In container grown plants and hydroponic systems, flushing the system by applying plenty of clean water to leach excess nutrients away from the root zone will reduce nutrient concentrations in the root zone. For field crops, good drainage becomes essential to prevent nutrients from

accumulating in waterlogged soils. Iron and manganese absorption by the plants can be reduced by raising soil pH. Balanced nutrition helps to overcome nutrient antagonisms. Addition of specific nutrients can help counteract the effects of toxic levels of others. For example, addition of Zn in case of phosphorous toxicity and addition of calcium help in alleviating aluminum toxicity.

Microbial inoculants for nutrient management in horticultural crops

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Microbial inoculants are one of the important components of integrated nutrient management, as they are cost effective and renewable source of plant nutrients to supplement the chemical fertilizers for sustainable agriculture production. These are preparations containing living cells or latent cells of efficient strains of microorganisms that help crop plants' uptake of nutrients by their interactions in the rhizosphere when applied through seed or soil. They accelerate certain microbial processes in the soil which augment the extent of availability of nutrients in a form easily assimilated by plants.

Types of Microbial inoculants

Symbiotic N-Fixing microorganisms

Rhizobium

Rhizobium is a soil habitat bacterium, which can able to colonize the legume roots and fixes the atmospheric nitrogen symbiotically. Its application has enhanced the crop yield to an extent of 18-20% with a saving of 20-25% chemical nitrogenous fertilizer. Application of crop specific *Rhizobia* is most important. They have seven genera and highly specific to form nodule in legumes, referred as cross inoculation group.

Asymbiotic N-fixing micro organisms

Azotobacter

It is a free-living nitrogen fixing bacteria, also secrets plant growth promoting substances like IAA, GA for the benefit of plant growth. It is recommended for cereal crops, vegetables, fruit crops, ornamental plants, plantation and commercial crops. Its application helps in saving 20-25% nitrogenous fertilizers and enhancing the yield to an extent of 20-30%. Of the several species of *Azotobacter*, *A. chroococcum* happens to be the dominant inhabitant in arable soils.

Azospirillum

It used in all cereals, grasses, millets, vegetables and ornamental plants. Its application saves 20-25 kg of chemical nitrogen with an increased yield to an extent of 18-20%. This biofertilizer is most suited to paddy and sugarcane. The organism proliferates under both anaerobic and aerobic conditions but it is preferentially micro-aerophilic in the presence or absence of combined nitrogen in the medium. Apart from nitrogen fixation, growth promoting substance production (IAA), disease resistance and drought tolerance are some of the additional benefits due to *Azospirillum* inoculation.

Phosphate solubilizing and mobilizing micro organisms

In soil, P gets fixed and becomes unavailable for absorption by plants. Phosphate solubilizing microorganisms play a major role on the solubilization and uptake of native and applied phosphorous. By its usage an improvement in yield to an extent of 25-30% with a saving of 20-25% P fertilizer. This can be used in all monocots and dicots.

Mycorrhiza

This fungus helps in transportation of available phosphorus and micronutrients like zinc, copper, iron, manganese *etc.,* to crop growth and helps to overcome root borne diseases.

Potassium mobilizing bacteria

The bacteria play a predominant role in potassium nutrient uptake. These can be applied along with *Rhizobium, Azotobacter, Azospirillum* and PSB. It enhances early root development and enhances soil health and fertility. By applying K mobilizers, 15-25% yield can be enhanced. It can reduce the potash application by 50-60%. This can be used in all types of crops.

Biocontrol agents

Trichoderma and *Pseudomonas fluorescns* exert biocontrol against fungal phytopathogens like *Fusarium, Phytopthara, Rhizactonia* and *Sclerotia*. These act as plant growth promoters, wilt controllers and phosphate solubilizers. *Trichoderma* also helps in organic matter decomposition. These can be used in crops like cardamom, banana, groundnut, vegetables, ornamental plants *etc.*

Advantages of using Microbial inoculants

- Biologically fixed nitrogen helps plant growth and the residual nitrogen in soil helpful for the succeeding crops.
- Improvement of soil fertility, nutrient recycling and soil physical properties.
- It helps in better seed germination and induces vigor in the seedlings.
- It helps in the steady growth of the plant system with increased photosynthetic activity, setting more number of flowers and to obtain higher quality yield.
- Microbial inoculants help the plants to overcome biotic and abiotic stresses.
- It is eco-friendly, nonpolluting and usage of chemical fertilizers can be reduced.

ICAR-IIHR Microbial inoculants technologies for Horticultural crops

I. Arka Microbial Consortium

The "Arka Microbial Consortium" (AMC) developed at the institute and released for usage in the year 2011, is an excellent input for sustainable horticultural crop production and sustenance of soil health. In 2008- 09, a survey undertaken by IIHR, Bangalore in major vegetable growing regions of Karnataka, recorded low population levels (2.0 to 14.8 x 10^3 g^{-1} soil) of beneficial microbes in the fields that were surveyed. This indicates the necessity of microbial interventions for raising the beneficial microbial populations in the rhizosphere to threshold levels wherein

they exert beneficial effects and improve the overall soil biological health. At present, most farmers do not apply microbial inoculants due to various reasons such as lack of awareness, lack of a visible effect on crop growth, poor performance of applied inoculants, non-availability of individual inoculants (N fixers, P solubilizers, growth promoters) at the time of application, *etc.* Another major hurdle in bio-inoculant technology is poor quality microbial cultures used for inoculant formulation and the inability of these inoculant strains to compete with the native soil microflora. To overcome these problems, it was always felt that it would be beneficial to formulate a microbial consortium that combined multiple useful strains, in order to harness the synergistic effects amongst the microbial strains used in inoculum production, and sustained itself at threshold levels in the plant rhizosphere in order to exert the beneficial effects of inoculation. Keeping these aspects in view, the Indian Institute of Horticultural Research, Bengaluru, has developed the "Arka Microbial Consortium" for sustainable horticulture production. This product contains N fixing, P & Zn solubilizing, plant growth promoting bacterial strains. This product has been evaluated systematically in the institutional trials and various farmers' fields, and is one of a kind for exclusive use in horticultural crop production.

II. Arka Actino Plus – A Novel Actinobacterial Consortium for Horticultural Crops

Actinobacteria represent a high proportion of the soil microbial biomass and have the capacity to produce a variety of extracellular enzymes, phytohormones, organic acids and antibiotics, which play an important role in plant growth promotion by means of organic waste recycling, mineralization & solubilization of soil nutrients, enhancement of other beneficial microbes and suppression of harmful pathogens *etc*. Many scientific evidences have reported that among the Actinobacteria *Streptomyces* spp are noteworthy as antibiotic producers, phosphate solubilizers, chitinase inducers and growth regulator producers in soil. The *Streptomyces* and other Actinobacteria are major contributors to biological buffering of soils and have roles in organic matter decomposition conducive to crop production. The growth promoting attributes of Actinobacteria have been proved by many researchers, but most of the information is of academic interest only. In our country, bacterial and fungal inoculants packages are available for many crops, but there is no much information on Actinobacterial inoculants. In view of above, efficient P and Zn solubilizing, IAA and GA_3 producing, cellulase and chitinase excreting Actinobacteria were screened from different horticultural crops rhizosphere soils in Karnataka. After characterization and determination of compatibility, an Actinobacterial consortium was prepared by using three efficient compatible *Streptomyces* spp. It is a carrier based microbial product contains P & Zn solubilizing, phytohormone producing, cellulase and chitinase excreting Actinobacterial strains. It can be applied either through seed, seedlings, soil, water (drip irrigation – soil drenching), and compost/FYM/ coco peat enrichment.

The benefits of the Actinobacterial consortium are as follows

- Increased seedling vigour.
- Creating a nutrient rich environment in and around rhizosphere by mineralization.
- Enhances the population of beneficial microbes in soil.

- Suppress deleterious root microbes.
- Revitalizes plant health
- Reduces 25 % of N fertilizer when recommended dosage of organic amendments are applied.
- Reduces 25 % of P fertilizer application
- Enhances the nutrient uptake of plants
- Increases vegetable (tomato, ridge gourd, bottle gourd and bitter gourd, cucumber) yield by 6.0 to 14%.

How to apply the Arka Microbial Consortium/Arka Actino-plus

Seed treatment: 10-20 g of the carrier based inoculant should be mixed with 20 ml rice gruel to make slurry. Vegetable seeds (100-200 g) can be mixed with this slurry. Care should be taken to ensure a uniform coating of the slurry on the seed surface. Treated seeds should be shade dried for 30 minutes and sown within 24 hours.

Cocopeat enrichment: One kg of the Arka Microbial Consortium (AMC)/Arka Actino Plus (ACT) is sufficient to enrich 1 tonne of cocopeat. A suspension of AMC (20g/l)or Arka Actino Plus can be applied with a rose can onto the cocopeat, prior to filling in portrays.

Soil drenching: For transplanted crops, AMC/ACT can be suspended with water @ 20 g/ lit and applied near the root zone on the 10th day after transplantation.

Main field application: For one acre of land, five kg of AMC or 6 Kg ACT can be mixed with 500 kg of FYM and applied near the root zone of a standing crop. Alternatively it can be applied basally during land preparation.

III. Soilless AM Fungal Inoculant Technology

The AM fungal association and their benefits to the plants have been proved by many researchers, but the farmers seldom use this group of microbes in horticultural production mainly unavailability of quality inoculum in the right time and right quantity. The AM fungal inoculum is usually recommended at the rate of 100 g (solid substrate based inoculum) per square meter area. This indicates that the inoculum is required in huge quantities for field application this is a burden for both farmers and entrepreneurs, and hence it has become an impediment in the popularization of this technology. In this context a simple method has been developed by ICAR-IIHR for the production of AM fungal inoculum on Arka Fermented Cocopeat as a substrate. A patent application (3817/CHE/2014) has been filed for this. Traditionally, the inoculum is multiplied on live host plant roots grown on different substrates like sand: soil mixture, vermiculite, perlite, etc., which are bulky materials for handling and transport. Further, propagule count on such media does not meet the standards often. In this context, the technology developed by ICAR-IIHR, provides a method for soilless production of AM fungal inoculum by utilizing sterile Arka Fermented Cocopeat as the sole substrate for host plant growth with the intervention

of a beneficial bacteria (applied at the rate of 0.5 kg per 1000 kg Arka Fermented Cocopeat substrate). This helps in enhancing the host plant root growth, AM fungal colonization and proliferation within the host plant roots, and to derive an inoculums free of any cross contamination. The entire process can be carried out in a time span of 60 days under ambient conditions either under shade or glass house. A count of 0.28 – 0.35 x10^5 Infective propagules / gram of substrate was obtained using this method. The shelf life is upto one year. The fermented cocopeat based AM fungal inoculum can be used as a bio-inoculant for raising vegetables, fruits, ornamental and plantation crops.

IV. Arka Fermented Cocopeat

Coir pith a bye-product of the coir industry is a mass of tiny, brown, irregularly shaped particles that has posed a problem of disposal until its utility as a horticultural growth media was known. It contains less than one percent of any of the major nutrients and thus cannot be used as manure. Besides it has a Carbon: Nitrogen ratio in the range of 80- 100:1 *i.e.,* it contains 80 to 100 parts of carbon for every part of nitrogen, therefore making it difficult to be decomposed and utilized as manure. It is primarily composed of the structural molecule lignin, which comprises nearly 40-50 % percent of its composition and roughly around 10- 12 percent of pentosans. This low pentosan- to-lignin ratio is an indicator of it's of extremely slow decomposability and utilization. Another issue with coir-pith is its extremely high content of tannins and polypolyphenols, which are largely dependent on the age of the material and the extent to which it is weathered by natural elements. These tannins and polyphenols retard a wide range of natural biological processes including decomposition and the germination of seeds sown on raw coir pith. In order to overcome these deficiencies leaching of the raw coir pith with good quality water has been recommended in order to remove the water extractable tannins and polyphenols, thereby making the material amenable for use as a plant growth substrate. This process of conversion using fresh water to reduce the levels of plant growth inhibiting compounds is widely followed commercially. A drawback with this method is that it consumes huge quantities of fresh water besides contributing to environmental degradation by way of disposal of waste water rich in tannins and polyphenols. Arka Fermented Cocopeat is a novel substrate for raising of vegetable seedlings has been developed by the solid state fermentation of the raw coir pith with a tannase producing fungal consortium, in order to reduce the concentration of tannins and polyphenols that are naturally present in coir pith to levels that no longer retard seed germination and plant growth. An unique feature of this product is the enrichment with beneficial microbes that aid and promote plant growth. Some features of this product are

- Reduced production cost and effort
- No need for washing of the raw coir pith, hence environmentally friendly
- Can be done at the nursery itself
- Dispenses the need for pasteurization of the growth media
- Enriched with beneficial microorganisms, *viz.*, N fixers, P soubilizers and plant growth promoters
- Better seed germination and vigorous uniform seedlings
- Seedling raised on this growth media attain early transplantation maturity.

Nutrient management practices for sustainable crops production

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Plants need 17 essential elements for their growth and development. The three elements *viz.*, carbon (C), hydrogen (H), and oxygen (O) are derived from the atmosphere and soil water. The remaining 13 essential elements *viz.*, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl) and (Ni) are obtained/supplied either from native soil or by external inputs (organic or inorganic fertilizers).Nutrients are required in most horticultural crop production systems.Plants require differing amounts of nutrients at differing phases of their growth cycles. The nutrients in soil may not be always available in adequate amounts for economical crop production. Fertiliser nutrients play a major role in meeting the crop yield and quality goals of modern horticulture.Better crop and soil management has resulted in higher crop yields. This, in turn, has increased the need to replace the nutrients removed by the larger crop harvests. Generalized recommendations of fertilisers for different groups of horticultural crops are given in Table1.In general, fertilisers formulated for flowering plants would contain amounts of N less than or equal to the amounts of phosphorus. This is because phosphorus encourages flowering. Excess N may stimulate green leafy growth at the expense of flower production.

Supplying needed nutrients for crop production involves attention to four major fertilization factors (the 4Rs): right rate, right source, right placement, and right timing. Attention to these factors will provide adequate nutrition for crop production while minimizing the risk of loss of nutrients to the environment. The 4Rs (terminology promoted by the International Plant Nutrition Institute [2014]) are important components of nutrient best management practices. Fertiliser best management practices (FBMPs) are agricultural production techniques and practices developed through field researches and verified in farmers' fields to maximize economic, social and environmental benefits. FBMPs are aimed at managing the flow of nutrients in the course of producing affordable and healthy food in a sustainable manner that protect the environment and conserve natural resources at the same time profitable to producers. With FBMPs, farmers implement under specific site, crop and soil conditions, the concepts and elements of balanced fertilization, site-specific nutrient management (SSNM), integrated plant nutrient management (IPNM), among others.

Table 1. Recommended dose of N, P and K for horticultural crops

Crops	Recommended dose of NPK (kg ha^{-1})		
	N	**P_2O_5**	**K_2O**
Fruit Crops			
Banana	620	310	620
Mango	75	20	70

Citrus	110	35	55
Papaya	925	925	925
Guava	250	175	175
Apple	320	320	320
Pineapple	275	70	200
Sapota	100	50	50
Grapes	300	300	600
Pomegranate	500	425	975
Litchi	50	50	25
Vegetable Crops			
Potato	60	100	120
Tomato	180	120	150
Onion	125	75	125
Brinjal	180	150	120
Tapioca	45	90	120
Cabbage	150	125	100
Cauliflower	150	100	100
Okra	100	50	50
Peas	25	75	60
Sweet Potato	20	40	60
Chilli	150	75	75
Plantation Crops			
Coconut	100	55	210
Cashewnut	100	40	60
Arecanut	140	55	200
Cocoa	70	30	100
Spice Crops			
Garlic	40	75	75
Turmeric	150	60	108
Ginger	37.5	50	37.5
Cumin	30	20	20
Coriander	10	40	20
Tamarind	20	15	25
Fenugreek	30	25	40
Fennel	50	10	10
Pepper	110	50	155
Cardamom	75	75	150
Ajwan	40	20	20
Nutmeg	187.5	187.5	600

Source: *IIHR (2010, 2012); Muvel et al. (2015)*

Tree crop nutrition differs from annuals. In perennial fruit crops more than 90% of the absorbed nutrient gets locked-up in the woody part of the tree and current application will not influence the yields of current season. It is because of this yield predictions to applied nutrients is difficult in perennial fruit crops. The deep root systems help them to bring in nutrients from a large

volume of soil. Because the perennial fruit crops can store nutrients in the vegetative part and resume them again and again during later growing seasons, perennials do not need as much fertilisers as annuals. An annual plant's whole life is dedicated to setting as much seed as possible and sacrifices the entire plant at the end of the growing season. Perennial plants like fruit crops goal is to make it to next year and the years beyond and set seeds (fruits) in the years it can. Trees take a long time to respond to fertilisers, with new leaves, flowers and fruit dependent on reserves in the tree rather than on fertiliser applied to the soil. There are key stages in the phenology of every fruit crop that have a greater demand for nutrients than others. Flowering, fruit set (with its associated period of early fruit drop) and fruit drop that occurs when exponential fruit growth and vegetative shoot and root growth are simultaneous are phenological stages of high nutrient demand. It is during these stages that the greatest gains in fruit number and retention, determinants of final yield, can be made. Hence field crops and perennial fruit crops have different goals and different strategies.

Certain recommended fertiliser management practices, such as timing, placement, form of fertiliser, etc., play a vital role in the environmental aspects of a fertiliser recommendation. Fertiliser best management practices must aim at proper timing and placement of fertilisers to coincide with crop requirement to attain high nutrient use efficiency. Applying fertilisers to the soil, or foliage, at key stages of crop phenology when nutrient demand is high is fundamental to fertiliser best management practices because it improves fertiliser use efficiency, is cost effective and protects the environment. Studies conducted at ICAR-IIHR, Bengaluru using radio isotope tagged fertilisers and fertiliser use efficiencies were worked out for different fruit crops on a sandy loam soil. It has been shown that the absorption of nutrient from the fertiliser was quite low (0.51-2.90% for P and 6.8% for N) under some treatments. However, appropriate timing and placement in other treatment invariably improved the absorption which was substantial for P (17.70%) in guava and 60.0% for N in banana. While the scope of applying solid fertilisers is limited to shallow depths (0-5 cm), the use of liquid forms as fertigation through drip irrigation appears promising for deeper application.

Balanced fertilizer

Balanced fertilizer is the application of required plant nutrients in right proportion and in right quantity for a specific soil and crop condition. Continuous imbalanced use of fertilizer led to the deterioration in the soil health and decrease in soil productivity. Integrated plant nutrient supply system could help in meeting the objectives of balanced fertilization. An inadequatenutrition and indiscriminate use of chemicalfertilizers (imbalance use of nutrients), neglectingorganic and bio fertilizers paved the way fordeterioration of soil health and in turn affects crops.In order to maintain soil health and to obtainoptimum yield of better quality horticultural produce, it is essential to adopt integrated nutrient management (INM)approach.Integrated nutrient management involving inorganic fertilizers with organic manures and biofertilizers has greater potential in stabilizing the yields over a period of time.

Site Specific Management

Site-specific nutrient management (SSNM) aims to enable farmers to dynamically adjust their fertiliser use to optimally fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources such as soil, crop residues, organic inputs and irrigation water. The implementation of SSNM can involve using different management of nutrients in different areas of a field or landscape, in different cropping seasons, and in different years in the same area of a field. The SSNM approach does not specifically aim to either reduce or increase fertiliser use. Soil based and canopy based sensors are available and are also in developing stages for different nutrients. These sensors can be used to monitor the nutritional stresses in plants and accordingly corrective steps can be taken to correct these problems. Such approach will enhance the nutrient use efficiency and minimises the environmental pollution in addition to enhancing the productivity and income of the farmers.

Controlled-Release Fertilisers

Several brands of controlled-release fertilisers (CRFs) are available for supplying N. Some vegetables increase in yield when controlled-release fertilisers, such as polymer-coated or sulfur-coated urea are used to supply a portion of the N requirement. Although more expensive, these materials may be useful in reducing fertiliser losses through leaching and possible N loss through ammonia volatilization in high pH soils, in decreasing soluble salt damage, and in supplying adequate fertiliser for long-term crops. Controlled-release potassium fertilisers also have been demonstrated to be beneficial for several vegetables. It is essential to match the nutrient release pattern of the CRFs with the crop's uptake pattern.

Mulching, Drip irrigation and Fertigation

Many vegetable crops, such as tomato, chillies, bhendi, eggplant, watermelon, cucumber, and others are grown on polyethylene-mulched raised beds. This mulched cultural system characteristically includes drip irrigation for providing water and fertiliser to the crops. The mulched system is considered a best management practice as it helps protect losses of fertiliser from leaching by rainfall when the fertiliser is placed beneath the mulch. Mulching and drip irrigation contribute directly to improving fertiliser use by the crop and reduced leaching. Drip irrigation is becoming popular in horticultural crops. Water management and fertiliser management are interconnected. Changes in one programme will influence the efficiency of the other programme. Leaching potential is high for the mobile nutrients such as N and K; therefore, over irrigation can result in movement of these nutrients out of the root zone. This could result in groundwater pollution in the case of N. The aim of water management is to keep the irrigation water and the fertiliser in the root zone.

With the changing pattern in irrigation system fertiliser use pattern is also changing and fertigation(applying nutrients through the irrigation) has started gaining importance for horticultural crops. For fertigation, completely water soluble sources of nutrients are in demand. Fertilisers should be applied in synchrony with crop demand in smaller quantities during the growing season. Application of fertilisers to horticultural crops through drip irrigation has the

greatest potential for the efficient use of water and fertilisers. Fertigation allows precise timing and uniform distribution of applied nutrients to meet the crop nutrient demand with ensures substantial saving in fertiliser usage. The limited area of wetting under this method reduces the active root zone and also the foraging area of plants to draw water and nutrients from the soil. Fertigation has several advantages such as higher use efficiency of water and fertiliser, minimum losses of nutrients through leaching, supplying nutrients directly to root zone in available forms, control of nutrient concentration in soil solution and saving in application cost. Application strategies can vary the timing, placement, andquantity of fertiliser to be applied.

ICAR-IIHR's Technological advances in best management practices and good agricultural practices

The ICAR-Indian Institute of Horticultural Research (ICAR-IIHR) has made significant strides in developing innovative technologies that promote Best Management Practices (BMP) and Good Agricultural Practices (GAP) for horticultural crop production. These efforts include the development of Arka products such as crop-specific micronutrient formulations and microbial intervention products. These products aim to enhance soil health, boost crop productivity, and support sustainable farming practices. Notable technologies include crop-specific micronutrient formulations for fruits like mango, banana, grapes, citrus, and vegetables, as well as microbial consortiums like the Arka Microbial Consortium and ArkaActinobacterial Consortium.

Crop-specific micronutrient formulations

The nutrient requirements of horticultural crops are distinct and depend on factors like crop physiology, growth stages, and soil characteristics. Micronutrient demands vary significantly across different crops and regions. For instance, tomatoes need micronutrient supplementation during early fruiting stages, while mangoes require nutrients during the new flush and pre-flowering stages. Similarly, bananas require consistent micronutrient supply throughout their growing period. To address these specific needs, IIHR has developed tailored micronutrient formulations for crops such as mango, banana, grapes, citrus, and vegetables. These formulations are commercially available and have been licensed to private companies and KrishiVigyanKendras (KVKs).

Arka Microbial Consortium (AMC)

The overuse of chemical fertilizers and pesticides, coupled with poor soil management practices, has degraded soil health, affecting its physical, chemical, and biological properties. In response to this challenge, ICAR-IIHR developed the AMC, a product that promotes sustainable vegetable production by enhancing the microbial health of the soil. The consortium contains a mix of nitrogen-fixing, phosphorus and zinc-solubilizing bacteria, and plant growth-promoting microorganisms. The technology uses synergistic effects among microbial strains to optimize soil conditions and improve plantgrowth. This product has beentested in various institutional trials and farmers' fields, yielding an average increase in vegetable yields by 10-17%, along with a reduction in the use of synthetic fertilizers by 25%.

ArkaActinobacterial Consortium – ArkaActino-Plus (ACT)

Actinobacteria, particularly strains like *Streptomyces spp*.**,** play a crucial role in promoting plant growth through organic waste recycling, mineralization of nutrients, and suppression of harmful pathogens. However, actinobacterial inoculants have not been widely used in India. ICAR-IIHR has developed an actinobacterial consortium consisting of three *Streptomyces* strains that have been tested for their compatibility and efficiency. This consortium enhances seedling vigor, improves nutrient uptake, and suppresses deleterious root microbes. It has been shown to reduce the application of nitrogen and phosphorus fertilizers by 25%, while increasing vegetable yields by 6-14%. In fruit crops like pomegranate and guava, it has been effective in controlling wilt disease, demonstrating the broader benefits of microbial interventions.

Arka Fermented Cocopeat

Coirpith, a by-product of the coir industry, has long been a challenge for disposal due to its slow decomposition and the presence of growth-inhibiting compounds like tannins and polyphenols. To overcome this issue, ICAR-IIHR developed Arka Fermented Cocopeat, a novel substrate for raising vegetable seedlings. The process involves fermenting coirpith with a fungal consortium that breaks down tannins and polyphenols, improving the material's suitability for plant growth. This substrate is enriched with beneficial microbes such as nitrogen-fixers and phosphorus-solubilizers, enhancing seedling growth, uniformity, and early transplant maturity. Unlike traditional methods, this process eliminates the need for washing raw coirpith, making it more environmentally friendly and cost-effective.

A**rbuscularMycorrhizal (AM) fungal inoculant technology**

ArbuscularMycorrhizal (AM) fungi are essential for improving nutrient uptake and plant health. ICAR-IIHR has developed an innovative AM fungal inoculum production technology using fermented cocopeat as the substrate. This method allows for the mass production of AM fungal propagules, which are necessary for creating mycorrhizal-colonized seedlings. This technology significantly increases the number of infective propagules compared to traditional methods and is free from cross-contamination. The process is completed in 45-60 days, and the inoculum can be applied to a variety of crops, including vegetables, fruits, and ornamentals. This approach is essential for ensuring the successful establishment of horticultural crops and promoting sustainable farming practices.

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Soil physical constraints and their management in horticultural crops

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Introduction

Soil constraints are among the most important factors limiting crop productivity and are responsible for significant yield reductions in horticultural systems worldwide. A soil constraint refers to any inherent or induced soil property that restricts plant growth and reduces the efficiency of resource use. These constraints may be physical (such as surface sealing, crusting, compaction, hard pans, poor aeration, waterlogging, shallow depth, or low water-holding capacity), chemical(acidity, salinity, sodicity, nutrient imbalances), or biological (soil-borne pathogens, reduced microbial diversity, nematode infestation).

In horticultural crops, physical soil constraints are particularly critical**,** as they directly affect root establishment, water and nutrient uptake, and overall plant vigor. Compaction and hard pans restrict root penetration in fruit orchards; waterlogging in poorly drained soils leads to root asphyxiation and disease incidence in crops like banana and papaya; sandy soils with low water-holding capacity limit productivity of vegetables and spices; while erosion-prone hill soils reduce effective rooting depth and degrade the growing environment for perennial crops like apple and citrus.

These constraints often occur simultaneously and vary both spatially across landscapes and vertically within soil profiles. Their management is therefore complex and site-specific. Broadly, management strategies can be categorized into three approaches:

1. **Amelioration** – removal or reduction of the constraint through interventions such as subsoiling, deep ploughing, incorporation of organic matter, gypsum application, or drainage installation.
2. **Agronomic management**– adapting cropping practices to minimize the impact of constraints, such as raised-bed planting, mulching, micro-irrigation, and cover cropping.
3. **Land use change** – shifting to more suitable crops, rootstocks, or production systems when other interventions are not feasible or economical.

Addressing soil physical constraints is therefore essential for improving soil health, crop productivity, and sustainability of horticultural production systems.

Amelioration

Amelioration involves the use of some management input to correct or improve a constraint. Common examples include the application of lime to treat soil acidification, gypsum to treat soil sodicity, fertiliser to treat nutrient deficiencies, and cultivation to treat compaction.

Where a soil is affected by multiple constraints, these must all be ameliorated before maximum yield can be achieved. In these situations, a combination of amendments can sometimes be more effective than singular applications. This typically occurs when different amendments improve different aspects of problem soil behaviour, and/or when one amendment increases the effectiveness of another.

Agronomic management

Agronomic management refers to the manipulation of farming practices to help crops grow better despite the presence of a soil constraint. This can be used either in conjunction with amelioration, or as an alternative option where amelioration is uneconomic or likely to take an extended time.

- The identification and use of plant species/cultivars that are best suited to growth in a particular soil given its constraint characteristics; and
- The manipulation of cultural practices such as sowing times, row spacings, seeding densities and tillage management to best manage constraints.

Land use change

In some instances, soil constraints may be so severe or difficult to manage that sustaining crop production using either amelioration or agronomic management is not logistically or economically feasible. Under these circumstances a move to an alternative land use may be the most appropriate management option.

Soil physical constraints causes

Soil physical constraints in horticultural crops arise mainly due to intensive tillage, continuous monocropping, and heavy machinery use, which result in soil compaction and hardpan formation. Poor irrigation practices often create waterlogging in clay soils or excessive drying and cracking in light soils. Low organic matter content leads to poor aggregation, crusting, and reduced water-holding capacity, while erosion in hill regions makes soils shallow and unsuitable for deep-rooted fruit crops. In addition, inherent soil properties such as sandy soils with low retention capacity or clay soils with poor drainage further limit plant growth. If these constraints are not managed, they restrict root development, reduce nutrient and water availability, and ultimately lower productivity and quality of fruits and vegetables.

However, effective management of these physical limitations offers several advantages. Practices like adding organic amendments, sub-soiling, mulching, raised-bed planting, and improving drainage not only enhance root penetration and soil aeration but also increase water and nutrient use efficiency. These interventions reduce erosion and degradation, improve microbial activity, and create a favorable environment for crop establishment. As a result, yields and produce quality improve significantly, and the long-term sustainability of horticultural systems is ensured.

Physical problems

An optimum physical environment of soils is essential for better growth of plants, consequently for better yields. Based on soils physical properties viz., infiltration, bulk density, hydraulic conductivity, porosity (capillary and non capillary, aggregates etc. soil physical constraints are identified as below.

1. Slow permeable soils
2. Excessively permeable soils
3. Subsoil hardening
4. Surface crusting
5. Shallow soils

Slow permeable soils

Slow preamble soils are those having infiltration rates less than 6 cm/day due to high clay content of the soil. Due to low infiltration rates, the amount of water entering the soil profile is reduced thus increasing the run-off. Further, it encourages erosion of surface soil leading to nutrient removal in the running water. More ever, due to heavy clay content, the capillary porosity is relatively high resulting in impeded drainage and reduced soil conditions. This results in increase of some soil elements to the level of toxicity to the plants. It also induced nutrient fixation in the clay complex thereby making the nutrient becoming unavailable to the crop, eventually causing deficiency of nutrients.

Management

The constraints in such soils can be managed by adopting suitable practices like

1.Provision of drainage facilities either through open or closed sub surface drains.
2. Forming contour and compartmental bunding to increase the infiltration rates of soils.
3. Application of huge quantities of river sand or red soils of coarser texture to dilute heaviness of the soil.
4. Application of liberal doses of organic manures like Farm Yard Manure, Compost, Green manure, Composted coir pith, sewage waste, press mud etc.
5. Adopting ridges and furrows, raised beds, broad bed and furrow systems.
6. Application of soil conditioners like H-concentrate, Vermiculite, Jalasakti etc. to reduce run-off and soil erosion.

Excessively Permeable Soils

Excessively permeable soils are those having high amount of sand exceeding 70 percent. Due to this, the soils are inert and unable to retain nutrient and water. These soils being devoid of finer particles and organic matter, the aggregates are weakly formed, the non-capillary pores dominating with very poor soil structure. Due to low retaining capacity of the soils, the fertilizer nutrients are also lost in the drainage water.

Management

The excessively preamble soils can be managed by adopting the techniques given below.

1. Compacting the field with 400 kg stone roller (tar drum filled with 400 kg of sand or stones can also be used) 8-10 times at optimum moisture conditions.
2. Application of clay soil up to a level 100 t ha^{-1} based on the severity of the problem and availability of clay materials.
3. Application of organic materials like farm yard manure, compost, press mud, sugar factory slurry, composted coir pith, sewage sludge etc.
4. Providing asphalt sheet, polythene sheets etc. below the soil surface to reduce the infiltration rate.
5. Crop rotation with green manure crops like sunnhemp, sesbania, dhaincha, kolinchi etc.

Sub soil hardening /hard pan

The sub soil hard pan in red soils in due to illuviation of clay to the sub soil horizon coupled with cementing action of oxides of Fe, Al and Calcium carbonate, which increases the soils bulk density to more than 1.8 g cm^{-3}. Further, the hard pan can also develop due to continuous cultivation of crops using heavy develop due to continues cultivation of crops using heavy implements up to certain depth constantly. Besides, the higher exchangeable sodium content in black soils areas also result in compactness. All put together lowered the infiltration and percolation rates, nutrient movement and free air transport within the soils profile. It prevents root proliferation and limits the volume of soils available for nutrients uptake resulting in depleted, less fertile surface soil. Due to this, the contribution of sub soil fertility to crop growth is hampered.

Management

These soils are managed by adopting following practices

1. Ploughing the soil with chisel plough at 0.5m interval criss cross at 0.5m depth once in 2-3 years.
2. Application of organics to improve the aggregation and soil structure so as to prevent further movement of clay to the lower layers.
3. Deep ploughing of the field during summer season to open up the sub soils.
4. Cultivating deep rooted crops like tapioca, cotton so as to encourage natural breaking of the hard pan.
5. Raising deep rooted semi perennial crops like Mulberry, Jasmine, Match wood tree etc. can also help in opening up the sub surface hard pan.

Surface crusting

Surface crusting is due to presence of colloidal oxides of iron and Aluminium in Alfisols which binds the soil particles under wet regimes. On drying it forms a hard mass on the surface.

The ill effects of surface crusting are

1. Prevents germination of seeds
2. Retards/inhibits root growth.
3. Results in poor infiltration.
4. Accelerates surface run off
5. Creates poor aeration in the rhizosphere
6. Affects nodules formation in leguminous crops

Management

Surface crushing can be managed as below

1. When the soil is at optimum moisture regime, ploughing is to be given.
2. Lime at 2 t ha-1 may be uniformly spread and another ploughing given for blending of amendment with the surface soil.
3. Farm yard manure at 10 t ha-1 or composted coir pith at 12.5 t ha-1 or other organics may be applied to improve the physical properties of the soils, after preparation of land to optimum tilth.
4. Scraping surface soil by tooth harrow will be useful.
5. Bold grained seeds may be used for sowing on the crusted soils.
6. More number of seeds/trill may be adopted for small seeded crops.
7. Sprinkling water at periodical intervals may be done whenever possible.
8. Resistant crops like cowpea can be grown

Shallow soils

The shallow soils are characterized by the presence of the parent root immediately below the soil surface at about 15-20 cm depth. This restricts the root elongation and spreading. Hence, the crops grown in these soils necessarily are shallow noted crops, which can exhaust the soil within 2-3 seasons. Therefore, frequent renewal of soil fertility is a must in these soils. These soils can be managed by growing crops which can withstand the hard rooky sub soils like mango, ber, fig, country, goose berry, west, Indian cherry, Anona, Cashew, and Tamarind etc.

Management Options for Improving Soil Physical Environment

It is estimated that out of the 328 m ha of the total geographical area in India, 173.65 m ha are degraded, producing less than 20% of its potential capacity (GOI, 1990) and out of this 89.52 m ha suffers from one or the other form of physical constraints viz., shallow depth, soil hardening, slow and high permeability, sub-surface compacted layer, surface crusting, temporary water logging etc. (Painuli and Yadav, 1998). Soil physical environment can be improved by following site specific technologies for optimal use of manures, crop residues, fertilizers, water, tillage practices and following appropriate cropping systems.

1. Improving Soil Physical Environment through Optimal Use of Manures and Fertilizers

Application of organic manures viz., compost, farmyard manure and green manure improve soil physical properties through improvement of soil organic matter. The increased plant biomass

produced by fertilizer, results in increased return of organic material to soil in the form of decaying roots, litter and crop residues. Thus mineral fertilizers indirectly influence soil organic matter content by increasing crop productivity and thereby increasing the amount of organic matter returned to soil in various crop residues.

Structure and aggregation

Soil aggregation is the process by which aggregates of different sizes are joined and held together by different organic and inorganic binding agents. In surface soils, organic matter is the main binding agent responsible for the water stability of soil aggregates with the formation of clay humus complex.

Bulk density and porosity

Long term application of organic manures normally reduces the bulk density of the soil due to higher organic matter content of the soil, better aggregation and a consequent increase in volume of pores, soil aeration and increased root growth. Furthermore, addition of large quantity of organic manure or wastes reduces the bulk density of the soil due to a dilution effect caused by mixing of the added organic material with the denser mineral fraction of the soil.

Water retention properties

Water retention by soils is known to be controlled primarily by: (i) the number of pores and pore-size distribution of soils; and (ii) the specific surface area of soils. Because of increased aggregation with application of organic manures, total pore space is increased. Furthermore, as a result of decreased bulk density, the pore-size distribution is altered and the relative number of small pores increases, especially for coarse textured soils. Organic manure application improves water retention properties of soil through its effect on pore size distribution and soil structure and increases soilwater retention more at lower suctions due to increase in micro-pores and inter-aggregate pores caused by enhanced soil organic matter content and higher activity of soil fauna e.g. earthworms and termites. At higher tensions close to the wilting point (1.5 MPa) nearly all pores are filled with air and the surface area and the thickness of water films on soil particle surfaces determine moisture retention. Following the addition of organic matter, specific surface area increases resulting in increased water holding capacity at higher tensions.

Water transmission properties

Application of organic manure also indirectly influences the water transmission properties of the soil through aggregation and porosity. As good structural conditions are usually associated with adequate water transmission properties, it can be inferred as a thumb rule that organic manure will generally also improve the water transmission properties.

Hydraulic conductivity

Addition of organic manure and mineral fertilizer results better aggregation, increase in effective pore volume and an increase in continuity of pores due to enhanced root growth and formation of

biopores, increased faunal activity and earthworm population and burrows. As soil permeability is a function of effective pore volume, increased pore volume has a direct influence on the saturated hydraulic conductivity of the soil.

Infiltration

Infiltration through the soil surface depends on soil surface features and the hydraulic conductivity in the underlying soil mass. The application of organic manures generally improves the initial and steady state infiltration rate due to increase in water stability of soil aggregates, reduction in crust formation and consequent increase in hydraulic conductivity.

2. Improving Soil Physical Environment through Optimal Use of Tillage Practices

Tillage practices change the initial state of soil to a new state, with changes in the physical, chemical and biological environment of soil. These in turn, influence crop growth and yield and thereby, the input use efficiency of crops. Tillage either loosens or compacts the soil and changes its volume and mass relationship. One property of soil that is likely to get changed by tillage is bulk density of soil (Cassel, 1982). A decrease in bulk density increases the total porosity and the proportion of macropores. The changes in total porosity, pore size distribution and particle-toparticle contact affect all (physical) state variables of soil, which in turn, induce behavioural changes in soil properties and processes, modifying the edaphic environment. Thus, all physical parameters affecting seedling emergence and root growth, i.e. soil wetness, aeration, temperature and penetration resistance are affected by the tillage (Gajri *et al*., 1994).

Bulk density, porosity, aggregation and mechanical impedances

Loosening of soil decreases and its compaction increases the bulk density. The deep tillage in a sandy soil decreased the bulk density of tilled zone than what is achieved by conventional tillage (Gajri *et al*., 1994). No tillage generally increases the bulk density of soil in the surface layer. Conventional tillage significantly reduces macro-aggregates with a significant redistribution of aggregates into micro-aggregates. Thus conventional tillage leads to the formation of carbon depleted micro-aggregates at the cost of carbon rich macro-aggregates. Increased macro-aggregate turnover under conventional tillage is the primary mechanism for loss of soil organic carbon. Conservation tillage usually increases the soil strength in the surface layers. Loosening of soil by tillage also decreases cohesiveness and particle-to-particle contact and hence reduces soil strength in the tilled layer.

3. Improving Soil Physical Environment through Optimal Use of Mulching Practices

Mulch means a layer of dissimilar material separating the soil surface from the atmosphere and mulching is the artificial application of mulch, practiced to obtain beneficial changes in soil physical environment. Mulching improves physical conditions, chemical environment and biological activities of soil. Favourable modification of the soil hydrothermal regime, improvement of soil aggregation and retardation of erosion and soil loss, improve the physical condition of soil under mulch.

Soil moisture regime

Mulching favorably influences the soil moisture regime by controlling evaporation from soil surface, improving infiltration and soil moisture retention and facilitating condensation of water at night due to temperature reversals.

Controlling evaporation from soil surface

Water saving under mulching is prominent if rains are frequent. However, under extended length of dry spell mulch may keep the soil surface moist for longer period and prolong the first stage of evaporation without net saving of water.

Improving infiltration rate

Mulching with organic materials improves the infiltration rate because it serves as a barrier for runoff, which allows more opportunity time for water to infiltrate into the profile. Secondly, mulch intercepts the rainwater and protects the soil from erosion under the impacts of rain drops. It prevents the crust formation due to clogging of soil pores, which increases infiltration rate. Furthermore, organic mulches improve the macro porosity and stability of the structural aggregates of soil and thereby improve the water transmission properties, which facilitate better infiltration and recharge of the soil profile

Soil moisture retention

Mulching improves moisture retention properties of soil through its effect on pore size distribution and soil structure. Higher mulch rate increases soil water retention more at lower suctions (Lal, 1987) due to increase in macro-pores and inter-aggregate pores caused by enhanced soil organic matter content and higher activity of soil fauna e.g. earthworms and termites in mulched plots.

Water condensation at night

Stone and gravel mulches induce lateral movement of heat and vapour, which could in turn collect water under the stones due to condensation of vapor at night, in amounts sufficient enough to serve as the source of water for some species of desert plants and soil fauna.

Controlling runoff and soil erosion:

Mulching invariably decreases soil erosion and often reduces runoff rate and its amount. Mulch cover protects the soil from raindrop impact and surface sealing, increases the infiltration rate and decreases run-off velocity through physical resistance to water flow. In general, loss in water through runoff decreases exponentially with increase in mulch rate.

Modification of soil thermal regime

Mulch has a moderating influence on the soil thermal regime and the effect varies among the soils, climate, kind of mulch materials used and rate of application. It increases soil temperature during cooler weather and decreases it during hot spells. In general, mulch has a damping effect on the amplitude of the diurnal fluctuations in soil temperature. Organic mulching enhances the soil temperature at night and early morning hours but it decreases the daytime temperature as compared to un-mulched plots.

Soil aeration

Crop residue mulch improves soil aeration by promoting free exchange of gases between the soil and the atmosphere. This is facilitated by improvement of structural stability, total porosity and macroporosity, decrease of surface crusting and by improving the overall soil drainage. Oxygen diffusion rate is higher under mulch than under un-mulched condition. The gaseous composition of soil air under mulch depends on the nature of the mulch material (C:N ratio), its rate of decomposition, the soil moisture regime and the climatic condition. Plastic mulch is practically impervious to carbon dioxide (CO_2), a gas that is of prime importance for photosynthesis. Very high levels of CO_2 build up takes place under the plastic, as the film does not allow it to escape. It has to come through the holes made in the plastic for the plants and a "chimney effect" is created, resulting in localized concentrations of abundant CO_2 for the actively growing leaves that accelerate the growth of the crop.

Soil structural improvement

Mulching improves soil structural properties directly and indirectly by promoting the biological activity. Organic mulching improves the total porosity, macro porosity and mean weight diameter of water stable aggregates, because of addition of organic matter upon decomposition by soil microorganisms. The mean weight diameter of water stable aggregates increases with increase in the mulch rate

Case studies of physical constraint and management in horticultural crops

Dung et al (2022) studied in Pommelo orchard (Fig.1), with the treatments are no cover crop (control), non legume (*Commelina communis* L.) cover crop (NLC), legume cover crop (LCC), and rice straw (*Oryza sativa* L.) mulching (RSM) and found that, cover cropping with pinto peanut and rice straw mulch reduced BD at depths of 0–10 cm and 10–20 cm, ~0.10 g cm^{-3} and ~0.08 g cm^{-3} in a 3-year consecutive trial, respectively (Fig.1).Similarly (Fig. 2), in soil porosity at two depths was reported that, 0–10 cm and 10–20 cm (Fig. 2). Like BD, non-legume or legume cover crops and RSM did not improve in deeper soil layers (20–30 cm and 30–40 cm). The use of conservation practices (LCC and RSM) enhanced soil porosity by ~5% and ~3% at 0–10 and 10–20 cm, after 3 years of experiments, respectively. In the depths of 20–30 and 30–40 cm, there was no significant difference between soil conservation measures compared to no conservation

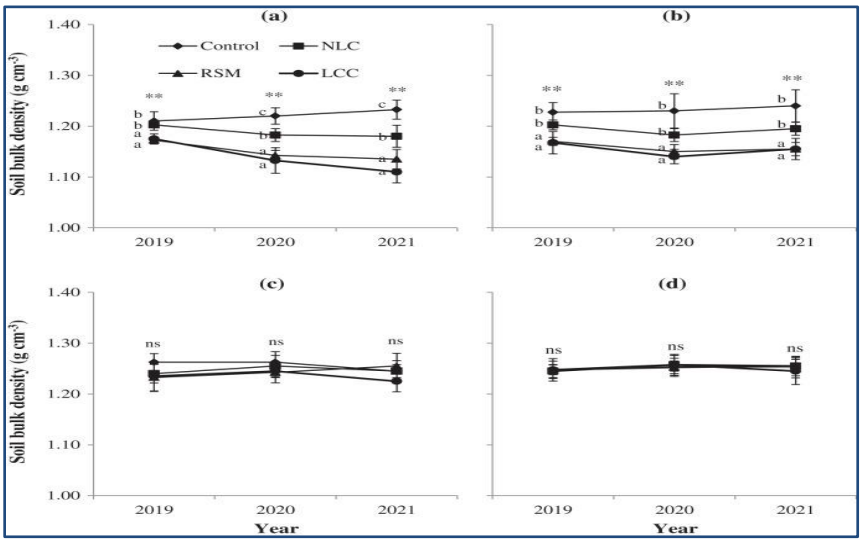

Fig 1. Effect of cropping methods on soil bulkdensity

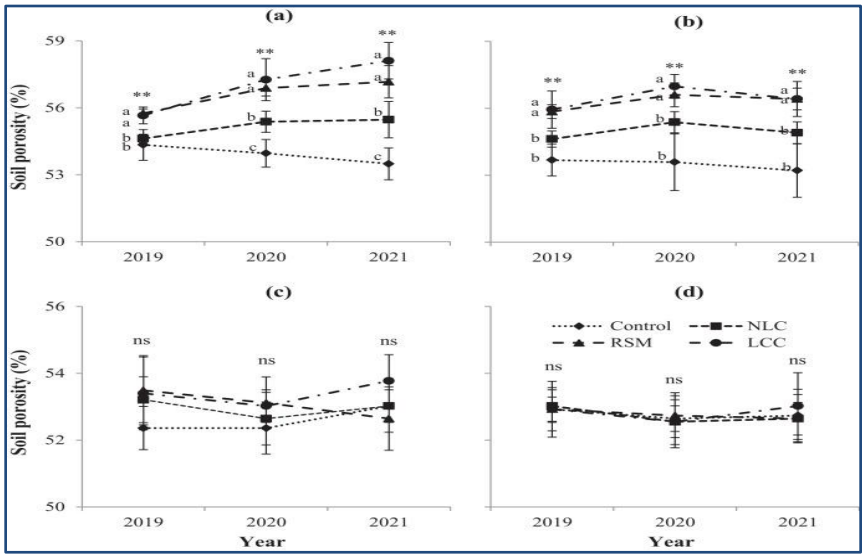

Fig 2. Effect of cropping methods on soil porosity

Table 1. Effect of land use system on MWHC and pore space

Horticultural land use system	MWHC (%)		Pore space (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Mango orchard	41.25	40.15	48.56	47.25
Cashew orchard	40.58	39.56	49.25	47.96
Rose block	37.56	36.44	43.52	43.00
Vegetable block	36.54	36.00	43.15	42.86
Medicine and aromatic block	33.45	35.41	42.95	41.33
SEm±	1.89	1.42	2.08	2.13
CD at 5%	5.14	4.45	6.11	6.43

Bhavya et al., (2017) studied MWHC and pore space in different orchard and reported that, the moisture retention capacity of the soil is directly related to the total porosity and indirectly related to the bulk density (Table1). Further, continuous addition of organic matter under perennials crops helps in maintaining the soil structure, soil texture (sand, silt and clay) and reduces the soil crust formation thus increases the micro pores and macro pores in soil which helps to increase the moisture retention capacity of the soil in surface layers.

Table 2. Effect of conservation practices in horticultural crops on bulk density

Soil depth (cm)	Soil bulk density (g/m^{-3}))					
	CCVF	CCIM	WCIM	CHP		
				CHPM (Mucuna)	CHPSP (Sweet potato)	CHPC (Cow peas)
0-5	1.32a	1.30a	1.19b	1.03c	1.16b	1.07c
5-10	1.47a	1.38b	1.29c	1.17d	1.22c	1.17d
10-15	1.52a	1.49a	1.48a	1.39b	1.44a	1.38b
15-30	1.53a	1.51a	1.50a	1.50a	1.51a	1.50a

Note*: Letters following similar alphabets within a row are non-significant.

Ganeshamurthy et al., (2016) studied different conservation practices like (Table2 and Fig.3), clean vegetable, clean intensive, weed with intensive and conservation horticultural practices with mucuna, sweet pea and cow pea and found that conservation practices with mucuna applied field was recorded lowest bulk density than the other conservation practices. Similarly, in infiltration rate was also affected by application of mucuna in the horticultural orchard.

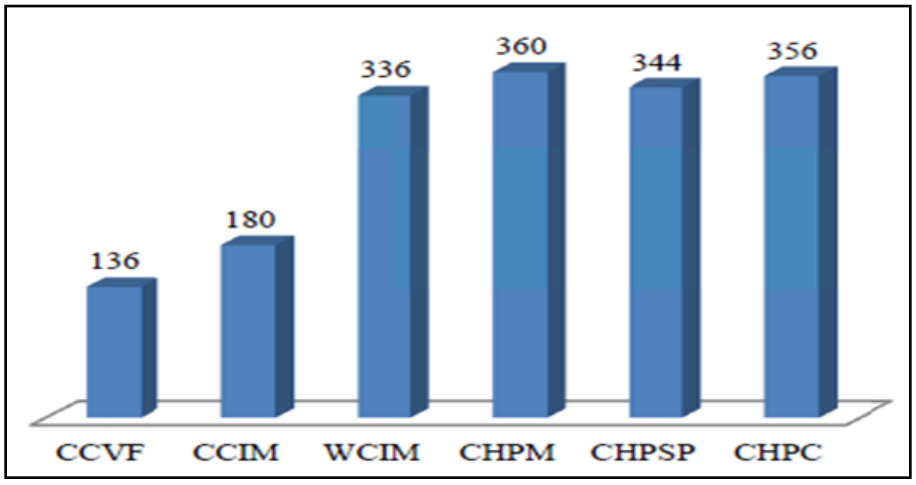

Fig.3. Effect of conservation practices in horticultural crops on infiltration rate

Mohammad et al, (2021) reported that, application of residue mulching has significantly improved the bulk density than the plastic mulching (Table 3). The use of biochar has been shown to reduce soil compaction by more than 10% (Peake *et al*.2014). Using 1% compost with

4% biochar resulted in a 16%reduction in bulk density and an 8% increase in porosity. Increased use of biochar (6%) and compost(1%) reduced bulk density and further increased porosity to 16% and 22%, respectively (Jien *et al*., 2021). A review of studies on 22 different soils showed that biochar addition reduced soil bulk density by 3–11% (average 12%) and increased porosity by 1–64% (Blanco-Canqui., 2017)

Table 3. Effect of mulching on soil physical properties

Soil parameters mulch	At planting	Plastic mulch (pm)	After planting (Residues)	No (Nm)
% sand	89.3	87.4	85.3	87.6
% Silt	3.4	4.3	3.9	4.1
% Clay	7.3	8.3	10.8	8.3
Texture sand	Loamy sand	Loamy sand	Loamy sand	Loam
Bulk density (g/m^{-3})	1.43	1.38	1.32	1.40
Soil temperature 10cm (depth)	28.2	37.4	32.7	30.1
Soil moisture (%)	25.33	32.66	30.77	29.14

Conclusions

Thus this eco-friendly site specific technologies viz., efficient use of organic manures and fertilizers, optimum tillage practices and mulching can improve the soil physical environment, which in turn will lead to efficient use of inputs and help in sustaining horticulture production at higher level.

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Assessment of soil for physical parameters

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Soil physical properties

Physical properties (mechanical behaviour) of a soil greatly influence its use and behaviour towards plant growth. The plant support, root penetration, drainage, aeration, retention of moisture, and plant nutrients are linked with the physical condition of the soil. Physical properties also influence the chemical and biological behaviour of soil. The physical properties of a soil depend on the amount, size, shape, arrangement and mineral composition of its particles. These properties also depend on organic matter content and pore spaces.

Important physical properties

1. Soil texture,
2. Soil structure
3. Soil colour
4. Soil consistence
5. Soil density
6. Soil water content
7. Soil temperature
8. Soil aeration.

1. Soil texture

Determination of particle size distribution

Definition

Soil texture refers to the relative proportion of particles or it is the relative percentage by weight of the three soil separates viz., sand, silt and clay or simply refers to the size of soil particles.

Table 1. Soil texture by USDA classification

Soil separates	Diameter (mm)
Clay	< 0.002 mm
Silt	0.002 – 0.05
Very Fine Sand	0.05 – 0.10
Fine Sand	0.10 – 0.25
Medium Sand	0.25 - 0.50
Coarse Sand	0.50 - 1.00
Very Coarse Sand	1.00 – 2.00

Soil texture determination methods

1. Feel method – Evaluated by attempting to squeeze the moistened soil into a thin ribbon as it is pressed with rolling motion between thumb and pre finger or alternately to roll the soil into a thin wire. Four aspects to be seen – i) Feel by fingers, ii) Ball formation, iii) Stickiness and iv) Ribbon formation.

Table 2. Guide for assessment of soil texture in the field

Sl. No.	Textural class	Feel	Coherence of bolus at sticky point	Ribbon length (mm)	Other features	Approx. clay %
1.	Sand	Very gritty	Nil	Nil	Single sand grains adhere to fingers	<5
2.	Loamy sand	Very gritty	Slight	5	Discolours fingers with and organic strain	5-10
3.	Sandy loam	Gritty	Just coherent	15-25	Medium sand readily visible	10-20
4.	Loam	Neither very gritty not very smooth	coherent	About 25	No obvious sandiness	25
5.	Silty loam	Smooth or buttery	coherent	About 25	Silky; very smooth when manipulated	25 (>25% silt)
6.	Sandy clay loam	Moderately gritty	Strong	25-40	Medium sand in fine matrix	20-30
7.	Clay loam	Slightly gritty	Strong	40-50	No obvious sand grains	30-35
8.	Silty clay loam	Very smooth	Coherent	40-50	Silky feeling	30-35 (>25% silt)
9.	Sandy clay	Sticky	Coherent	50-75	Fine to medium	35-40
10.	Silty clay	Sticky	Coherent	50-75	Smooth and silky	35-40 (>25% silt)
11.	Clay	Sticky	Coherent	> 75	Smooth with slight to fair resistance to shearing	35-50
12.	Heavy clay	Very sticky	Coherent	> 75	Firm resistance to shearing	>50

2. Laboratory method

Two steps are involved

1. Mechanical analysis for determination of the amount of individual soil particle (Separation of all the particles from each other i.e. Complete dispersion into ultimate particles and Measuring the amount of each group)
2. Determination of soil textural class with the help of an equilateral triangle or table.

1.) Mechanical analysis or Particle size analysis

I. International Pipette Method

II. Bouyoucos Hydrometer Method

Mechanical analysis or Particle size analysis

Principle

Stirring a known quantity of the soil with water and allotting it to settle for a definite period of time and pouring off the turbid supernatant containing particles' up to a certain diameter. By repeated stirring, settling and decanting, particles of different sizes are separated out.

The involves two main principle

I. Dispersion of aggregates to individual particle by following reagents

1. Lime and oxides of Fe & Al dissolving in HCl
2. Organic matter oxidises with H_2O_2
3. High concentration of electrolytes (soluble salts) precipitate and decant or filter with suction.
4. Surface tension elimination of air by stirring with water or boiling after removing the cementing agents, disperse by adding NaOH.

ii. Fractionation of sand by sieving and determination of silt and clay by sedimentation process.

Materials required

i. 600 ml tall beaker, ii. rubber tipped glass rod, iii. 2 mm sieve, iv. porcelin basin, v. wash bottle, vi. mechanical stirrer, vii. oven& stop watch, viii. 1 litre measuring cylinder, ix. pipette.

Reagents:-i. 6% H_2O_2, ii,2 N HCl, iii. $AgNO_3$, iv. Sodium hexametaphosphate 5%

Procedures

I. Transfer 20 g of soil to a 60 mL tall beaker. Add approximately 50 mL of 6% H_2O_2 to remove organic matter and place the beaker on a water bath. Stir occasionally until frothing ceases. If necessary, add more H_2O_2 to ensure complete removal of organic matter.

II. Add a few drops of 1N HCl to the mixture until effervescence stops, ensuring the removal of CO_3^{2-} and HCO_3^- ions. Stir the contents thoroughly, then dilute the mixture to a final volume of 250 mL. Allow the solution to stir mechanically for 2 hours.

III. Filter the solution using filter paper No. 50 or a Buchner funnel. Collect the filtrate and test it for chloride ions.

IV. Transfer the filtrate into a beaker and stir mechanically for another 2 hours. Before starting the stirrer, add 10 mL of a 5% sodium hexametaphosphate solution to help disperse the particles and maintain individual particle suspension.

V. Pour the entire solution into a 1-liter spouted measuring cylinder or jar. Shake the cylinder well, note the time, and allow the mixture to settle for 4 minutes and 20 seconds at 22°C. After settling, pipette out 25 mL of the suspension into a porcelain dish, which will contain clay and silt. Dry it in an oven and weigh the contents.

VI. Shake the solution again and allow it to settle for an additional 7 hours and 20 minutes. After the second settling period, pipette 25 mL of the suspension into a porcelain dish, this will contain only clay. Dry the dish in the oven and weigh the contents.

VII. Transfer the contents from the measuring jar into a beaker and decant the liquid until the clay and silt are removed. Then, transfer the remaining material into the pre-weighed porcelain basin. Dry the contents and weigh them. To separate fine sand from coarse sand, sieve the material using a 0.2 mm sieve.

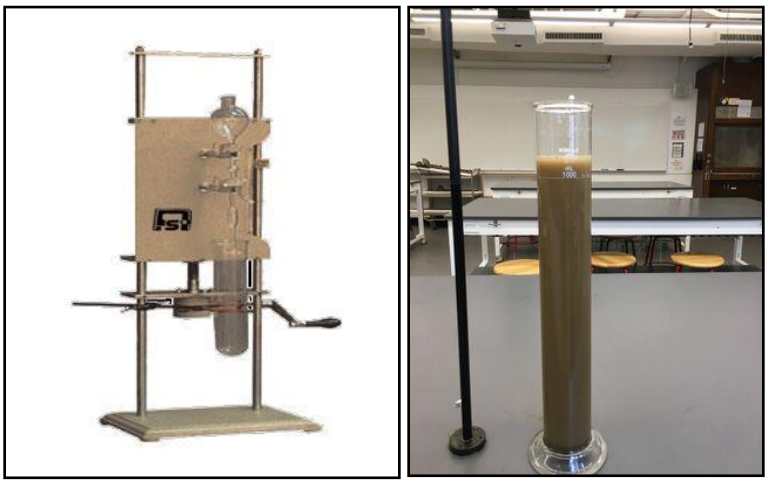


Fig. 1. Robinson pipette

Sedimentation time for silt + clay and clay fractions (for 10 cm depth)

Temperature (°C)	Silt + clay (min, sec)	Clay (Hrs, min)	Temperature (°C)	Silt + clay (min, sec)	Clay (Hrs, min)
14	5.40	9.20	24	4.20	7.15
15	5.30	9.05	25	4.15	7.05
16	5.20	8.50	26	4.10	6.55
17	5.10	8.35	27	4.05	6.45
18	5.00	8.25	28	4.00	6.40
19	5.00	8.10	29	3.55	6.30
20	4.48	8.00	30	3.50	6.20
21	4.40	7.50	31	3.45	6.15
22	4.30	7.25	32	3.40	6.05
23	4.30	7.25	33	3.35	5.55

Example

Observation and calculation:-

1. Weight of sample taken = a gram = 20 g
2. Let the moisture in % soil = m gram = 2.1 g
3. Weight of coarse sand = b grams = 5.7194 g
4. Weight of fine sand = c grams = 6.1348 g
5. Weight of clay + silt = d grams = 0.1871 g

6. Weight of clay = e grams = 0.1458 g
7. Weight of silt = f grams = 0.0416 g

Calculation

% Coarse Sand = b/a x 100x100/100-m
= 5.7194/20 x100x100/97.9
= 29.2104%

% Fine Sand = c/a x 100x100/100-m
= 6.1348/20 x100x100/97.9
= 31.3319%

% Clay+Silt = d/a x 100x100/100-mX1000/25
= 0.1871/20 x100/97.9x1000/25X100
= 38.2226%

% Clay = c/a x 100x100/100-mx1000/25
= 0.1455/20 x100/97.9x100x1000/25
= 29.7242%

% Silt = (A-V) = 8.4984%

Total
% Coarse Sand = 29.2104%
% Fine Sand = 31.3319%
% Clay = 29.7242%
% Silt = 8.4984%

Total = 98.7649%

i) Determination of Textural Class

In the American system as developed by the United State Department of Agriculture twelve textural classes are proposed.

The textural triangle

It is used to determine the soil textural name after the percentages of sand, silt, and clay are determined from a laboratory analysis. Since the soil's textural classification includes only mineral particles and those of less than 2mm diameter, the sand plus silt plus clay percentages equal 100 percent. (note that organic matter is not included.) Knowing the amount of any two fractions automatically fixes the percentage of the third one.

To use the diagram, locate the percentage of clay first and project inward parallel to sand line. Do likewise for the per cent silt and project inward parallel to clay line and for sand, project inward parallel to silt. The point at which the projections cross or intersect will identify the class

name sometimes, the intersecting point exactly fall on the line between the textural classes. Then it is customary to use the name of the finer fraction when it happens. (eg). 42% sand, 35% silt, and 23% clay. The soil would be *loam*.

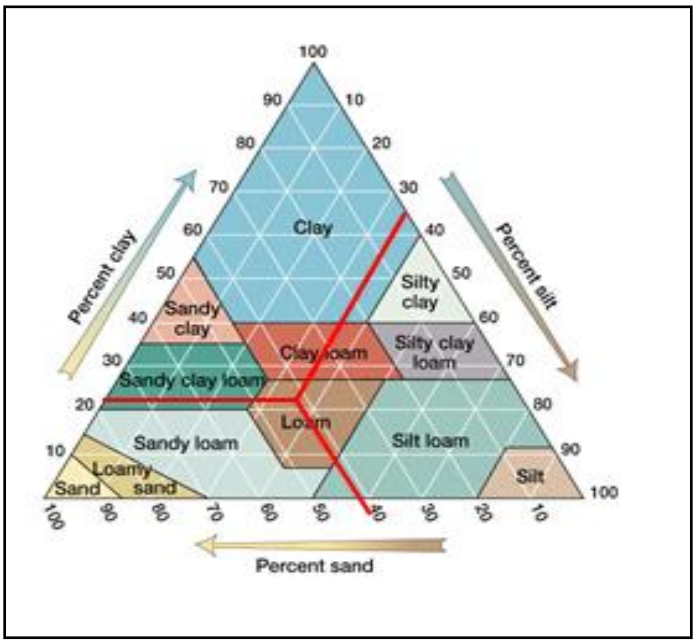


Fig.2. Textural classes' triangle

2. Soil structure

Determination of soil aggregates by wet sieving

Principle

Soil aggregates of different sizes, ranging from 5 mm to 0.1 mm, are collected. The sieves are then moved up and down in a Yodar-type wet sieving apparatus. The water-stable aggregates in each sieve are determined by oven-drying the soil material at 105°C.

Apparatus required

i. Yodar-type sieving apparatus, ii. sieve holder, sieve of different diameter (8.0, 5.0, and 2.0, 1.0, 0.5, 0.25 and 0.10 mm), iii. hot air oven, iv. balance, v. funnel.

Procedure

Collect the soil samples with spade, dry the sample. After drying pass through 8 mm sieve. Aggregates size should be passing though 8 mm sieve and retain in 5 mm size. Then take 5 mm soil aggregates for analysis. Fix up all the sieve in to nest of sieve (5.0, 2.0, 1.0, 0.5, 0.25 and 0.10 mm) in such a way that 5 mm sieve should be on top and lowest diameter at the bottom in the decreasing order.

Install the nest of sieves in the water slowly and at moderate angle to avoid entrapping air bubbles below the sieves. Adjust the mechanism so that the top sieves make contact with water surface when the oscillation mechanism is at top of its sieve so that wetting occurs by capillary

and wait 5 to 10 minutes. After the soil surface appears wet to insure saturation of aggregates ossilarates the sieve for 30 minutes, with a stroke of 3.8cm and a frequency of 30 cycles per minutes. Keeping soil in submerged at all the times. Remove the sieves from the water and drain for few minutes in an individual position. Remove excess water from the bottom of the sieves with absorbent tissue and place it the sieve on water glasses. Then transfer aggregates in each sieve to separate watch glasses dry at 105^{o}C for 24 h and weigh. The mean weight diameter (MWD) was calculated as per the procedure by van Bavel (1949) using the following relationship:

Fig.3. Yoder apparatus

Formula for Mean Weight Diameter (MWD):$MWD=\sum(Wi\times Di)/\sum Wi$
Where:

- Wi = weight of aggregates retained on the sieve (in grams) for each sieve
- Di = mean diameter of the soil aggregates for the corresponding sieve (in mm)
- $\sum(Wi\times Di)$ = sum of the product of weight and diameter for each sieve
- $\sum Wi$ = total weight of aggregates across all sieves

Mean Weight Diameter (MWD) of soil aggregates based on data from sieving:
Example Data**:**
Suppose you have sieved a soil sample and obtained the following results for aggregates retained on sieves of various sizes

Sieve Size (mm)	**Weight of Aggregates Wi (g)**	**Diameter Di (mm)**	**Wi×Di (g^{-1} mm)**
5	10	5	50
2	7	2	14
1	5	1	5
0.5	3	0.5	1.5
0.25	2	0.25	0.5
0.1	2	0.1	0.2

Steps for calculation:

1. Multiply weight and diameter: For each sieve, multiply the weight of the aggregates Wi by the sieve diameter Di to get Wi×Di
    - For the 5 mm sieve: 10×5=50
    - For the 2 mm sieve: 7×2=14
    - For the 1 mm sieve: 5×1=5
    - For the 0.5 mm sieve: 3×0.5=1.5
    - For the 0.25 mm sieve: 2×0.25=0.5
    - For the 0.1 mm sieve : 2x 0.1= 0.2
2. Sum the Wi×Di Values: Add all the Wi×Di products.
   50+14+5+1.5+0.5+0.2=71.2
3. Sum the Weights: Add up the total weight of the aggregates Wi for all sieves.
   10+7+5+3+2+2=29
4. Calculate the Mean Weight Diameter (MWD): Using the formula:
   $MWD=\sum(Wi\times Di)/\sum Wi$
   Substituting the values: MWD=71.2/29 =2.455 mm

Result

The mean weight diameter (MWD) of the soil aggregates is 2.46 mm.

Water stable aggregates:

Aggregate analysis was done by wet sieving technique as described by Yoder (1936 &1937). The per cent aggregates > 0.25mm diameter and the per cent aggregate stability were calculated from the following equation

$$\text{Per cent Aggregates} > 0.25 \text{ mm diameter} = \frac{\text{Weight of aggregates} > 0.25 \text{ mm diameter}}{\text{Weight of the soil}} \times 100$$

$$\text{Per cent Aggregates stability} = \frac{\text{Weight of aggregates} > 0.25 \text{ mm diameter} - \text{weight of sand}}{\text{Weight of the sample} - \text{weight of sand}} \times 100$$

3. Soil Colour

Soil colour indicates many soil features. A change in soil colour from the adjacent soils indicates a difference in the soil`s mineral origin (parent material) or in the soil development. Soil colour varies among different kinds as well as within the soil profile of the same kind of soil. It is an important soil properties through which its description and classification can be made. Kinds of soil colour Soil colour is inherited from its parent material and that is referred to as lithochromic, e.g. red soils developed from red sandstone. Besides soil colour also develops during soil formation through different soil forming processes and that is referred to as acquired or pedochromic colour, e.g. red soils developed from granite or schist.

Determination of soil colour

The soil colours are best determined by the comparison with the Munsell colour. This colour chart is commonly used for this purpose the colour of the soil is a result of the light reflected from the soil.

Soil colour rotation is divided into three parts

Hue: It denotes the dominant spectral colour (red, yellow,blue and green).

Value: It denotes the lightness or darkness of a colour (the amount of reflected light).

Chroma: It represents the purity of the colour (strength of the colour). The Munsell colour notations are systematic numerical and letter designations of each of these three variables (Hue, Value and Chroma).For example ,the numerical notation 2.5 YR6/6 suggests a hue of 2.5 YR, value of 5 and chroma of 6. The equivalent or parallel soil colour name for this Munsell notation is `red`.

4. Soil Consistency

Determination of sticky point of the soil

Principle

A known quantity of soil is taken and a small quantity of distilled water is added to it till the soil is wet and sticky. Then knead the soil until it ceases to stick to fingers. At this point, the moisture percentage is measured, which is referred to as the "sticky point."

Procedure

- Take approximately 20 grams of soil and place it in a porcelain bowl.
- Add a small quantity of distilled water to the soil.
- Using a spatula, mix the soil and water until the soil becomes wet and sticky.
- Continue mixing the soil mass into a paste using a flexible spatula.
- Knead the soil paste with your fingers until it no longer sticks to your fingers or the spatula.
- At this point, the soil can be cut cleanly through without adhering to the spatula. This is the soil's sticky point.
- Transfer the soil paste into a watch glass.
- Determine and record the weight of the soil paste as quickly as possible.
- Dry the soil paste in an oven at 105°C to a constant weight.
- Once dried, calculate the moisture content of the soil on an oven-dry basis.
- Using the moisture content, calculate the sticky point of the soil.

Observation and calculation

Weight of empty watch glass (a) = 20.2116g

Weight of empty watch glass +moist soil at its sticky point (b)= 51.7039

Weight of watch glass +oven dry soil (c) = 46.7280

Therefore, sticky point moisture % = (b-c x 100/c-a)

= (51.7039-46.7280 x 100 /46.7280-20.2116) x100

= (4.9759 x 100/26.5164)

= 18.7653%

Approximately = 19%

Result: Sticky point moisture % = 18.7653%

Determination of upper plastic limit of the soil

Principle

A known quantity of soil is taken, and a small amount of distilled water is added to moisten it. The soil is then kneaded, and the surface is leveled on a porcelain dish. The soil is cut into two halves, and the porcelain dish is tapped 10 times. When the two halves come together, the moisture percentage is measured. This is considered the upper limit of the soil.

Procedure

- Take approximately 20 grams of soil and place it in a porcelain dish.
- Add enough distilled water to moisten the soil.
- Knead the soil using your fingers until it is thoroughly mixed.
- Level the surface of the soil using a spatula.
- Neatly cut the soil into two halves using a blade, with a slit size of 1/10 inch.
- Hold the dish against your palm and tap the dish 10 times.
- After tapping, the two halves of the soil mass will come together and be in close contact. At this point, the soil is said to be at its upper plastic limit.
- Transfer the soil into a watch glass.
- Quickly determine and record the weight of the soil.
- Dry the soil in an oven at 105°C until it reaches a constant weight.
- After drying, calculate the moisture content of the soil on an oven-dry basis.
- Using the moisture content, calculate the upper plastic limit of the soil.

Observation and calculation:-

Weight of empty watch glass (a) = 20.2116g

Weight of empty watch glass+ moist soil (b) = 42.6163g

Weight of empty watch glass+ oven dry soil at UPL (c) = 37.4787g

Therefore, Moisture percentage at upper plastic limit = (b-c) x100/(c-a)

= (42.6163-37.4787) x100/937.4787-20.2116

=5.1332 x100/17.2671=29.7282%

Approximately = 30%

Result: Upper plastic limit of the soil in % = 30%

Determination of lower plastic limit of the soil

Principle

A known quantity of soil is taken and distilled water is added to it. Knead the soil till it is slightly sticky. Then soil mass is rolled and broke. This is the point where moisture at its lower plastic limits.

Procedure

- Take approximately 20 grams of soil and place it in a porcelain basin.
- Add enough distilled water to the soil to moisten it.
- Knead the soil thoroughly in the porcelain basin until it shows a slight tendency to stick to the fingers.
- Roll the soil mass between your fingers until a stage is reached where the rolled soil breaks off.
- The point at which the soil mass breaks off is considered the lower plastic limit.
- Transfer the soil into a porcelain dish.
- Quickly determine and record the weight of the soil.
- Dry the soil in an oven at 105°C until it reaches a constant weight.
- After drying, calculate the moisture content of the soil on an oven-dry basis.
- Using the moisture content, calculate the lower plastic limit of the soil.

Observation and calculation

Weight of watch glass (a) = 25.3766g

Weight of watch glass + moist soil at LPL (b) =57.3666g

Weight of watch glass+ oven dry soil (c) = 53.2548g

% moisture at LPL = (b-c) x100/(c-a)

= (57.3666-53.2548) x100/53.2548-25.3766

=4.4118 x100/27.8782

= 15.8252%

Approximately = 16%

Result: Lower plastic limit of the soil in % = 16%

5. Soil Density

Determination of Bulk Density (core sampler method)

BD is defined as the oven dry height of a unit volume of soil inclusive of pore space and expressed as g/cm^3.

Principle

Volume of undisturbed soil core from the field and the mass per unit volume are calculated. Using the mass-volume relationship, the bulk density is calculated.

Materials required

i) Core sampler, ii) Spade, iii) Crow bar, iv) Balance, v) Aluminium tin, vi) Hot air oven, vii) Knife.

Procedure

- Drive a core sampler into the soil gently with the help of a hammer so that the entire ring goes into the soil.

- ❖ Remove the soil surrounding the ring with the help of a spade. Remove the core sampler with the soil intact by using a crow bar.
- ❖ Remove the excess soil on the both sides of the ring gently using a sharp knife.
- ❖ Transfer the soil in the ring to aluminium tin and dry in it an oven at 105° C for at least 24 hours.
- ❖ The cool the sample in a desiccators and record the weight.
- ❖ Find out the volume of the ring from the height and diameter and calculate the bulk density of the soil.

Calculation

Volume of the ring V $= \pi r^2 h$

Where r is the radius and h is height of the ring ($\pi = 3.142$)

Weight of oven dry soil = W g

Bulk density of the soil $= W/ \pi r^2 h$ g/cc

Example

i. Volume of core sample **=** $\pi r^2 h$

r = Radius of the column = 2.6 cm

h – Height of the column = 10.7 cm

Therefore, volume of the sampler = $3.14 \times (2.6)^2 \times 10.7 = 227.33$ cc

ii. Weight of the moist soil + dish

Sample 524.5 gms – 85.3gms

Weight of moist soil = 439.2 gms.

iii. Weight of the dry soil + dish

Sample = 480.2 gm- 85.3 = 394.9

Calculation

BD of the soil gm/cc= 394.9/227.33 gm/cc **= 1.74 g/cm^3**

Advantages

- Relatively simple and easy to carry out and the needed equipment is relatively simple and easily available
- The sampled soil could also be used for other analysis

Disadvantages

- The metal ring compacts the soil during sampling
- It is not easy on stony or gravelly soils
- Heating at 105ºC is not appropriate for soils containing gypsum; in those cases the samples must be dried at 40ºC for several days or until constant weight.

Determination of Bulk Density (Wax coating method)

Principle

A soil clod of known weight is coated with wax and immersed in a known volume of water from the volume of water displaced the bulk density is determined.

Materials required

ii) Balance ii) 250 ml measuring cylinder iii) Twine and iv) Wax

Procedure

- ❖ Take a small clod from the field, the bulk density of which is to be determined and record its weight. Then tie the clod with a twine.
- ❖ Immerse the clod in melted wax so that there is a complete coating of the clod with wax.
- ❖ Take a known volume of water in a 250 ml measuring cylinder.
- ❖ Immerse the wax coated clod in the water and note the rise in volume of water in the cylinder.
- ❖ Calculate the bulk density of the clod from the weight and volume of the clod.

Calculation

Weight of the clod = W g

Initial water level in the cylinder = A ml

Final water level in the cylinder after immersing the clod = B ml

Volume of the clod = (B-A) ml

Bulk density of the soil = W/(B-A) g/cc

Advantages

- While not accurate as mentioned below, this method tends to be relatively precise.

Disadvantages

- If not done properly and the soil is not well covered in wax, some water may penetrate the clod and increase the weight of the soil which may overestimate the density of the soil.
- The method usually results in higher bulk densities than do other methods because the method does not take into account the inter-clod spaces and that it uses the air-dry soil volume, which may be slightly less than the volume of a field moist soil sample.

Determination of particle density

The weight per unit volume of the of solid portion of soil is called particle density

Particle density = oven-dry soil weight / volume of soil solids

Particle density of most the soils is 2.65 g/cm^3. Soil particle density is lower for soils with high organic matter content, and is higher for soils with high Fe-oxides content.

Pore space or porosity

Soil porosity refers to that part of a soil volume that is not occupied by mineralor organic matter.

Percentage of total pore space = (1-BD/PD) x 100

Size of pores

6. Soil Water

Determination of Saturated Hydraulic Conductivity of Soil

Principle

The rate of flow of liquid through a porous medium depends upon the size distribution and conductivity of pore and temperature of the fluid which is indexed as Hydraulic conductivity. In case of soil saturate with water it's directly related to the permeability o the porous medium using constant head of water. The water is passed though the soil column and conductivity of water per unit time is calculated using Darcy's equation.

Material used

1. Hydraulic rungs
2. Measuring cylinder

Procedure

- The undisturbed soil sample was collected following the prescribed procedure and processed accordingly.
- The bottom of the sectional cylinder was covered with muslin cloth.
- The samplers were placed in a tray containing water overnight to achieve saturation.
- A filter paper was placed on the surface of the sample to prevent the loss of soil particles.
- The hydraulic ring was connected over the saturated samples and waterproofed using a thick rubber band.
- The sampler was positioned on a metal screen with an attached outflow unit.
- A constant head of water was maintained in the entire sampler for a few minutes to allow water to pass through.
- Water passing through the soil column was collected over a period of 10 minutes in three replicates.
- The collected water was measured using a measuring cylinder.
- The average of the three measurements was calculated.
- The average value was substituted into Darcy's equation to determine the hydraulic conductivity.

$$Ks = QL/tA\ \Delta H\ cm/hr$$

Where,

Ks is saturated hydraulic conductivity

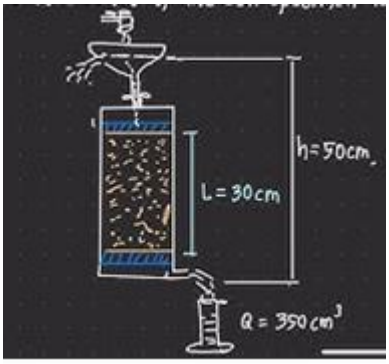
Q = Quantity of water collected

L = Length of soil core

t = Time interval in hours

A = Cross sectional area of the core

ΔH = Hydraulic head (L = column water standing over the soil).



Example

Observation in 10 minutes= 41 ml (R1) + 39 ml (R2) + 42 ml (R3) = avg. 40.666

L= 8.5cm

t=10 minutes = 1/6= 0.167 hrs.

$A= \pi r^2=3.14 \times (3.5)^2$

$\Delta H=8.5x1.5=10$

$Ks = QL/tA\ \Delta H$ cm/hr = 40.67 x 8.5/0.17 x 38.5 x 10

Result: 5.28 cm hr^{-1}

Estimation of infiltration rate of soil using double ring infiltrometer

Aim: Determination of infiltration rate of the soil under field condition.

Principle

Therate of entry of water depends upon the distribution and continuity of both capillary and non capillary pore in addition to soil moisture content and condition of the soil. The water is allowed infiltrate into the soil using a double ring infilterometer and drop in water level in the inner ring is measured by peizometer.

Materials used

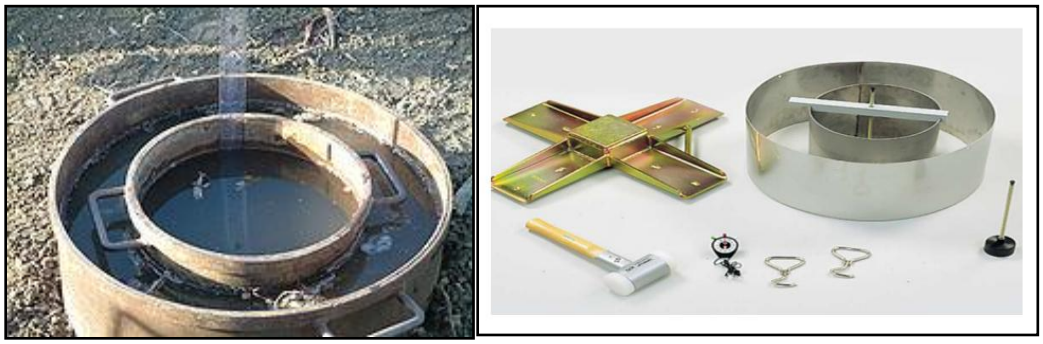
1. Double ring infiltrometer: It consists of an outer ring and an inner ring, both with sharp-edged bottoms. The infiltrometer is available in two dimensions: the outer ring has a diameter of 60 cm and a height of 20 cm, while the inner ring has a diameter of 30 cm and a height of 20 cm.
2. Iron plate
3. Hammer
4. Peizometer: It consists of a right angled triangular wooden stand on which a graduated glass tube is fixed at hypothermal side. The frame has a slop of 1:2. The advantage of using

peizometer is that it avoids paradox error. The water drop indicated by peizometer in double the actual drop.

5. Screw auger
6. Polythene bag

Procedures

- A levelled area of the field, free from cracks, stones, stubbles, etc., was selected for the test.
- The outer ring and inner ring were driven into the soil to a depth of 10 cm using an iron plate and hammer.
- The outer ring was filled with water, and the soil was allowed to saturate to prevent lateral water movement.
- Water was then added into the inner ring after placing some twigs on the soil surface to avoid soil splashing.
- The free end of the stubbles tube of the piezometer was inserted into the water in the inner ring, and water was sucked through the other end.
- The water level was adjusted so that it reached the top of the piezometer scale.
- The initial reading of the piezometer was recorded.
- Subsequent readings were taken at 1, 2, 5, 15, 30, and 60-minute intervals until the piezometer readings became constant.
- The infiltration rate and cumulative infiltration were calculated and recorded in the table.
- A curve was plotted showing infiltration rate versus time.
- Another curve was plotted showing cumulative infiltration versus time.



Source: Internet

Fig. 4. Double ring infiltrometer

Precaution

a. Double ring infitrometer should be installed in a place free of crakes to avoid the seepage losses.
b. Both the ring should drive into the soil to depth 10 cm to avoid lateral movement of water.
c. The outer ring should be first filled with water followed by inner ring.
d. While adding water into the inner ring care should be taken to avoid splashing of soil particles.

e. Water drops in the infitrometer should not be allowed beyond 2.5 cm. If water drops is greater than 2.5 cm, water should be added and fresh reading/time should be noted to avoid time lag.
f. Reading should be taken till we reach steady state infiltration.

Calculation and observation:

Time	**Peizometer reading**	**Time interval (Min.)**	**Cumulative time (Min.)**	**Drop in reading**	**Actual drop**	**Infiltration Rate (cm/hr)**	**Cumulative Infiltration Rate (cm/hr)**
3.39	18	-	-	-	-	-	-
3.40	17.4	1	1	(18-17.4)=0.6	(0.6/2)=0.3	(0.3*60)=18	18
3.42	16.0	2	(1+2)=3	(17.4-16)=1.4	(1.4/3)=0.46	(0.46*60)=28	39
3.47	12.7	5	(3+5)=8	(16.0-12.7)=3.3	(3.3/10)=0.33	(0.33*60)=19.8	47.8
3.48-4.03	19.8-10.1	15	(8+15)=23	(19.8-10.1)=9.7	(9.7/15)=0.64	(0.64*60)=38.8	86.6
4.04-4.34	19.8-3.0	30	(23+30)=53	19.8-3.0)=16.8	(16.8/30)=0.56	(0.56*60)=33.6	120.2

Result: The infiltration rate of soil (insitu) is 16.8 cm/hr (steady state).
The cumulative infiltration rate of soil is 120.2 cm/hr.

Example 2

Calculation & observation:

Watch reading (hrs:min)	Time interval (min)	Cumulative time (min)	Water level before	Water level after	Infiltration (mm)	Infiltration Rate (mm/min)	Infiltration Rate (mm/hr)	Cumulative infiltration rate (mm)
2:05	0	(0+0)=0	100	0	0	100/0=0	0×60=60	(0+0)=0
2:07	2	(0+2)=2	100	93	(100-93)=7	7/3=3.5	3.5×60=210	(0+7)=7
2:10	3	(2+3)=5	94	89	(94-89)=5	5/3=1.6	1.6×60=96	(7+5)=12
2:15	5	(5+5)=10	88	80	(88-80)=8	8/5=1.6	1.6×60=96	(12+8)=20
2:25	10	(10+10)=20	79	70	(79-70)=9	9/10=0.90	0.90×60=54	(20+9)=29
2:35	10	(20+10)=30	69	60	(69-60)=9	9/10=0.90	0.90×60=54	(29+9)=38
2:45	10	(30+10)=40	59	48	(59-48)=11	11/10=1.1	1.1×60=66	(38+11)=49
3:05	20	(40+20)=60	47	38	(47-38)=9	9/20=0.45	0.45×60=27	(49+9)=58
3:25	20	(60+20)=80	37	30	(37-30)=7	7/20=0.35	0.35×60=21	(58+7)=65

Result: The infiltration rate of soil (insitu) is 21 mm/hr (steady state)
The cumulative infiltration rate of soil is 65 mm/hr.

Estimation of soil moisture (gravimetric method)

Gravimetric water content is the mass of water per mass of dry soil. It is measured by weighing a field moist soil (wet weight) and then either drying that soil (over a period of a week) or oven drying it for about 24 hours at a temperature of 105°C to remove all water. The soil should then

be weighed again (to determine the dry weight). The difference between the wet and the dry weight is the amount of water in that soil.

Materials needed

i). Soil probe or soil auger, ii). Sealable soil sample bags, iii). Balance and iv). Hot air oven

Procedure

- ❖ Using the normal procedure for soil sampling, obtain a soil sample from a desired depth using a soil probe or soil auger (or even a shovel/trowel)
- ❖ Then place the soil samples in the sealable sample paper bags, label the samples and transport them to the laboratory or any soil processing facility
- ❖ Measure the weight of the field wet soil (Wt)
- ❖ Oven dry the soil for about 24 hours at 105 degrees Celsius or air dry the soil for 7 days
- ❖ After drying, weigh the soil in order to obtain the dry weight of that soil (Wd)
- ❖ Then calculate the water content of the soil

Calculations

Gravimetric water content = ⍵d = (Wt-Wd/wd) ×100

Where: Wt= Weight of field moist soil (g)
Wd= Weight of dried soil (g)

Advantages: The method is easy to perform and does not require much technical knowledge.

Disadvantages

- Some equipment like oven dryers can be expensive, but the drying of the soil could be done by allowing the samples to air-dry for a period of 7 days.
- A weighing scale is needed for this method.

Determination of moisture at different tension at 1/3 bar(Pressure plate apparatus)

Principle

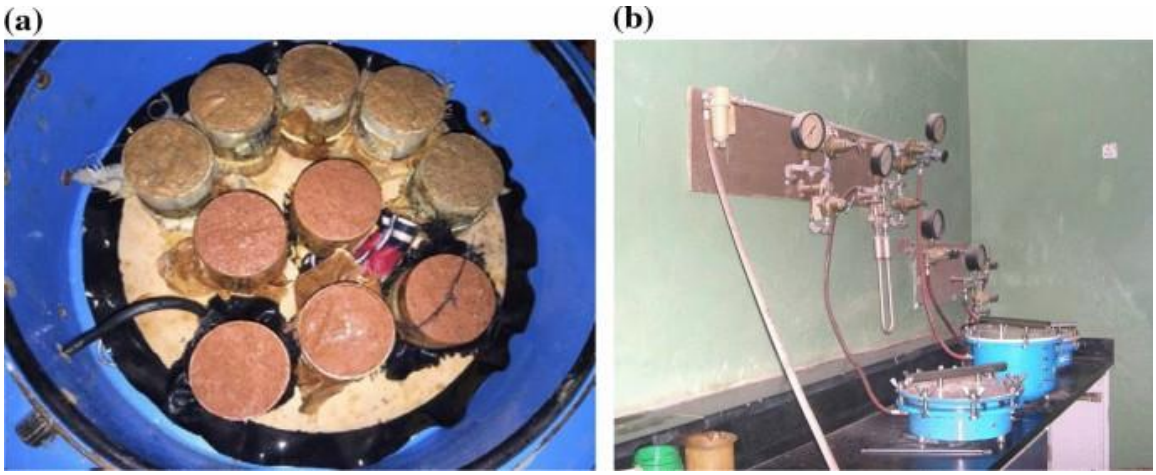
Moist soil is taken in a pressure plate. 1/3 bar pressure is applied on the soil after keeping plate inside the pressure plate apparatus. After 48 hrs, soil is removed from pressure plate and moisture content is determined after over dry the soil at 105^{o}C for 24 hrs.

Apparatus required: pressure plate apparatus, retainer rings to hold the soil samples, balance, hot air oven.

Procedure

Prepare duplicate about 25 g soil samples that have been passed through a 2 mm sieve. Place the samples retainer ring on the porous plate. In order to avoid particle size aggregation, makeup all of the soil samples from each container into each ring and level. Allow the samples to stand with an excess of water on the plate. Close the apparatus and apply a pressure of 1/3 atmospheric

sample can be removed any time after 48 hrs. From initiating the extraction or when reading on a burette indicate that, on flow had cessed from all of the samples on each plate. To avoid the changes in the moisture content of the samples quickly to moisture boxed. Determine the moisture content by drying to constant weigh 105^{o}C. Express the moisture content as percent dry weight basis.



Source: Internet

Fig. 5. Pressure plate apparatus

Observation and Calculation

Weight of moist soil = 30.5188 gms

Weight of oven dry soils=27.4475 gm

Therefore of % moisture at 1/3 bar = (30.5188/27.4475)/27.4475=(3.0713x100)/27.4475= 11.1879%

Result: Average moisture percentage at 1/3 bar = 11.1879%

Determination of crust strength by using penetrometer

Principle: By driving the penetrometer into the soil we can measure the crust strength.

Materials require: Saturated soil, crusted soil, hard soil surface and penetrometer.

Procedure

Drive the penetrometer into the saturated soil and measured the crust strength. Similar procedure is repeated on hard surface and crusted surface.

Result

Saturated soil – Zero reading mean no crust formation

Hard soil - > 5 reading, very hard

Little moist - 4.5 reading this shows very high crust formation.

Source: Internet

Fig. 6. Cone penetrometer

Source: Internet

Fig. 7. Pocket penetrometer

7. Soil Temperature

Determination of soil temperature

Aim: Measurement of soil temperature using a soil thermometer.

Materials Required:

1. Soil thermometer 2. Notebook or data sheet, 3. Ruler or tape measure

Procedure

Choose a representative location for the soil measurement and decide the depth. Commonly, 5, 10 and 20 cm soil depth will be chosen for measurement. Insert the thermometer probe vertically into the soil at the selected depth.Ensure the probe is centered in the soil without touching the sides of the hole or any foreign materials. This ensures that the thermometer measures the ambient soil temperature rather than the temperature of the surrounding air or the container if you're using a sampling tube. After inserting the thermometer into the soil, wait for the reading to stabilize. This may take anywhere from 1 to 5 minutes, depending on the type of thermometer.Once the thermometer has stabilized, read the temperature on the thermometer

display. The reading should be taken once the needle or digital display has stopped fluctuating. Record the temperature in your notebook or data sheet. If multiple measurements are being taken, repeat the process at different depths or locations.

Precaution

- Avoid direct sunlight: When measuring soil temperature, make sure the thermometer is not exposed to direct sunlight during insertion, as this can cause a false reading.
- Check for consistency: If soil temperature measurement is for agricultural or scientific purposes, repeat the readings at different locations within the same plot or field to ensure consistent data.
- Temperature fluctuations: Soil temperature can fluctuate with the time of day and season, so measurements at different times will provide a more comprehensive understanding of soil conditions.
- Consider using a soil temperature probe: For more precise and in-depth analysis, especially over time, some digital soil temperature probes can log temperature data at specific intervals (e.g., hourly or daily).

8. Soil Aeration

Determination of Soil Air

Aim: measuring the movement of oxygen through the soil

Materials Required

1. Oxygen diffusion chamber, 2. Oxygen sensor, 3.Soil auger or core sampler, 4. Notebook or data sheet.

Procedure:

- ❖ Choose an area that is representative of the soil conditions.
- ❖ Choose common depths for ODR measurement are 5 cm, 10 cm, and 20 cm.
- ❖ Set up the oxygen diffusion chamber according to the manufacturer's instructions.
- ❖ The chamber should fit securely over the soil at the selected measurement depth. Ensure the chamber is tightly sealed to prevent air from entering or escaping during the measurement.
- ❖ Place the oxygen sensor inside the diffusion chamber (if not already integrated) to measure the oxygen concentration. This will allow you to assess the rate at which oxygen diffuses into the soil.
- ❖ Seal the chamber over the soil sample to create an airtight environment. This ensures that the measurement will only reflect the oxygen movement within the soil and not from external air.
- ❖ The oxygen concentration inside the chamber should be measured over time to detect how oxygen diffuses from the surrounding air into the soil.

- As oxygen diffuses through the soil, the oxygen level inside the chamber should decrease over time. This decrease is directly related to the soil's oxygen diffusion rate.
- Oxygen Diffusion Rate (ODR) can be calculated by measuring the rate of change in oxygen concentration inside the chamber. The ODR is usually given in $\mu g\ O_2\ cm^{-2}\ hr^{-1}$ (micrograms of oxygen per square centimeter per hour).

Interpretation

- The oxygen diffusion rate (ODR) is an indicator of the soil's aeration status. A higher ODR indicates that oxygen is diffusing more readily into the soil, which usually corresponds to better soil structure, good porosity, and active microbial processes.
- A lower ODR could suggest that the soil has poor aeration, possibly due to soil compaction, high moisture content, or low porosity.

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