Soil Fertility And Nutrient Management

Lesson No.	Topic
Lesson 1	Plant nutrients - Classification and sources, Essential and Beneficial elements, Criteria of essentiality

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Course Name	Soil Fertility and Nutrient Management
Lesson 1	Plant Nutrients - Classification and Sources, Essential and Beneficial Elements, Criteria of Essentiality
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Objective

To acquire knowledge about classification and sources of plant nutrients and their criteria of essentiality

Soil fertility

It is the inherent capacity of the soil to provide essential chemical elements for plant growth

Soil productivity

Soil productivity emphasizes the capacity of soil to produce crops and is expressed in terms of yield.

Plant nutrition

Plant nutrition is defined as the supply and absorption of chemical compounds required for plant growth and metabolism. It is the process of absorption and utilization of essential elements for plant growth and reproduction.

Nutrient

Nutrient may be defined as the chemical compound or ion required by an organism. The mechanism by which the nutrients are converted to cellular material or used for energetic purposes are known as metabolic processes.

Beneficial elements

The elements, the essentiality of which for growth and metabolism has not been unequivocally established, but which are shown to exert beneficial effects at very low concentrations are often referred to as beneficial elements, or potential micronutrients. The beneficial effect of these nutrients may be due to the ability of these elements affecting the uptake, translocation and utilization of the essential elements. They may be essential only for certain plant species or under specific conditions. Eg : Silicon, vanadium, cobalt and aluminium.

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1. Classification of essential nutrients:

Nutrients are chemical compounds needed for growth and metabolic activities of an organism. The essential plant nutrients may be divided into macronutrients (primary and secondary nutrients) and micronutrients.

1.1. Macronutrients.

Macronutrients or major nutrients are so called because they are required by plants in larger amounts. These are found and needed in plants in relatively higher amounts than micronutrients. They include C, H, O, N, P, K, Ca, Mg and S. C, H and O constitute 90 – 95 per cent of the plant dry matter weight and supplied through CO_2 and water. Remaining six macronutrients are further sub divided into primary and secondary nutrients.

i) **Primary nutrients:** Nitrogen, phosphorus and potassium are termed as primary nutrients because the correction of their wide spread deficiencies is often necessary through the application of commercial fertilizers of which these are the major constituents.

ii) **Secondary nutrients:** Calcium, magnesium and sulphur are termed as secondary nutrients because of their moderate requirement by plants, localized deficiencies and their inadvertent accretions through carriers of the primary nutrients. For example, the phosphatic fertilizer, single super phosphate (SSP) contains both Ca and S. Similarly, ammonium sulphate, a nitrogenous fertiliser also supplements S.

1.2. Micronutrients:

Micronutrient is an element that is required in relatively small quantities but is as essential as macronutrients. These elements have often been called trace elements. They are again classified into micronutrient cations (eg. Fe, Mn, Zn and Cu) and micronutrient anions (eg., B, Mo and Cl) depending upon the form in which they are available.

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Table 1. Classification of plant nutrients

Plant nutrients	
a. Macronutrients	
Primary nutrients (C, H, O, N, P,	Secondary nutrients (Ca, Mg, S)
b. Micronutrients	
Cationic Eg: Fe, Mn, Cu, Zn, Co	Anionic Eg: Mo, B, V, Cl,

This above division of plant nutrients into macro and micro nutrients is somewhat arbitrary and in many cases, the differences between the contents of macronutrients and micronutrients are considerably less well defined. Therefore, classification of plant nutrients according to biochemical behaviour and physiological functions seems more appropriate. The classification of plant nutrients is as below:

Essential plant nutrient	**Biochemical functions**
1 st group C, H, O, N, S	Major constituent of organic material, essential elements of atomic groups which are involved in enzymatic processes and assimilation by oxidation – reduction reactions
2 nd group P, B, Si	Esterification with native alcohol groups in plants. Involved in energy transfer reactions.
3 rd group K, Na, Mg, Ca, Mn, Cl	• Non specific functions establishing osmotic potentials. • Enzyme activation, balance of ions, controlling membrane permeability and electro

	potentials.
4 th group Fe, Cu, Zn, Mo	Present predominantly in a chelated form incorporated in prosthetic groups.

Based on mobility in plant

Mobile	**Partly mobile**	**Immobile**
Nitrogen	Iron	Sulphur
Phosphorus	Zinc	Boron
Potassium	Copper	Calcium
Magnesium	Molybdenum	

1.2.1. Mobile nutrient:

Mobile nutrients are those when deficient in the plant, move from the matured tissue (older leaves) to the young meristem thus the deficiency symptoms are manifested on the older tissue.

1.2.2. Immobile nutrient:

Immobile nutrients are those which under the situation of deficiency in the soil cannot move from older to younger tissue and hence the deficiency symptoms appear first on the younger leaves.

2. The criteria of essentiality

The criteria of essentiality put forth by Arnon In the nature there are nearly one hundred and three elements. Of them nearly ninety elements are taken in by the plants. In order to distinguish the elements which are essential from those which may be taken in by the plants but are not essential, Arnon (1954) has laid down the following criteria.

1. The plant must be unable to grow normally or complete its life cycle in the absence of the element.

2. The element is specific and cannot be replaced by another.

3. The element plays a direct role in plant metabolism.

4. It appears that an element would have to be considered essential even if it has not been possible to demonstrate that it fulfills the second criterion of essentiality.

For ex., for many bacteria, diatoms and other algae, vitamin B_{12} is known to be essential, but the essentiality of cobalt per se has not been demonstrated. According to this criterion, molybdenum and chlorine cannot be considered as essential though they are functional in plant metabolism since they can be replaced by vanadium and halides respectively. D.J. Nicholas gave more exact definition of essential elements and advanced the term “functional or metabolic nutrient” to include any mineral element that functions in plant metabolism, whether or not its action is specific.

3. Functional element:

Nicholas D J (1961) advanced the term functional or metabolic nutrient to include any mineral element that functions in plant metabolism whether or not its action is specific. To describe the level of nutrient element in plants the following terms are proposed.

3.1. Deficient: When an essential element is at low concentration that severely limits yield and produces more or less distinct deficiency symptoms.

3.2. Toxic: when the concentration of either essential or other element is sufficiently high to inhibit the plant growth to a great extent.

Forms of nutrient elements absorbed by plants

i) Absorbed as single nutrient ion

Nutrient element Forms absorbed by plants

Potassium	K^+
Calcium	Ca^{2+}

Magnesium	Mg^{2+}
Iron	Fe^{2+}
Manganese	Mn^{2+}
Copper	Cu^{2+}
Zinc	Zn^{2+}
Chlorine	Cl^{-}
Silicon	Si^{4+}
Cobalt	Co^{2+}
Sodium	Na^{2+}

ii) Absorbed in a combined form

Nitrogen	Ammonium (NH_4^{+}) and Nitrate (NO_3^{-})
Phosphorus	$H_2PO_4^{-}$, HPO_4^{2-}
Sulphur	SO_4^{-2}
Boron	H_3BO_3, $H_2BO_3^{-}$, HBO_3^{2-}, BO_3^{3-}
Molybdenum	MoO_4^{2-} (Molybdate)
Carbon	CO_2
Hydrogen	H_2O

References:

- Arnon, D. I., Allen, M. B., & Whatley, F. R. (1954). Photosynthesis by isolated chloroplasts. *Nature*, *174*(4426), 394-396.

Course Name	Soil Fertility and Nutrient Management
Lesson 2	Forms of Nutrients in Soil, Mechanisms of Nutrient Transport to Plants
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Objective:

- To understand the mechanism and form of nutrient uptake by plants

1. Forms of nutrients in soil.

1.1. Forms of nutrient elements absorbed by plants

Absorbed as single nutrient ion

Nutrient element forms absorbed by plants

Potassium	K^{+}
Calcium	Ca^{2+}
Magnesium	Mg^{2+}
Iron	Fe^{2+}
Manganese	Mn^{2+}
Copper	Cu^{2+}
Zinc	Zn^{2+}
Chlorine	Cl^{-}
Silicon	Si^{4+}
Cobalt	Co^{2+}
Sodium	Na^{2+}

1.2. Absorbed in a combined form

Nitrogen	Ammonium (NH_4^{+}) and Nitrate (NO_3^{-})
Phosphorus	$H_2PO_4^{-}$, HPO_4^{2-}
Sulphur	SO_4^{-2}
Boron	H_3BO_3, $H_2BO_3^{-}$, HBO_3^{2-}, BO_3^{3-}

Molybdenum	MoO_4^{2-} (Molybdate)
Carbon	CO_2
Hydrogen	H_2O

2. Mechanisms of nutrient transport to plants

Movement of ions from soils to roots for the ions to be absorbed by plants roots, they must come in contact with the root surface. This generally takes place by three ways in which the nutrient ions in soil may reach the root surface

- Movement of ions by mass movement in the soil solution – Mass flow.
- Diffusion of ions in the soil solution – Diffusion.
- Root interception and contact exchange.

2.1 Mass flow:

- Movement of ions from the soil solution to the surface of roots is accomplished largely by mass flow and diffusion.
- Mass flow, a convective process occurs when plant nutrient ions and other dissolved substances are transported in the flow of water to the root in enemas that results from transpiration water uptake by the root.
- This depends on the rate of water flow or the water consumption of plants. Mass flow supplies an overabundance of calcium, magnesium is many soils and the most mobile nutrients such as N and S.

2.2. Diffusion:

- Most of the phosphorus, potassium (relatively immobile) and micronutrients (present in small quantities), move to root by diffusion.
- Diffusion occurs when an ion moves from an area of high concentration to one of low concentration by random thermal motion. As plant roots absorb nutrients from the surrounding soil solution, a diffusion gradient is set up.
- A high root absorbing power results in a high diffusion gradient favouring ion transport.
- The three principal factors influencing the movement of nutrients into the roots are the diffusion coefficient, concentration of the nutrient in soil solution and the buffering capacity of the solid phase to release nutrients into the soil solutions.

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Soil moisture is a major factor that affects the relative significance of the mass flow and diffusion. Diffusion becomes progressively less important as the moisture content decreases. The amount of nutrient ion diffusing across a unit area in unit time (F) with a concentration gradient, dc/dx is given for steady state diffusion by

Fick's first law of diffusion

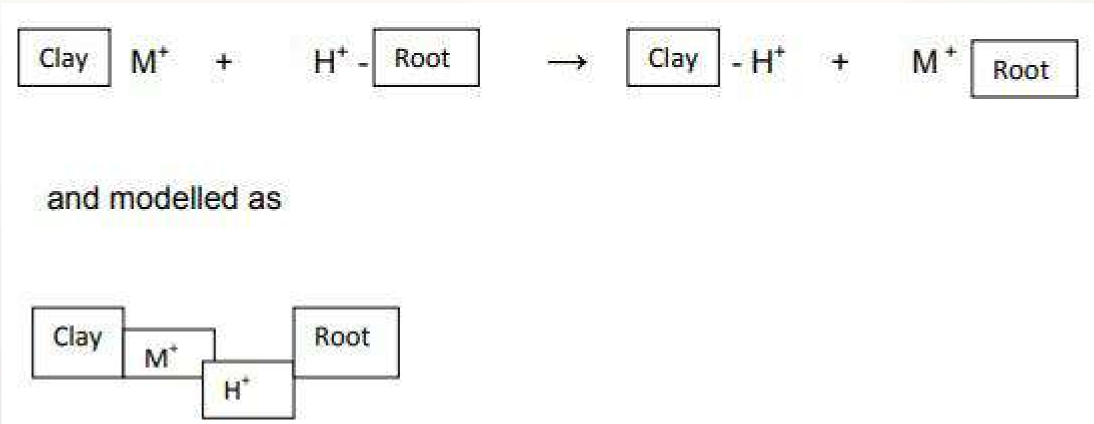
$F = -D\ (dc/dx)$

D is the diffusion coefficient in the soil with unitscm^2 /s

The minus sign indicates movement from higher to lower concentration.

2.3. Root interception and ion exchange:

Jenny and Overstreet (1939) propounded the 'theory of contact exchange'. Theory of contact exchange rests on the concept of overlapping oscillation spaces of adsorbed ions, or redistribution within intermingling electric double layers. Contact exchange as a mechanism for nutrient movement could be pictured as



- Cation exchange theory on further refining gave rise to the concept of 'root interception' a term coined by Stanley A Barber, which is used to describe the soil nutrients at the root surface that do not have to move to the interface to be positionally available for absorption, but are approached by the root itself in the soil.
- As the root system develops and exploits the soil more completely, soil solution and soil surfaces retaining the adsorbed ions are exposed to the root mass and absorption of these ions by the contact exchange mechanism is accomplished.
- The quantity of nutrients that can come in direct contact with the plant roots is the amount in volume of soil equal to the volume of roots.

- It can be assumed that roots usually occupy 1 % or less of the soil. It is estimated that roots would contact a maximum of 3 % of the available nutrients in the soil.
- It has been observed that plant roots also possess the cation exchange property, ranging from 10 to 100 c mol/ kg roots. This property could be due to the –COOH groups of pectic substances of cell wall.
- Legumes have high root CEC and absorb more divalent cations, monocots have low root CEC and absorb more of monovalent cations like K^+.
- Ions attached to the surface of roots may exchange with those held on the surface of clays and organic colloids because of the contact between roots and soil particles. The mucilaginous gel around root surface could serve as contact complex.
- The presence of mycorrhiza, a symbiotic association between fungi and the roots of plants, enhances the uptake of nutrients particularly phosphorus.

References:

- Reid, Robert, and Julie Hayes. "Mechanisms and control of nutrient uptake in plants." *International review of cytology* 229, no. 3 (2003): 73-114.
- Shukla, Rajni, Yogesh K. Sharma, and Arvind K. Shukla. "Molecular mechanism of nutrient uptake in plants." *International Journal of Current Research and Academic Review* 2, no. 12 (2014): 142-154.

Course Name	Soil Fertility and Nutrient Management
Lesson 3	Factors Affecting Availability of Major, Secondary and Micro Nutrients to Plants, Measures to overcome Deficiencies and Toxicities
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Objective:

- To get acquainted with the factors affecting the availability of nutrients to plants.
- To know the deficiencies and toxicities of nutrients and measures to overcome them

1. **Nitrogen**

1.1. Factors affecting N availability

- Dosage of application
- Time of application
- Method of application
- Source of fertilizer
- Irrigation scheduling
- Voltalization of ammonia

Voltalization

- It is related to surface application of N fertilizers
- Volatilization depends on quantity and pH

$$NH_4^+ \longrightarrow NH_3 + H^+$$

$$NH_4^+ + H_2O + OH^- \longrightarrow NH_3 + 2H_2O$$

- In acid and neutral soil, little or no NH_3 volatilization
- High voltalization occurs in alkaline and calcareous soils

$$(NH_4)_2SO_4 + CaCO_3 \longrightarrow 2NH_3\uparrow + CO_2\uparrow + H_2O + CaSO_4$$

- Increases with increasing temperature up to 45°C
- Loss through voltalization accounts to 10 to 30%

1.2. Deficiency symptoms

Plants having less than 1 % nitrogen are usually regarded as deficient in N.

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- Due to high mobility of N in plants, its deficiency symptoms first appear on the older leaves in the form of light green to pale yellow coloration due to proteolysis).
- Stunted growth is the manifestation.
- In grasses, the lower leaves usually fire or turn brown beginning at the leaf tip, and progressing along the midrib in the form of inverted 'V' shape.
- Reduction in flowering and crop yields and lower protein content are associated with N deficiency.

1.3. Corrective measures

- Nitrogen in the form of NO_3^- is more prone for leaching especially on light textured soils with more permeability. So, split application of nitrogen is recommended.
- Foliar application in the form of urea @ 2 per cent concentration is advocated in dry land areas.

Table 1. List of N fertilizer sources

N Source	% N
Ammonium sulfate	21.0
Ammonium chloride	25 – 26.0
Ammonium nitrate	33 – 34
Ammonium nitrate sulfate	30.0
Monoammonium phosphate	11.0
Diammonium phosphate (DAP)	18-21.0
Calcium nitrate	15.0
Urea	45-46
Urea ammonium nitrate	28-32

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1.4. Toxicity symptoms

Under conditions of large nitrogen availability, succulence of the plant increases; taller plants and heavier heads cause lodging. A nitrogen rich, luxuriant crop is more susceptible to insect pest and disease attacks.

2. Phosphorus

2.1. Factors affecting P availability

- Soil pH
- Soluble Fe, Al and Mn
- Presence of Fe, Al and Mn containing minerals
- Available Ca and Ca minerals
- Amount of decomposition of organic matter
- Activities of microorganism
- Moisture regimes – Submergence increases P availability

2.2. Deficiency symptoms

In general, plants having less than 0.1 % phosphorus are designated as P-deficient. Because of its faster mobility in plants, P gets translocated from older tissues to the meristematic tissue. Therefore, deficiency symptoms of P first appear on the older leaves. P deficiency results in the production of dark green color leaves.

- Severe restriction of root growth.
- Thin, erect and spindly plants with sparse and restricted foliage.
- Suppressed lateral bud production.
- Bluish green foliage, and under continued deficiency the older leaves become bronzed or develop reddish purple tip or leaf margins.

2.3. Toxicity symptoms

- Excess of P causes trace element deficiency particularly Fe and Zn.

2.4. Correction of deficiency

Generally, P is applied as a basal application by bandplacement. The following are the phosphatic fertilizers.

- Single Super Phosphate (SSP) contains 16 to 22% P_2O_5
- Rock phosphate contains 30-38 % P_2O_5
- Triple Super Phosphate contains 46 % P_2O_5
- Diammonium phosphate contains 46 % P_2O_5

- Monoammonium phosphate contains 52 % P_2O_5
- Basic slag contains 10-20 % P_2O_5

3. Potassium

3.1. Factors affecting K availability

- Clay minerals – High K minerals – more availability
- Cation exchange capacity – High CEC –more K can hold
  - Coarse textured – more solution K
- Amount of exchangeable K – measure of K availability
- Capacity to fix K – Higher– K availability less
- Soil moisture – High moisture – K diffusion to roots more
- Soil temperature – K diffusion effects & low root activity
- Soil aeration – Poor aeration less uptake of K
- Soil pH – Acid pH – High amounts of Al &Mn – unfavourable
- Ca and Mg – Compete with K

3.2. Deficiency symptoms

- Potassium deficiency does not manifest immediately in the form of visible symptoms. First growth rate decreases and later deficiency symptoms appear. Deficiency symptoms first develop on the older leaves.
- Chlorosis along the margins followed by scorching and browning of tips of older leaves which gradually progresses inwards giving burning appearance. Slow and stunted growth of the plant and crop lodging.
- Shrivelled fruits and seeds.
- Reduced crop yields without the appearance of definite symptoms; the phenomenon is called hidden hunger.
- Decrease in resistance to certain plant diseases
- Decrease in the quality of fruits and vegetables.
- Potassium deficiency disturbs the overall physiological activity within the plant system by altering the activities of enzymes like invertase, catalase in crops like sugarcane.

3.3. Correction measures

- Potassium chloride or muriate of potash constitutes 99% of usage of K fertilizer and potassium sulphate accounts for 1%. Muriate of potash contains 60% K_2O or 50% K and sulphate of potash contains 50 % K_2O or 41.5% K.
- Some crops are sensitive to high amounts of potassium chloride. These include tobacco, grapes, cotton, fruit trees, sugarcane, potatoes, tomatoes, straw berries, onion and cucumber.
- Oil palm and coconut on the contrary appear to be chloride loving crops.

4. Calcium

4.1. Factors influencing Ca availability:

4.1.1. Total calcium supply:

- Soils that have a low cation exchange capacity are typically low in calcium.
- Calcareous and black soils are rich
- Alluvial and acid soils are deficient.

4.1.2. Soil pH:

- Acidic soils tend to be low in calcium due to high aluminum saturation.
- High H^+ activity impede Ca uptake
- High in neutral and alkaline pH (7-8.5)

4.1.3. Type of soil:

- Moderately weathered soils typically have greater amounts of available calcium as compared to highly weathered soil.
- Type of clay influences the availability
- 2:1 require high Ca saturation (>70%), but 1:1 require low (40-50%)

4.1.4. CEC:

- If the cation exchange capacity contains less than 25% calcium, it is recommended that calcium should be applied to the soil.
- Ca availability depends on CEC
- Black soil high CEC with high Ca availability
- Red soil low CEC with low availability

4.1.5. Per cent Calcium Saturation:

- Directly proportional to Ca availability
- Poor base saturation exhibit deficiency

- Below 40-60% reduce the yield of cotton
- 20% or less reduce the yield of soy bean

4.1.6.Ratio of Ca^{2+} to other cation in solution:

- A Ca/total cation ratio of 0.10 to 0.15 is desirable
- Ca^{2+} uptake depressed by NH_4^+,K^+,Mg^{2+}, Mn^{2+} and Al^{3+}
- Absorption increased with supply of NO_3-N

4.2. Deficiency symptoms

1. Blossom end rot of tomato
2. Bitter pit in apple
3. Red brown spots in guava

4.3. Correction measures

Calcium as a plant nutrient is more important in calcium deficient acid soils.The application of carbonate or sulphate salts of calcium @ 2 – 4 q ha-1 in furrows could increase the yield by 48 %.

5. Magnesium

5.1. Factors influencing Mg availability

5.1.1. Soil type:

- Inherently low in magnesium-containing minerals
- Acidic condition, Light textured soils rich in K – less available

5.1.2.Amount of exchangeable Mg:

- Exchangeable Mg^{2+} below 60 ppm cause deficiency
- Highly leached – less availability

5.1.3.Liming:

- Limed with non-magnesium-containing material – low availability

5.1.4.Ratio with other ion:

- Excessive amounts of other cations compete with magnesium and reduces at cation exchange sites
- With a Ca: Mg ratio greater than 10:1 to 15:1, magnesium will likely be deficient.
- K:Mg ratios < 5/1 for field crops, 3/1 for vegetables, 2/1 for fruit crops.
- NH_4^+ induced Mg stress also reported in soil of low Mg.

5.2. Deficiency symptoms

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Mg^{2+} is a mobile element and is readily translocated from older to younger plant parts in the event of deficiency and hence deficiency symptoms are manifested in the older leaves. The magnesium deficient plants usually have less than 0.1% Mg. Magnesium deficiency is common in the plants grown on coarse textured acidic soils.

- As a consequence of Mg^{2+} deficiency, the proportion of protein nitrogen decreases and that of non protein nitrogen increases in plants.
- Shortage of Mg^{2+} results in an interveinalchlorosis of the leaf in which only the veins remain green and the interveinal areas turn yellow with streaky or patchy appearance. In more advanced stages the leaf tissue becomes uniformly pale yellow, then brown and necrotic.
- Affected leaves turn small in final stage and curve upwards at the margins.
- In some vegetables, interveinalchlorosis with tints of red, orange and purple colors is observed
- Grass tetany: Cattle consuming forages with low Mg may suffer from “Hypomagnesemia” (low level of blood Mg) commonly known as Grass tetany. This happens due to high levels of NH_4^+ - N and K application.

5.3. Correction measures

Use of dolomitic lime stone Ca Mg $(CO_3)_2$

Magnesia $\longrightarrow$ Mgo 55 % (Mg)

Basic slag $\longrightarrow$ 3-4 % Mg

- At a dose of 30 – 50 kg ha^{-1}

6. Sulphur

6.1.Factors affecting S transformation in soil

- **Microbial activity**
  - Mineralization and immobilization, oxidation and reduction all depends on microorganisms
  - *Thiobacillus* involved in minerlaization and oxidation
- **Soil temperature**
  - Mineralization impeded at 10^{o}C
  - Then increases with increasing temperature (20 to 40^{o}C)

- Decreases at temperature >40^{o}C

- **Soil moisture**
  - Affects the activity of Sulfatases, the rate of mineralization and the movement of SO_4^{2-} in soil
  - Between PC and WP little influence on mineralization
  - Air drying releases considerable SO_4^{2-} (20 to 80% at room temperature) and readily available to plants
- **Soil pH**
  - S release is directly proportional to pH up to 7.5
  - Near neutral soil pH - more microbial activity - more mineralization
- **Cation effect**
  - Mono valentcations more efficient than divalent ion
  - Na^+ and H^+ influences S transformations
- **Humidity**
  - Increases the rate of mineralization
  - Presence and absence of plants
  - Mineralize more S in presence of plants
  - Due to stimulations of microbial activity in rhizosphere
  - Appreciable immobilization observed in un cropped soils (fallowing)

6.2. Deficiency symptoms

Sulphur content in plants ranges between 0.1 to 0.4 %. In view of the large field scale occurrences of sulphur deficiencies in India, it has been described as the fourth major nutrient after N, P and K. Plants suffering sulphur deficiency accumulate non protein nitrogen in the form of nitrate and amide. N:S ratio of plants is between 9 to 12 : 1. As sulphur is immobile in the plant, its deficiency is manifested on young leaves.

1. The fading of normal green colour of the young meristem followed by chlorosis.
2. Shoot growth is restricted.
3. In *Brassica,* the lamina is restricted and the leaves show cupping owing to the curling of leaves.
4. The older leaves become puckered inwardly with raised areas between veins.
5. The older leaves may develop orange or reddish tints and may be shed prematurely.
6. The stem and leaf petiole may become brittle and may collapse.
7. Reduced synthesis of proteins and oil.

6.3. Management of sulphur or correction measures for S deficiency

1. Application of elemental sulphur or gypsum particularly on alkaline soils.
2. Application of sulphur containing fertilizers like single super phosphate (12-14% S), Magnesium sulphate (30 % S), Ammonium sulphate (24.2% S).
3. For correcting deficiencies of sulphur on the standing crop, foliar application of sulphate containing salts like Ferrous sulphate (32.8% S) and ferrous ammonium sulphate (16% S) etc.

7. Iron

7.1. Factors affecting Fe availability

- **Soil pH –** Increase in pH decreases the availability
    - **For every unit, Fe^{3+} decreases 1000 fold and Fe^{2+} 100 fold**
- **Effect of H_2CO_3 and PO_4:**
    - H_2CO_3 increases the solubility of PO_4 and induce precipitation of $FePO_4$
    - Causes HCO_3 induced chlorosis.
- **Presence of Ca& K**: Antagonistic effect.
- **Organic matter: Increases** the availability and forms chelates.

- **Soil texture :**

- Fine textured soils have more Fe.

- **Water logging :**
  - Anaerobic Fe^{3+} to Fe^{2+} - increases availability
  - Chelates are formed with OM.

8. Manganese

8.1. Factors affecting Mn availability

- **Soil pH:** Mn^{2+} decreases 100 fold for each unit increase in pH.
  - Similar to behavior of other divalent metal cations.
- **OM:** strongly influence. Low availability in high OM.
- **$CaCO_3$:** Decreases solution and exchange Mn due to precipitation as MnO_2.
- **Water logging:** Increases the availability
- **Soil texture:** Fine textured has more total, exchangeable and active Mn.
- **Soil type:**
  - Red and Laterite soil have more available Mn.
  - Montmorillonite clay has high total Mn.
  - Kaolinite clay has more exch. and water soluble Mn.
- **Interaction with other nutrients :**
  - high levels of Cu, Fe or Zn, reduce Mn uptake by plants.
  - Addition of acid forming NH_4^+ enhance Mn uptake
  - Neutral KCl, NaCl, $CaCl_2$ application increase Mn availability.

9. Zinc

9.1. Factors affecting Zinc availability

- **Soil pH:**
  - Decreases with increased pH.
  - Availability between 5 and 7.5
  - Above 8, Zn form Zincate ion as precipitate (insoluble and unavailable)

- **OM:**
  - Increase the availability as chelate.
  - Immobilize by high molecular weight- organic substances like lignin.
- **$CaCO_3$:**
  - Leads to fixation of Zn as $ZnCO_3$ precipitate.
- **Interaction with other nutrients:**
  - Cu, Fe & Mn inhibit Zn^{2+} uptake.
  - Antagonistic effect especially by Cu^{2+}& Fe^{2+}.
  - High P availability induce Zn deficiency.
  - SO_4 and N increases the availability and uptake.
- **Flooding:** normally deficient in flooded soils.
- **Climate:**
  - Zn deficiencies are more during cool, wet season and disappear in warmer weather.
  - Increasing soil temperature increases the availability.

10. Copper

10.1. Factors affecting copper availability

- Soil pH
- $CaCO_3$

- Phosphates
- Clay minerals:
    - Bentonite and Montmorillonite held Cu tightly.
    - Al_2O_3 fix high amount of Cu and reduce availability.

11. Boron

11.1. Factors affecting B availability

- Soil pH.
- $CaCO_3$
- OM
- Irrigation water- B toxicity may occur, if contain high.
- Salt concentration- increases with increasing EC.
- Soil texture
- Type of clay: B adsorption capacities follow the order - mica >montmorillonite> Kaolinite
- Interaction with Ca and K.

12. Molybdenum

12.1. Factors affecting Mo availability

- **Soil pH:** increases with increasing pH (unlike other micronutrients).
- **Liming:** increase the availability.
- **OM:** increase the availability
- **Texture:** Mo availability increased with clay content.
- **Amount of Fe and Al oxides:** strongly adsorbed and becomes available.
- **Interaction with other elements:**
    - P enhances, SO_4 depresses.

- Cu and Mn reduce, but Mg encourages.
- NO_3-N encourages but NH_4-N reduce.

13. Deficiency symptoms

13.1. Zinc

1. Khaira disease of rice
2. White bud in maize
3. Mottle leaf or frenching in citrus
4. Little leaf in mango
5. Fern leaf in potato
6. Rosette appearance

13.2. Copper

1. Exanthema and dieback in citrus
2. Empty glumes in wheat
3. Stem melanosis disease of wheat
4. Reclamation disease
5. Dieback in citrus

13.3. Iron

1. Iron chlorosis in paddy nurseries
2. Iron chlorosis in groundnut

13.4. Manganese

1. Grey speck of oats
2. Speckled yellow of sugarbeet
3. Marsh spot of peas
4. Pahala blight in sugarcane
5. Frenching of tung grass

13.5. Boron

1. Heart rot of sugarbeet

2. Browning or hollow stem of cauliflower
3. Brown heart or black heart in root crops
4. Crown chocking in coconut
5. Top sickness of tobacco
6. Internal cork of apple
7. Cracking of fruits

13.6. <u>Molybdenum</u>

1. Yellow spot in citrus
2. Whiptail in cauliflower

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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Course Name	Soil Fertility and Nutrient Management
Lesson 4	Soil Fertility- Different Approaches for Soil Fertility Evaluation
Content Creator Name	DR S. Sheeba
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	DR J. C. Sharma
University/College Name	Dr. Yaswant Singh Parmar University of Horticulture & Forestry, Nauni- Solan

Objective:

To know different approaches for soil fertility evaluation

1. **Soil fertility evaluation**

- Gives an idea about the nutrient supplying power of the soil.
- Optimum productivity depends on adequate supply of plant nutrients.
- Quantity of nutrients required by plant depends on,
    - Plant species and variety
    - Yield level
    - Soil type
    - Environment (climate, water, temperature, sunlight, etc.)
    - Management
- For optimum productivity, nutrient requirement of the crop and nutrient supplying power of the soil are to be known.
- Based on that, fertilizer recommendation could be given.

2. **Diagnostic Techniques**

Various diagnostic techniques employed to evaluate soil fertility i.e., to assess the nutrient status of a soil

- Nutrient deficiency symptoms of plants
- Analysis of tissue from plants growing on the soil
- Biological tests – growth of higher plants or microorganism
- Soil analysis

Two important tools are

- Soil testing
- Plant analysis

2.1 Nutrient deficiency symptoms

- Growing plants act as integrators of all growth factors.
- Identification and observation of nutrient deficiency in plants
- Visual evaluation of nutrient stress used as a supplement to other diagnostic techniques (soil and plant analysis)
- Apparent visual deficiency symptoms caused by many factors other than specific nutrient stress

2.1.1. Precaution in interpreting deficiency symptoms include

  - Symptom may be caused by more than one nutrient
  - Deficiency of one nutrient may be related to an excessive quantity of another
  - Difficult to distinguish between deficiency symptoms and damage caused by insect, disease or herbicide
  - Symptom may be caused by more than one factor.

2.1.2. Hidden hunger

- Refers to a situation in which a crop needs more of a given nutrient without showing deficiency symptoms

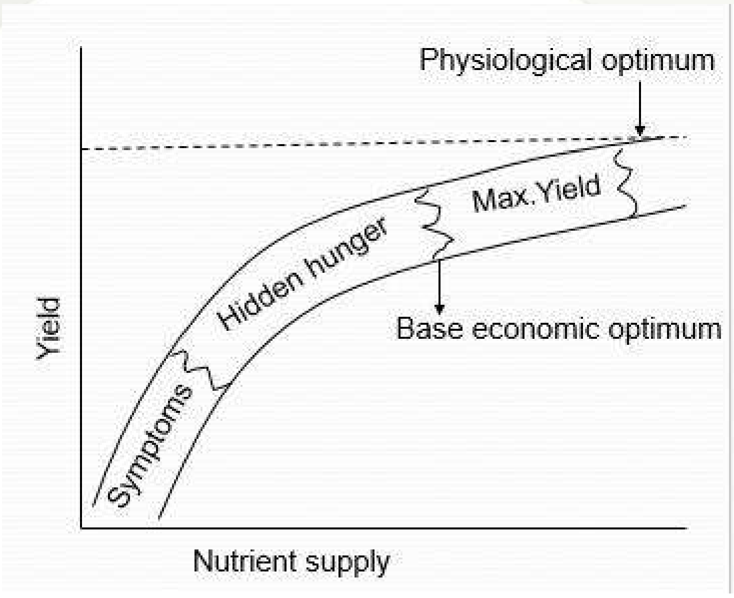

Fig.1 Relation between yield and nutrient supply

2.2. Analysis of tissue from plant (Plant Analysis)

2.2.1. Two general types of analysis

- Tests on fresh tissue in the field
- Tissue analysis performed in the laboratory

2.2.2. Tissue tests / Plant analysis are made for

- To help in identifying deficiency symptoms and to determine nutrient shortages before they appear as symptoms
- To aid in determining the nutrient supplying capacity of the soil
- To aid in determining the effect of fertility treatment on the nutrient supply in the plant
- To study the relationship between the nutrient status of the plant and crop performance

2.2.3. Tissue tests

- Rapid tests for the determination of nutrients in fresh tissue
- Concentration of nutrients in the cell sap
- Plant parts may be chopped up and extracted with reagents
- In more rapid tests, plant tissue is squeezed with pliers to transfer plant sap to filter paper and colour developing reagent are added
- In both the methods, the intensity of resulting colour is compared with standards / standard chart
- Easy to conduct and interpret

➢ Otherwise, for a particular growth period, specific plant parts are tested and they give the best indicators of the nutritional status**.**

Ex: Corn – Flowering – Base of stalk for NO_3,

Midrib, first mature leaf for PO_4 and K

Soybean – Midseason – Pulvinus, first mature leaf for SO_4,
Petiole, first mature leaf for K

Cotton – Early bloom – Petiole basal leaf for NO_3, PO_4&K

➢ In general, latest mature leaf is used for testing, while immature leaves at the top of the plant are avoided.

- Plant parts and time of testing are important

2.2.4. Total Analysis

- Performed on the whole plant or on specific plant parts
- Dried, ground, digested with H_2SO_4/ Triacids (9:2:1)/ Diacids (5:4) and determined the nutrient content
- Plant sampling guidelines
- Critical nutrient concentration (CNC) is commonly used in interpreting plant analysis results and diagnosing nutritional problems.

2.3. Biological Tests

2.3.1. Use of higher plants – By field plot method

2.3.1.1. Simple fertilizer trials (SFT)

- Results of research stations not applicable to farmers field
- SFT gives an idea about the hidden hunger
- Usually the effect of macronutrients are tested
- Ex: 8 treatments – C, N, P, K, NP, NK, PK & NPK

2.3.1.2. Complex field trials

- Micronutrients can also be included
- Many interaction studies are possible
- Recommendations can be extrapolated to other soils with similar characteristics
- Plant analysis of samples collected from various treatments help to establish CNR

2.3.1.3. Strip tests on farmer's fields

- Narrow field strips with selected nutrient treatments can help to verify the accuracy of recommendations
- Place treatments in as similarly uniform areas as possible
- If several soil types or condition occur, each soil type occurs equally in each treatment

- Yield - monitoring is needed

2.3.1.4. Laboratory and greenhouse tests

- Simpler and more rapid techniques utilize small amounts of soil to quantify nutrient availability
- Soils are collected to represent a wide range of soil properties
  Specific nutrient is evaluated
  - Crops sensitive to specific nutrient is used (Ex: Sorghum for Fe)
  - This test reports Fe – deficient and Fe – sufficient soils
  - Decreasing Fe deficiency with increasing DTPA extractable Fe

2.3.2. Neubauer test

- When large number of seedlings are grown in a minimum quantity of soil, it is expected that the seedlings would completely exhaust the soil nutrient (Assumption)
- 100 g of air dried soil + 50 g of coarse sand + 250 g of fine sand – moistened with water
- Glass tube inserted in the soil to provide aeration
- 100 rye seeds sown and grown for 17days
- Seedlings removed, dried and analysed
- Run a blank without soil
- From the experimental values, blank value is deducted

2.3.3. Mitscherlich pot culture method

- Oats or a cereal grown to maturity in pots containing 2.72 kg soil
- Ten treatments – N, P, K in different combinations (No N, N+P(3pots), N+K(3pots), NPK (3 pots)
- Yield increased by each single factor even when it was present in minimum as long as it reached the optimum

$$dy/dx = C_1 (A-Y)$$

- dy – increment in growth for the addition of X growth factor
- C_1 – Proportionality constant (efficiency factor)
- A – Maximum yield   Y – Estimated yield

- Yield from NPK considered as maximum yield (100%)
- Yield of other nutrients converted as percentage increase
- A table arrived between percentage of yield and soil nutrient suggested

2.3.4. Jenny's pot - culture method

- Pots containing 1.81 Kg soils used
- Romaine lettuce (*Lactuca sativa longifolia*) tested for six weeks.
- Treatments: N_0,P_0,K_0; N_{150},P_{150},K_{100}; No-N,No-P,No-K combinations with four replications
- Percentage values grouped in to three categories and a table was arrived

2.3.5. Stanford and Dement Technique

- Modified Neubauer method
- Round waxed card board carbon of 12 or capacity used for sowing the seeds
- After 2 to 4 weeks the seedlings allowed to take the nutrients in second carbon containing 200 g of soil with fertilizer.
- Allowed to feed for 3 to 5 days
- After 5 days plant samples analyzed and assessed for deficiency as marked deficiency, moderately deficiency and little or no deficiency.

2.3.6. Sunflower pot culture technique for boron

- Tested for vigorous extraction for boron from 0.5 Kg soil by sunflower seedlings
- 5 seedlings allowed to grow
- Soil fertilized with solution containing all nutrients except boron.

- Deficiency of boron is noticed and ranked

Deficiency class	Days after B deficiency in noticed
Marked deficiency	< 28
Moderate deficiency	28-36
Little or no deficiency	< 36

2.3.7. Use of indicator plants

- Plants are suited show the deficiency of nutrients
- Symptoms give a definite clue for deficiency of a specific nutrient called as biological indicator or indicator plants

Elements	Deficiency indicator plants
N	Cauliflower, Cabbage
P	Rape seed
K	Potato
Ca	Cauliflower, Cabbage
Mg	Potato
Fe	Cauliflower, Cabbage, Potato
Na	Sugar beet
Mn	Sugar beet, Oats , Potato
B	Sugar beet

2.3.8.Use of microorganisms (microbiological methods)

- General requirements of mineral nutrients for certain microbes is similar to that of crop plants
- Azotobacter plaque test
  - Sackett and Stewarts technique
- Used to find out P_2O_5 and K_2O status of soil
- Soil culture is prepared with P added in one portion, K in
  - another portion and both in a third portion
- Inoculated with Azotobacter and incubated for 72 hours.

Based on the amount of colony growth, the soil is rated.

- **Class I - Very deficient -** None or few to numerous extremely small pin point colonies on the unfertilized plaque.
- **Class II – Moderately deficient–** Few to numerous but small and weak colonies with little or no pigment on the unfertilized plaque**.**
- **Class III – Slight deficient-**The colonies on unfertilized plaques are equal in number and development.
- **Class IV – Not deficient-** Colonies on both fertilized and unfertilized plaques are equal in number and development.Thus a qualitative assesment can be made from the growth and development of azotobactercolonies.

2.3.9. Cunninghamella Plague test (Mechlich, Fred and Trough)

- To determine P_2O_5 deficiency
- Cunninghamella is very sensitive to P
- Soil is mixed with nutrient solution, paste is prepared and spread in clay dish
- Inoculated on the surface with cunninghamella (centre of the paste)
- Allowed to incubate for 41/2 days
- Diameter of mycelial growth denotes P deficiency

Diameter of colonies (mm)	Degree of deficiency
<10	Very deficient
11 - 15	Moderately deficient
16 - 21	Slightly deficient

>22	Not deficient

2.3.10. *Aspergillusniger* test

2.3.10.1. Mechlich technique for available K_2O

- To determine available K_2O content in soil
- Soil is taken in conical flasks and appropriate nutrient solution is added
- Inoculated with Aspergillusniger and inoculated for 4 days
- Weight of mycelial pad and its K_2O content are taken into account

S. No	Weight of pods (g)	K_2O absorbed by 100 g of soil (mg)	Degree of potassium deficiency
1.	<1. 4	<15	Very deficient
2.	1.4 – 2.0	15 - 20	Moderate to slight deficient
3.	>2.0	>20	Not deficient

2.3.10.2. Mulder's test for Cu and Mg

- Colour of mycelia and spores of *Aspergilusniger* indicates deficiency levels
- Known standards are prepared in weighed quantity of soil
- Compare the colour of mycelia and spores with those growing on unknown soils
- This method is extended to other nutrients such as Mo,C0,Mn,S,Zn

Cu in microgram of air dry soils	Deficiency degree	Mg in mg/ 3g of air dry soil
< 0.4	Very deficient	< 50

1.0 – 1.5	Slightly deficient	50 - 100
> 2.0	Not deficient	> 100

2.3.10.3. CO_2 evolution method

- Soil is incubated in a conical flask with compost , super and potash for 10 days
- CO_2 evolution is assessed by absorption in standard $Ba(OH)_2$
- Excess $Ba(OH)_2$ is titrated with standard HCl
- CO_2 evolution is a measure of microbial activity which in term a measure of soil fertility
- Addition of deficient nutrient increase CO_2 evolution

2.4.Soil analysis

- Though plant analyses are valuable in diagnosing the nutrient stress, analysis of soil is so essential to bridge the nutrient supply and crop demand
- Soil test is a chemical method for estimating the nutrient supplying power of a soil
- Soil analysis is the must for fertilizer recommendation to enhance /achieve the crop yield

2.4.1. Objectives of soil analysis

- To provide an index of nutrient availability or supply
- To predict the probability of obtaining a profitable response to manures and fertilizers
- To provide a basis for recommendations of fertilizers
- To evaluate fertility status of soils for a village/state/country to develop nutrient management programmes
- To identify problem areas such as saline, Alkaline or acid condition
- To assess the residual effect of previously added fertilizers, manures and pesticides

Reference

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Course Name	Soil Fertility and Nutrient Management
Lesson 5	Soil Testing for Available Nutrients and Critical Levels of Different Nutrients in Soil
Content Creator Name	DR S. Sheeba
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	DR J. C. Sharma
University/College Name	Dr. Yaswant Singh Parmar University of Horticulture & Forestry, Nauni- Solan

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Objective:

- To get acquainted with soil testing for different available nutrients
- To know the critical levels of different nutrients in soil

1. Soil analysis

- Though plant analyses are valuable in diagnosing the nutrient stress, analysis of soil is so essential to bridge the nutrient supply and crop demand
- Soil test is a chemical method for estimating the nutrient supplying power of a soil
- Soil analysis is the must for fertilizer recommendation to enhance /achieve the crop yield

1.2. Objectives of soil analysis

- To provide an index of nutrient availability or supply
- To predict the probability of obtaining a profitable response to manures and fertilizers
- To provide a basis for recommendations of fertilizers
- To evaluate fertility status of soils for a village/state/country to develop nutrient management programs.
- To identify problem areas such as saline, Alkaline or acid condition
- To assess the residual effect of previously added fertilizers, manures and pesticides

1.3. Methods of soil analysis

S.No	Nutrients analyzed	Methods
1	Total N	Digestion with H_2SO_4 and distillation
2	Available N	Alkaline $KMnO_4$
3	Organic carbon	Chromic acid oxidation
4	Total P	HCl extract by ammonium molybdate
5	Available P	Olsens and Bray
6	Total K	HCl extract

7	Available K	Neutral normal NH_4OAc
8	Total S/Available S	By gravimetry or turbidimetry using 0.15 % $CaCl_2$
9	Total Ca & Mg	Versenate method (0.02N EDTA)
10	Micronutrients	By AAS through DTPA/ Hot water/ oxalic acid

In addition, lime requirement for acid soil and gypsum requirement for alkali soils

1.4. Soil testing- Nutrient recommendation system:

1.4.1. Four consecutive steps

- Collect a representative soil sample from the field
- Determine the quantity of available nutrients
- Interpret the soil test results (soil test calibration)
- Estimate the quantity of nutrient required by the crop (Nutrient recommendation)

Table 1. Critical limits for available macronutrients

S.No	Nutrients	Low	Medium	High
1.	Organic Carbon (%)	<0.5	0.5-0.75	>0.75
2.	Available N (Kg ha^{-1})	<280	280-450	>450
3.	Available P (Kg ha^{-1})			
	Olsen P	< 11	11-22	>22
	Bray P	<24.2	24.2-49.7	>49.7
4.	Available K (Kg ha^{-1})	< 118	118-280	>280

Table 2. Critical Limits for Available Micronutrients as followed in Tamil Nadu

S.No	Elements	Deficient	Moderate	Sufficient
1.	$CaCl_2$ S (mg kg^{-1})	<10	10-15	>15
2.	DTPA Fe (mg kg^{-1})	<3.7	3.7-8.0	>8.0
3.	DTPA Mn (mg kg^{-1})	<2.0	2.0-4.0	>4.0
4.	DTPA Zn (mg kg^{-1})	<1.2	1.2-1.8	>1.8

5.	DTPA Cu (mg kg^{-1})	<1.2	1.2-1.8	>1.8
6.	Hot Water Soluble Boron (mg kg^{-1})	<0.45	0.45-1.0	>1.0

Table 3. Ratings for Soil pH as followed in Tamil Nadu

S.No	**Parameter**	**Acidic**	**Neutral**	**Alkaline**
1.	pH	<6.5	6.5-7.5	>7.5

Table 4. Ratings for Soil EC as followed in Tamil Nadu

S.No	**Parameter**	**Non Saline**	**Slightly Saline**	**Saline**
1.	EC (dSm^{-1})	upto1.0	1.1-3.0	>3.0

Course Name	Soil Fertility and Nutrient Management
Lesson 6	Plant Analysis- Total and Rapid Tissue Tests- Critical levels of Nutrients in Plants
Content Creator Name	DR S. Sheeba
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Course Reviewer Name	DR J. C. Sharma
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Objective:

- To know different techniques in plant analysis

Introduction

Although plant analysis is an indirect evaluation of soil, it is a valuable supplement to soil testing. Plant analysis is useful in confirming nutrient deficiencies, toxicities or imbalances, identifying hidden hunger, evaluating fertilizer programme and determining the availability of elements. Sometimes adequate nutrients may be present in the soil, but because of other problems like soil moisture and inadequate amounts of some other nutrients, the plant availability of the nutrient in question may be constrained. Plant analysis is based on the fact that the amount of a given element in plant is an identification of the supply of that particular nutrient and as such is directly related to the quantity in the soil.

For most diagnostic purposes, plant analyses are interpreted on the basis of critical value approach, which uses tissue nutrient concentration calibrated to coincide 90% or 95% of the maximum yield, below which the plants are considered to be deficient and above that value sufficient.

Two general types of plant analysis are in use.

1. The tissue test which is customarily made on fresh tissue in the field.
2. Total analysis performed in the laboratory with precise analytical techniques.

1. Tissue Tests:

Rapid tests for the determination of nutrient elements in the plant sap of fresh tissue. In these tests, the sap from ruptured cells is tested for unassimilated nitrogen, phosphorus and potassium. They are semi quantitative tests mainly intended for verifying or predicting deficiencies of N, P or K. The results are read as low, medium or high. Through the proper application of tissue testing it is possible to anticipate or forecast certain production problems which still in the field. The concentration of the nutrients in the cell sap is usually a good indication of how well the plant is supplied with nutrients at the time of testing.

1.1. **Plant Part to be selected**: In general the conductive tissue of the latest mature leaf is used for testing.

1.2. **Time of Testing**: The most critical stage of growth for tissue testing is at the time of bloom or from bloom to early fruiting stage. Nitrates are usually higher in the morning than in the afternoon if the supply is short.

Test for nitrates → Diphenylamine

Phosphates → Molybdate + Stannous oxalate test

For potassium → Sodium cobalti nitrate

2. Total Analysis:

Total analysis is performed on the whole plant / plant parts**.** Precise analytical techniques are used for measurement of the various elements after the plant material is dried, ground and ashed and used for estimating total nutrient content.

3. Critical Nutrient Concentration:

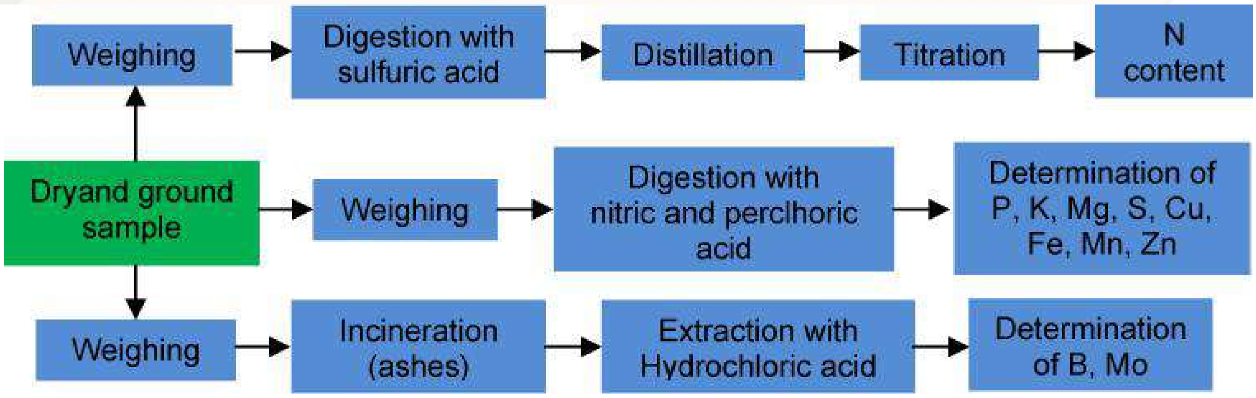
Critical Nutrient Concentration is the level of a nutrient below which crop yield, quality or performance is unsatisfactory. However it is difficult to choose a specific concentration. For crops such as sugarbeet, excessive concentration of N seriously affects the quality. So, CNC is maximum rather than a minimum consequently it is more realistic to use the critical nutrient range (CNR) which is defined as the range of nutrient concentration at a specified growth stage above which the crop is amply supplied and below which the crop is deficient.

Table 1. Critical concentrations of major nutrients in plants

Essential element	**Critical limits(%)**
Nitrogen	2.50-4.50
Phosphorus	0.20-0.75
Potassium	1.50-5.50
Sulphur	0.25-1.00

Sample preparation for analysis

- Place paper sample bag (do not use waxed or plastic bags) in oven set at 70-80 ^{o}C. Drying may require 12 to 24 hours depending on the original condition of sample.
- To facilitate rapid drying, loosen and separate plant parts in sample bag.
- Samples should be dried to a crisp and brittle state and ground immediately.
- Assign laboratory number to data sheet and sample submission form.



Steps for sample preparation

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Course Name	Soil Fertility and Nutrient Management
Lesson 7	DRIS Method, Deficiency Symptoms-Indicator Plants, Biological Method of Soil Fertility Evaluation
Content Creator Name	DR S. Sheeba
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	DR J. C. Sharma
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Objective:

- To acquire knowledge about DRIS and soil fertility evaluation techniques

1. Diagnosis and Recommendation Integrated System (DRIS)

DRIS proposed by Beaufils (1973) which considers nutrient concentration ratios rather than individual elemental concentration for interpreting plant tissue composition. The DRIS approach measures the relative balance between nutrients by means of index values with negative values indicating insufficiencies and vice versa. DRIS reveals not only the limiting nutrient but also the order in which the nutrients are likely to become limiting. It is a comprehensive system which identifies all the nutritional factors limiting crop production and in doing so increases the chances of obtaining high crop yields by improving the fertilizer recommendations. Index values which measure how far particular nutrients in the leaf or plant is deviating from the optimum are used in the calibration to classify yield factors in the order of limiting importance.

To develop a DRIS for a given crop the following requirements must be met.All factors suspected of having an effect on crop yield must be defined.

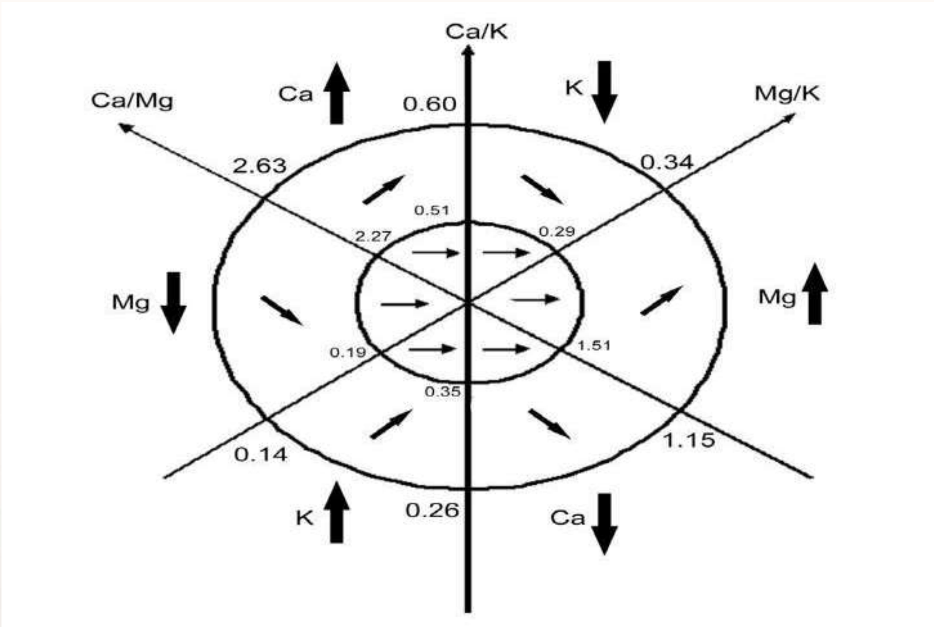
1. The relationship between these factors and yield must be defined.
2. Calibrated norms must be established.
3. Recommendations suited to particular set of conditions and based on correct and judicious use of these norms must be continuously refined.

1.1. Establishment of DRIS Norms:

Large number of sites is selected at random in order to represent the whole production area. At each site plants and soil samples are taken for all essential element analyses. The entire population of observation is divided into two subpopulations (high and low yielders) on the basis of vigour, quality and yield. Each element in the plant is expressed in as many ways as possible. For eg: Nutrient ratios N/P, N/K or products NxP, NxK etc. Each form of expression which significantly discriminates between high and low yielding sub populations is retained as a useful diagnostic parameter. The mean values of all the sites for each of these forms of expression then constitute the diagnostic norms.

NPK requirement of the crop is diagnosed using DRIS chart. The chart is constructed of three axes for N/P, N/K and K/P represented with mean values of the sub populations of the high yielder. The concentric circle can be considered as confidence limits. Horizontal arrows (→) in the inner circle indicate the balance between nutrients. Diagonal arrows indicate (↗↘) a tendency to imbalance. The inner being set at + 15% and outer at the mean + 30% for each expression. Vertical (↓↑) arrows representing nutrient imbalance. The arrow notation can be replaced by DRIS indices.

Fig 1. DRIS chart



1. The importance of nutritional balance is taken into account.
2. The norms for the elemental content can be universally applied.
3. Diagnosis can be made over wide ranges of stages.
4. The nutrients limiting the yield either through excess or insufficiency can be readily identified.

2. **Indicator plants**:

Certain plants are very sensitive to deficiency of a specific plant nutrient and they produce specific symptoms which are different from other deficiency symptoms. Thus the deficiency of that element can easily be detected. The indicator plants are the following

Element	**Deficiency indicator plant**
N	Cauliflower, Cabbage
P	Rape seed

K	Potato
Ca	Cauliflower, Cabbage
Mg	Potato
Fe	Cauliflower, Cabbage, Potato
Na	Sugar beet
Mn	Sugarbeet, Oats, Potato
B	Sunflower

3. **Microbiological test:**

By using various cultures of microorganisms soil fertility can be evaluated. These methods are simple, rapid and need little space. Winogradsky was one of the first to observe in the absence of mineral elements certain microorganisms exhibited a behaviour similar to that of higher plants. Microorganisms are sensitive to deficiency of nutrients and could be used to detect the deficiency of any nutrient. A soil is treated with suitable nutrient solutions and cultures of various microbial species (bacteria, fungi) and incubated for a few days. Then observing the growth and development of organisms in terms of weight or diameter of the mycelia pad, the amount of nutrient present in the soil is estimated.

Ex: a. Azotobactor method for Ca, P and K.
b. Aspergillus niger test for P and K
c. Mehlich's Cunninghamella (Fungus)- plaque method for phosphorus
d. Sackett and Stewart techniques (Azotobacter culture) to find out P and K status in the soil.

4. Laboratory tests

Neubauer seedling Method:

- The Neubauer seedling technique is based on the uptake of nutrient by growing a large number of plants on a small amount of soil. The seedlings (plants) exhaust the available nutrient supply within short time.

- The total nutrients removed are quantified and tables are established to give the minimum values of nutrients available for satisfactory yield of various crops.

Reference

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Course Name	Soil Fertility and Nutrient Management
Lesson 8	Soil Test Based Fertilizer Recommendations to Crops
Content Creator Name	DR S. Sheeba
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	DR J. C. Sharma
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Objective:

To get acquainted with the Soil Test Based Fertilizer Recommendations to Crops

1. Basic concept

A unique field experimental approach (Inductive methodology) as followed in the All India Coordinated Research Project for Investigation on Soil Test Crop Response Correlation studies was evolved through creating a macrocosm of soil fertility variability within a microcosm of an experimental field (Ramamoorthy *et al*., 1967) by applying graded doses of fertilisers. The relationship between soil available nutrients and grain yield was outlined by Truog (1960) and Ramamoorthy*et al.* (1967) established the fact that there exists a linear relationship between the nutrient absorbed by the plant and the grain yield or economic produce.This provides a scientific basis for balanced fertilization not only between fertilizer nutrients but also with the soil available nutrients. Since different levels of uncontrolled variable (Eg. soil fertility) cannot be expected to occur at one place, in the present approach, all the needed variation in soil fertility level is obtained by deliberately creating it in one and the same field experiment in order to reduce the heterogeneity in the soil population studied, management practices adopted and climatic conditions prevailing.

2. Experimental Technique

To achieve this, the following experimental technique is followed.

- ❖ A level field of about 0.5 ha which has low to medium level of soil fertility and representative of the experimental station or area is to be chosen and a composite soil sample is collected and analysed for its initial soil characteristics.
- ❖ The field is divided into three equal strips and eight pre sowing soil samples from each strip are collected from 0-15 cm and 15-30 cm depth and analysed for available N, P and K status.
- ❖ The first strip receives no fertiliser (NPK), the second and the third receive one (NPK) and two times (NPK) a standard dose of N, P and K respectively. The standard dose of P and K are fixed taking into account the phosphorus and potassium fixing capacities of the soil and the standard dose of N is fixed as per the general recommendation for the gradient crop.

- ❖ An exhaust or gradient crop is grown so that the fertilisers undergo transformations in the soil with plant and microbial agencies.
- ❖ After the harvest of this exhaust crop, twenty four soil samples one from each plot are taken and analysed for available N, P and K status and compared with the pre-sowing results for confirming the creation of soil fertility variations.
- ❖ In the subsequent season, each strip is divided into 24 sub-plots. Twenty one fertiliser treatments from 4 x 4 x 4 levels of N, P_2O_5 and K_2O in addition to 3 absolute controls are randomly allotted in each of the three strips.
- ❖ Across the strips, three levels of organic manures (0, 1 and 2) are superimposed. The treatments are randomised in such a way that all the 24 treatments occur on either direction and the test crop is grown.
- ❖ Pre-sowing soil samples are collected from each sub-plot and analysed for available N, P and K status by different soil test methods.
- ❖ The test crop is grown with good agronomic practices and is harvested at maturity.
- ❖ After harvest, grain and haulm yields are recorded and total nutrient uptake is determined plot wise.
- ❖ Post-harvest soil samples are collected and analysed for available N, P and K status.

3. Calculation of basic parameters

Using the data on the yield of economic produce, total uptake of N, P and K, initial soil test values for available N, P and K and doses of fertilizer N, P_2O_5 and K_2O applied, the basic parameters *viz*., nutrient requirement (NR), contribution of nutrients from soil (Cs), fertilizer (Cf) and organic manure (Co) are computed as furnished below.

a. Nutrient requièrent (NR) kg q^{-1}

$$\text{N required/quintal of economic produce production} = \frac{\text{Total uptake of N (kg ha}^{-1})}{\text{Yield of economic produce(kg ha}^{-1})}$$

$$\text{P}_2\text{O}_5\text{ required/quintal of economic produce production} = \frac{\text{Total uptake of P}_2\text{O}_5\text{ (kg ha}^{-1})}{\text{Yield of economic produce(kg ha}^{-1})}$$

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K_2O required/quintal of economic produce production $= \frac{\text{Total uptake of } K_2O \text{ (kg ha}^{-1}\text{)}}{\text{Yield of economic produce(kg ha}^{-1}\text{)}}$

b. Per cent nutrient contribution from soil to total nutrient uptake (Cs)

$$\text{Percent contribution of N from soil} = \frac{\text{Total uptake of N in control plot (kg ha}^{-1}\text{)}}{\text{Soil test value for available N in control plot (kg ha}^{-1}\text{)}} \times 100$$

$$\text{Percent contribution of } P_2O_5 \text{ from soil} = \frac{\text{Total uptake of } P_2O_5 \text{ in control plot (kg ha}^{-1}\text{)}}{\text{Soil test value for available } P_2O_5 \text{ in control plot (kg ha}^{-1}\text{)}} \times 100$$

$$\text{Percent contribution of } K_2O \text{ from soil} = \frac{\text{Total uptake of } K_2O \text{ in control plot (kg ha}^{-1}\text{)}}{\text{Soil test value for available } K_2O \text{ in control plot (kg ha}^{-1}\text{)}} \times 100$$

c. Per cent nutrient contribution from fertilizer to total uptake (Cf)

$$\text{Percent contribution of N from fertilizer} = \frac{(\text{total uptake of N in treated plot (kg ha}^{-1}\text{)}) - (\text{Soil test value for available N in treated plot (kg ha}^{-1}\text{)} \times \text{avg Cs})}{\text{Fertilizer N applied (kg ha}^{-1}\text{)}} \text{x100}$$

$$\text{Percent contribution of } P_2O_5 \text{ from fertilizer} = \frac{(\text{total uptake of } P_2O_5 \text{ in treated plot (kg ha}^{-1}\text{)}) - (\text{Soil test value for available } P_2O_5 \text{ in treated plot (kg ha}^{-1}\text{)} \times \text{avg Cs})}{\text{Fertilizer } P_2O_5 \text{ applied (kg ha}^{-1}\text{)}} \text{x100}$$

$$\text{Percent contribution of } K_2O \text{ from fertilizer} = \frac{(\text{total uptake of } K_2O \text{ in treated plot (kg ha}^{-1}\text{)}) - (\text{Soil test value for available } K_2O \text{ in treated plot (kg ha}^{-1}\text{)} \times \text{avg Cs})}{\text{Fertilizer } K_2O \text{ applied (kg ha}^{-1}\text{)}} \text{x100}$$

d. Percent nutrient contribution from organics to total uptake (Co)

i) Percent contribution from organic manure

$$\text{Percent contribution from organics} = \frac{(\text{total uptake of N/P/ K in treated plot (kg ha}^{-1})-(\text{Soil test value for available N/P/ K in OM treated plot (kg ha}^{-1})\times\text{avg Cs})}{\text{Fertilizer N/P/ K appliedthrough organic manure (kg ha}^{-1})}\text{x}100$$

4. Targeted yield equations under IPNS

Making use of these parameters, the fertilizer prescription equations under IPNS are developed for various crops as furnished below.

i) Fertilizer nitrogen (FN)

$$FN = \frac{NR}{Cf}\,T - \frac{C_s}{Cf}\,SN - \frac{C_0}{Cf}\,ON$$

ii) Fertilizer phosphorus (FP_2O_5)

$$FP_2O_5 = \frac{NR}{Cf}\,T - \frac{C_s}{Cf} \times 2.29 \times SP - \frac{C_0}{Cf} \times 2.29 \times OP$$

iii) Fertilizer potassium (FK_2O)

$$FK_2O = \frac{NR}{Cf}\,T - \frac{C_s}{Cf} \times 1.21 \times SK - \frac{C_0}{Cf} \times 1.21 \times OK$$

Where,

FN : Fertilizer N (kg ha^{-1});FP_2O_5: Fertilizer P_2O_5 (kg ha^{-1})

FK_2O : Fertilizer K_2O (kg ha^{-1}); NR:Nutrient requirement of N or P_2O_5 or K_2O (kg ha^{-1})

Cs : Per cent contribution from soil;Cf:Per cent contribution from fertilizer

SN : Soil test value for available N (kg ha^{-1}); SP:Soil test value for available P (kg ha^{-1})

SK: Soil test value for available K (kg ha^{-1}); Co: Per cent contribution from organic manure;
ON: Quantity of N applied through organic manure; OP: Quantity of P applied through organic manure; OK: Quantity of K applied through organic manure.

By substituting the required parameters in the fertilizer prescription equations under IPNS, fertilizer doses are arrived at for desired yield target of crops for a range of soil test values (nomograms). The Fertiliser Prescription equations (FPEs) are valid only under the following situations:
i) They should be used for the same or allied soil type ii) The maximum target should be based on the genetic character and the highest yield achieved for that crop in that area iii) FPEs must be used within the experimental range of soil test values and cannot be extrapolated iv) Good and recommended agronomic practices are to be followed v) Other micro and secondary nutrients should not be yield limiting vi) Locally available organic manures or crop residues may be made use of.

5. Research accomplishments of STCR Project in Tamil Nadu

The All India Coordinated Research Project on Soil Test Crop Response Correlation is in operation since 1967 in the Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore. Since then, the test crop experiments are being conducted based on inductive methodology and soil test crop response correlations are arrived at. Fertilizer Prescription Equations (FPEs) under IPNS have been developed for desired yield targets of 25 crops *viz.*, rice, wheat (hills & plains), sorghum, maize (*vars*. &hybrids), ragi, greengram, blackgram, groundnut, sunflower, gingelly, sugarcane, cotton (vars.&hybrid), onion, bhendi, tomato, cabbage, cauliflower, potato, carrot, beetroot, radish, tapioca, chilli, turmeric and ashwagandha on 16 soil series in Tamil Nadu. Fertiliser recommendations have also been developed for emerging technologies *viz.,* rice under SRI, drip fertigation, transgenic cotton *etc.* and also for rainfed transgenic cotton and rainfed hybrid maize.

6. Test Verification trials / Front Line Demonstrations

The soil test based fertiliser prescriptions developed for various crops were verified at farmers' holding on similar and allied soil series. The results of the test verification trials proved the validity of the equations by recording +/- 90 per cent of the yield targets aimed at. After validation, front line demonstrations were conducted with various crops and soils in different agro-climatic zones of Tamil Nadu with a view to popularize the STCR-IPNS technology. The results of the demonstrations have brought forth the possibility of increasing the productivity and profitability of crops and efficiency of added nutrients and created an awareness among the farmers about the STCR-IPNS technology.

Reference

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Course Name	Soil Fertility and Nutrient Management
Lesson 9	Factors Influencing Nutrient use Efficiency (NUE)
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Course Reviewer Name	DR J. C. Sharma
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Objective:

- To understand the factors affecting the nutrient use efficiency (NUE)
- To know the techniques and schedule of nutrients for different crops under rainfed and irrigated conditions

Introduction:

Nutrient use efficiency (NUE) may be defined as yield per unit input. In agriculture, this is usually related to the input of fertilizer, whereas in scientific literature, the NUE is often expressed as fresh weight or yield per content of nutrient. Improvement of NUE is an essential pre-requisite for expansion of crop production in marginal lands with low nutrient availability. NUE not only depends on the ability to efficiently take up the nutrient from the soil, but also on the transport, storage, mobilization, usage within the plant, and even on the environment. Nutrient use efficiency is defined as the extent to which the nutrients and management practices interact to give a specified yield level.

$$\text{NUE}\ (\%) = \frac{\text{yield with applied nutrient} - \text{yield without applied nutrient}}{\text{amount of nutrient applied}} \times 100$$

1. Factors affecting NUE

1.1. Soil factors: The most important factors are soil physical conditions, soil fertility and soil reaction. On soils with poor physical condition, plant growth will be poor due to impeded drainage, restricted aeration and unfavourable soil temperature due to which the nutrients will not be used efficiently. Coarse textured soils are usually poorer in available nutrients than fine textured soils. On such soils nitrogen and potassic fertilizers should be more frequently applied than in fine textured soils. The higher the fertility status of the soil, the lower is the response. Soil reaction is an important consideration in the selection of right type of Fertilizers. The higher the organic matter status, the more is the nutrient use efficiency.

1.2. Climatic factors: include temperature, rainfall and its distribution, evaporation, length of day and growing season. Rate of nitrification is slower in cooler climate than in warmer climate, hence more amounts of fertilizers should be added in cool climate. Higher amount of fertilizers are required in high rainfall region due to leaching to obtain an expected yield potential. In arid regions, soil moisture is a limiting factor to get higher nutrient use efficiency. The higher the light intensity, the better is the nutrient use efficiency.

1.3. Crop factors: CEC of plant roots influences the fertilizer responsiveness of the crop. A large ramifying root system of the plant absorbs nutrients more efficiently. The time of application of fertilizer should match the pattern of nutrient uptake to increase nutrient use efficiency. For legumes N fertilizer may be reduced as they can fix atmospheric N to increase N use efficiency.

1.4. **Agronomic factors**: include selection of fertilizer responsive crops and varieties, timely sowing, proper spacing, proper dose, time and method of fertilizer application to increase the yield and thereby increasing NUE.

2. How to enhance nutrient use efficiency

Use efficiency of any nutrient can be increased by achieving potential yields of crops by optimizing the factors of crop production.

1. Selection of suitable crops and varieties, which are input responsive recommended for the region.
2. Sowing or planting the crops at optimum time.
3. Maintaining optimum plant population.
4. Use of organic manures and bio fertilizers to supplement nutrients and also to bring ideal conditions for crop growth.
5. Inclusion of legumes in the cropping system as intercrop.
6. The crops should be irrigated at least to save life at critical growth stages.
7. Fertilizer scheduling must be based on soil test values to prevent nutrient deficiencies or luxury consumption.
8. P and K fertilizer and part of N fertilizer should be applied as basal and N in splits doses; for light textured soils K also should be applied in splits.
9. Band placement of fertilizers preferable to prevent losses. (Especially P to reduce fixation).
10. Under moisture stress condition, foliar application of urea at 2%concentration is effective.
11. Micronutrient deficiencies should be corrected instantly.

12. ZnSO4 should be applied as package once in two seasons @ 25-50 kg/ha.
13. Problem soils must be ameliorated by taking reclamation measures.

NUE of individual nutrients also can be increased by following the above management practices along with some specific measures as follows

3. Nitrogen use efficiency: can be increased through

- Split application of nitrogenous fertilizers to prevent losses due to leaching.
- The use of slow release nitrogenous fertilizer like urea formaldehyde, sulphur coated urea, Neem coated urea etc.
- Use of nitrification inhibitor (Eg: N-serve) to retard the conversion of NH_4^+-N to NO_3^--N to prevent leaching and make it available to crops for quite longer period.
- By the integration of inorganic N with organic sources the soil physical condition can be optimized besides adding nutrients to the soil.

4. P use efficiency can be increase by decreasing P fixation and balanced application of the nutrients. P fixation can be reduced by judicious application of organic manures, application of P fertilizer by placement, inoculation (either seedor soil) with phosphorus solubilising bacteria like *Pseudomonas*, *Bacillusmegathrium*var. *phosphaticum*.

5. K use efficiency: can be enhanced by preventing leaching loss either by split application on light soils, applying organic manure and balanced application of nutrients.

6. S use efficiency: Sulphur in soil solution is present as $SO_4^=$ and more prone for leaching losses. The losses can be prevented by applying organic manures to improve water holding capacity of the soil and it also acts as a source of S. Oxidation can be facilitated by providing oxidized conditions in the soil.

7. Fe use efficiency: Most available form of iron is Fe^{2+}. All the measures which govern the soil reaction will influence Fe availability. Fe availability is more in acidic soil pH.

- Application of organic manures including green manuring improve the use efficiency of iron by

i. Acidifying the rhizosphere due to the release of organic acids
ii. Supplementing with iron after decomposition

iii. Act as substrate for heterotrophic bacteria that can reduce ferric to ferrous form (eg.,*Bacillus, Clostridium and Klebsiella*etc.).

iv. The microbes also produce chelating ligands called as 'siderophores' that can form complex with Fe^{3+}, which can be absorbed into the plant.

- Reclamation of alkali soils
- If deficiency appears on standing crop foliar application of Fe.

8. Zn use efficiency

- Zn fertilizer should not be applied with phosphatic fertilizers.
- Maintaining the soil pH between 5.5 – 6.5 by applying organic manures.

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Course Name	Soil Fertility and Nutrient Management
Lesson 10	Integrated Plant Nutrient Supply System and its Management
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Objective:

- To understand Integrated Plant Nutrient Supply System

1. INM

Integrated nutrient management is the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner. Integrated nutrient management (INM) is an approach that seeks to both increase agricultural production and safeguard the environment for future generations.

2. Need for INM:

2.1. Essential Nutrients:

Plant growth is the result of a complex process whereby the plant synthesizes solar energy, carbon dioxide, water, and nutrients from the soil. In all, between 21 and 24 elements are necessary for plant growth. The primary nutrients for plant growth are nitrogen, phosphorus, and potassium (known collectively as NPK). When insufficient, these primary nutrients are most often responsible for limiting crop growth. Nitrogen, the most intensively used element, is available in virtually unlimited quantities in the atmosphere and is continually recycled among plants, soil, water, and air.

According to Swami Nathan, **"Soils in India are often not only thirsty but also hungry".** Inputs are needed for output. Therefore what we need is a reduction in the use of market purchased chemicals inputs. It is in this context that integrated nutrient supplies suitable for easy adoption include crop rotations, green manures and bio fertilizers. Biodynamic systems that make significant use of compost and humus will help to improve soil structure and fertility.

3. INM for sustainable agriculture:

Sustainable agriculture should ideally be based on integrated plant nutrition system (IPNS). The IPNS aims at use of chemical fertilizers, organic manures, crop residues, animal wastes and bio fertilizers in an integrated manner.

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4. INM—characters:

- Technically sound
- Environmentally friendly
- Economically viable
- Socially acceptable and
- Practically feasible.

5. Importance of INM:

It is a strategy that incorporates both organic and inorganic plant nutrients to attain higher crop productivity, prevent soil degradation, and thereby help meet future food supply needs. It relies on nutrient application and conservation, new technologies to increase nutrient availability to plants, and the dissemination of knowledge between farmers and researchers.

6. Goal of INM:

Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased output and incomes, especially for low-income groups, without depleting the natural resource base. In this context, INM maintains soils as storehouses of plant nutrients that are essential for vegetative growth. INM's goal is to integrate the use of all natural and man-made sources of plant nutrients, so that crop productivity increases in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations. INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers.

The goals of INM are:

- Maintain economic yield
- Reduce environmental pollution
- Integrate soil fertility restoring crops and livestock
- Crop residue recycling

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- Improve nutrient cycling
- Promote the use of organic manure
- Application of bio-fertilizers
- Development and introduction of better-quality genotypes
- Promote balanced use of fertilizers

7. Components of integrated nutrient management:

The main objective of the INM is to efficiently utilize all the sources of plant nutrients viz., soil nutrients, chemical fertilizers, organic manures and crop residues, green manures, biologically fixed N and bio fertilizers.

- **Fertilizers**- Fertilizer is any material of natural or synthetic origin added to the soil to supply one or more plant nutrients.
- **Organic Manure**- Organic manure is defined as the product resulting from the controlled biological decomposition of organic matter.
- **Green Manures**- green undecomposed material used as manure is called as green manure. Crops grown for green manure are known as green manure crops. There are two types of green manuring i.e., Green manuring in-situ and Green leaf manuring
- **Crop Residue**- The crop residue is the material left after the harvesting of crop and byproduct of agriculture based industry. Some of the examples of crop residues are stalks, leaves, and stems etc and processed residue like seed, bagasse, and roots etc.
- **Biofertilizers-** Biofertilizers are defined as 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.

  Importance of Biofertilizers:

  1. Biofertilizers are known to make a number of positive contributions in agriculture. • Supplement fertilizer supplies for meeting the nutrient needs of crops.

2. Add 20 – 200 kg N/ha (by fixation) under optimum conditions and solubilise/mobilise 30-50 kg P_2O_5/ha.
3. They liberate growth promoting substances and vitamins and help to maintain soil fertility.
4. They suppress the incidence of pathogens and control diseases.
5. Increase the crop yield by 10-50%. N_2 fixers reduce depletion of soil nutrients and provide sustainability to the farming system.
6. They improve soil physical properties, tilth and soil health.

Reference:

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