SAC 125: Soil Nutrient Management (1+1)

Lecture 1- Soil fertility- Introduction

Soil productivity and soil fertility are two terms which always create confusion in our minds. Soil fertility is the status or the inherent capacity of the soil to supply nutrients to plants in adequate amounts and in suitable proportions. Soil productivity is the capacity of the soil to produce crops with specific systems of management and is expressed in terms of yields. All productive soils are fertile, but all fertile soils need not be productive. It may be due to some problems like water logging, saline or alkaline condition, adverse climate etc. Under these conditions, crop growth is restricted though the soil has sufficient amounts of nutrients.

According to modem usage, soil fertility is the capacity of the soil to produce crops of economic value and to maintain health of the soil without deterioration.

Differences between soil fertility and productivity

Soil Fertility	Soil Productivity
It is an index of available nutrients to plants	It is a broader term used to indicate yields
It is one of the factors for crop production. The other factors are water supply, slope of the land, depth of water table etc.	It is the interaction of all the factors that determine the magnitude of yields
It can be analyzed in the laboratory	It can be assessed in the field under particular climatic conditions
It is the potential status of the soil to produce Crops	It is the resultant of various factors influencing soil management

It is very essential to manage soil fertility in such a way that one gets maximum production from his land. For better fertility management, one should always consider what elements are needed for a particular crop and in what quantity, and of the total requirements, how much is present in the soil. The first step, therefore, is to find out the soil fertility status i.e. what is the capacity of the soil to supply elements may be balanced and timely to avoid the following ill effects of unbalanced use of fertilizers:

1. Excess of elements (Mn, Cu and Zn) may be toxic to living materials (protoplasm) of the plant.
2. Excess of one plant food element may cause deficiency of another such as:

(a) Excess of N causes K starvation in certain crops like potato,
(b) Excess of K causes deficiency of Mn in tomato,
(c) Excess of P causes deficiency of Zn in most of the crops.

Apart from these, imbalanced fertilization increases cost of production because any amount more than required does not help in producing higher crop yields. Thus, the consumption of more than required quantity of elements is called **'luxury consumption'**, which is nothing but a waste. This type of loss is in addition to leaching, washing and other losses of elements. Thus, it is necessary for an agriculturist to know the fertility status of' his soil which is to be used for crop production. For evaluating soil fertility status, several techniques are commonly employed.

1. Nutrient deficiency symptoms of plants
2. Analysis of tissue from plants growing on the soil
3. Biological tests in which the growth of either higher plants or certain micro-organisms is used as a measure of soil fertility
4. Soil fertility

Manipulation of different factors to increase productivity

1. Climate

a	Rainfall	Manipulation
	i Quantity	Less – irrigation and moisture conservation, management of rainwater More – drainage
	ii Distribution	Adjustment of cropping time and sequence, cropping as per safe growing period;contingent plans
b	Air temperature	High – Modulation by wind breaks, shelterbelts, mulching Low- Adjusting time of planting; avoiding vulnerable
c	Light	
	Quantity	Orientation of crops, spacing (increase LAI and LAD) to harvest more light and increase PAR
	Intensity	Shading, avoiding coinciding grain filling period to high temperature and light intensity
	Duration	Choice of short duration crops, multiple cropping to increase total yield
d	Altitude	Growing of day neutral an thermo and photo insensitive crops
e	Wind velocity	Win belt, shelter belt, establishment of sand dunes
f	CO_2 concentration	Choice between C3 and C4 plants, more C4 plants (maize and sugarcane)

Lecture-2: Plant nutrients – Major nutrients, their forms, functions, deficiency symptoms and correction measures

Since centuries, it is known that roots of terrestrial plants obtain nourishment from the soil. During the first half of the nineteenth century, it was found that plants need certain chemical elements referred to as essential elements and that elements are absorbed by roots principally as inorganic ions. These inorganic ions in soils are derived mostly from mineral constituents of the soil. The term mineral nutrient is generally used to refer to an inorganic ion obtained from the soil and required for plant growth. The process of absorption, translocation and assimilation of nutrients by the plants is known as mineral nutrition.

Criteria of essentiality

Plant analysis reveals that plant body contains about 30 elements and in some cases as many as 60 elements. The presence of several elements in plant does not mean that all these are essential for plants. Arnon and Stout (1939) proposed criteria of essentiality which was refined by Arnon (1954). An element is considered as essential, when plants cannot complete vegetative or reproductive stage of life cycle due to its deficiency; when this deficiency can be corrected or prevented only by supplying this element; and when the element is directly involved in the metabolism of the plant. This criterion is considered as too rigid from practical point of view.

According to this criterion, sodium is considered as nonessential. However, sodium is known to increase yield of several crops such as sugar beet, turnip and celery. Therefore, a farmer considers sodium as an essential element. Nicholas (1961) proposed the term 'functional nutrient' for any mineral element that functions in plant metabolism whether or not its action is specific. With this criterion, sodium, cobalt, vanadium, nickel and silicon are also considered as functional nutrients in addition to 16 essential elements. Although, Al is not an essential plant nutrient, its concentrations in plant can be high when soils contain relatively large amounts of Al in soil solution. In fact, plants absorb many non-essential elements and over 60 elements have been identified in plant materials. When plant material is burned, the remaining plant ash contains all the essential and non-essential mineral elements except C, H, O, N and S which are burned off as gases. The plant content of mineral elements is affected by many factors and their concentration in crops varies considerably. Plant nutrient data are valuable to successful fertilizer management programs and can be used to help establish fertilizer recommendations.

Essential elements

Plants (16): C, H, O, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, Cl and B. Plants need 16 elements for their growth and completion of life cycle. They are: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, boron, molybdenum and chlorine. In addition, five more elements *viz*., sodium, cobalt, vanadium, nickel and silicon are absorbed by some plants for special purposes. All these elements are not required for all plants, but all have been found essential for one plant or the other. Among these, all carbon atoms and most of the oxygen atoms are derived from carbon dioxide, which is assimilated principally in photosynthesis. More specifically, approximately one-third of oxygen atoms in organic material in higher plants are derived from soil water and two-thirds from carbon dioxide of the atmosphere. The elements C, H, O are not minerals. The rest of the elements are absorbed from the soil and these are called mineral elements since they are derived from minerals. These mineral elements are mainly absorbed in ionic form and to some extent in non-ionic form as shown in Table below.

Table 1: Forms of mineral elements absorbed by plants

Mineral element	**Ionic form**	**Non Ionic form**
Nitrogen (N)	NO_2, NO_3	CO $(NH_2)_2$
Phosphorus (P)	P_2O_5	Nucleic acid, phytin
Potassium(K)	K_2O	
Calcium (Ca)	Ca^{2+}	
Magnesium (Mg)	Mg^{2+}	
Sulphur (S)	$S0^{4"}$	SO_2
Iron (Fe)	Fe^{2+} , Fe^{3+}	FeSO4 with EDTA
Manganese (Mn)	Mn2+	$MnSO_4$ with EDTA
Zinc (Zn)	Zn^{2+}	$ZnSO_4$ with EDTA
Copper (Cu)	Cu^{2+}	$CuSO_4$ with EDTA
Boron (8)	$B4O_7^{2-}$,$H_2BO_3^-$, $HB0_3^{2-}$	
Molybdenum (Mo)	Mo O_4^{2-}	
Chlorine (CI)	CI	

CLASSIFICATION OF ESSENTIAL ELEMENTS

The essential elements can be classified based on the amount required, their mobility in the plant and soil, their chemical nature and their functions inside the plant. .

Amount of Nutrients

Depending on the quantity of nutrients present in plants, they can be grouped into three:***Basic Nutrients.*** The basic nutrients viz. carbon, hydrogen and oxygen, constitute 96 percent of total dry matter of plants. Among them, carbon and oxygen constitute 45 per cent each.The total dry matter produced by rice crop in one season is about 12 t/ha. In this 5.4 t is carbon,5.4 t is oxygen and 0.7 t is hydrogen. ***Macronutrienls.*** The nutrients required in large quantities are known as macronutrients. They are N, P, K, Ca, Mg, and S. Among these, N, P and K are called primary nutrients and Ca, Mg and S are known" as secondary nutrients. The later are known as secondary nutrients as they are inadvertently applied to the soils when N, P and K fertilizers, which contain these nutrients,are used.

Micronutrienls. The nutrients which are required in small quantities are known as micronutrients or trace elements. They are Fe, Zn, Cu, B, Mo and Cl. These elements are very efficient and minute quantities produce optimum effects. On the other hand, even a slight deficiency or excess is harmful to the plants.

Functions in the Plant

Based on the functions, nutrients are grouped into four:

(1) Elements that provide basic structure to the plant-C, H and O.

(2) Elements useful in energy storage, transfer and bonding-N, S and P. These are accessory structural elements which are more active and vital for" living tissues.

(3) Elements necessary for charge balance-K, Ca and Mg. These elements act as regulators and carriers.

(4) Elements involved in enzyme activation and electron transport_Fe, Mn, Zn, Cu, B, Mn and Cl. These elements are catalysers and activators.

Mobility in the Soil

Mobility of nutrients in the soil has considerable influence on availability of nutrients to plants and method of fertilizer application. For plants to take up these nutrients, two processes are important: (1) movement of nutrient ions to the absorbing root surface, and (2) roots reaching the area where nutrients are available. In the case of immobile nutrients, the roots have to reach the area of nutrient availability and forage volume is limited to root surface area. For highly mobile nutrients, the entire volume of the root zone is forage area.
Based on the mobility in the soil, the nutrient ions can be grouped as mobile, less mobile and immobile. The mobile nutrients are highly soluble and are not adsorbed on clay complex; e.g.:$N0_3$-, $S0_4^{2-}$, $B0_3$-, Cl-, Mn^{2+}. Less mobile nutrients are also soluble, but they are adsorbed on clay complex and so their mobility is reduced; e.g.: NH+, K+, Ca+, Mg++, Cu++. Immobile nutrient ions are highly reactive and get fixed in the soil; e.g.: HPO_4^{2-}, H_2PO_4-, Zn^{++}

Mobility in Plants

Knowledge of the mobility of nu\fients in the plant helps in finding what nutrient is deficient. A mobile nutrient in the plant, moves to the growing points in case of deficiency. Deficiency symptoms, therefore, appear on the lower leaves.

1. N, P and K are highly mobile.
2. Zn is moderately mobile.
3. S, Fe, Mn, Cu, Mo and CI are less mobile.
4. Ca and B are immobile.

Chemical Nature

The nutrients can be classified into cations and anions and metals and non-metals based on their chemical nature.
Cations: K, Ca, Mg, Fe, Mn, Zn, Cu,
Anions: NO_3, H_2, PO_4, SO_4
Metals: K, Ca, Mg, Fe, Mo, Zn, Cu,
Non-metals: N, P, S, B, Mo, Cl

Functions/Role of plant nutrients

Every nutrient plays a specific role in nutrition, growth and development of plants. These roles may be described as under:
Carbon. It is available in abundance from air. Green plants for photosynthetic activities use CO_2. It is also required for cell formation in plants. About 45% or more part, of the plant tissues is made up of carbon.
Hydrogen. It is essential for cell and tissue formation in plants. This is obtained from water and is required for energetic reactions. It forms about 6% parts of the plant tissues.
Oxygen. Plants take oxygen from air and water. It forms about 43% parts of the plant structure. It is required for photosynthetic and respiratory activities. It helps in formation of tissues and cells.

Mineral elements

Nitrogen. It is a major structural part of the cell. Cytoplasm and the particulate fractions of the cell organelles contain nitrogen in varying amounts, which exist in combination with C, H, O,P and S. Primary cells are found to have about 5% of nitrogen. It plays a vital role in various metabolic activities of plants and is a constituent part of amino acids, proteins, nucleic acids, porphyrins, flavins, purine and pyrimidine nucleotides, enzymes, co-enzymes and alkaloids. It helps in harvesting solar energy through chlorophyll, in energy transformation through phosphorylated compounds, in transfer of genetic information through nucleic acids. Besides, it is essential in cellular and protein metabolism and acts as biological catalyst.

Phosphorus. It plays a vital role as a structural component of cell constituents and metabolically active compounds. It is a structural part of the membrane system of the cell, the chloroplasts and mitochondria. It is a part of sugar phosphates-ADP, ATP, etc. nucleic acids, nucleoproteins, purine, pyrimidine nucleotides, flavin nucleotides and many co-enzymes *viz.*
NADP, pyridoxyl phosphate and thiamine phosphate. The most essential constituents of plant cells like esters, phosphatides and phospholipids are synthesized by phosphorus when it combines with different organic acids. It also plays an important role in energy transformations and various metabolic activities of plants. Being a constituent of adenosine phosphate, phosphoglyceraldehyde and ribulose phosphate, it helps in basic reactions' of photosynthesis and activates several enzymes participating in dark reactions in photosynthesis.

Potassium. It helps in the maintenance of cellular organization by regulating the permeability of cellular membranes and keeping the protoplasm in a proper degree of hydration by stabilizing the emulsions of colloidal particles. Its salts stabilize various enzyme systems. It plays a catalytic role in activating several enzymes as incorporation of amino-acids in proteins, synthesis of peptide bonds etc. Presence of potassium is essential for optimal activation of aldehyde dehydrogenase, phosphate acetyle transferase etc. *in vitro.* Potassium increases resistance in plants against drought, heat frost and various diseases caused by fungi nematode and other micro-organisms. It helps in formation of mechanical tissues in cereals resulting into resistance to lodging. In fruit crops it improves colour, flavour and increases the size and weight of the fruits.

Calcium. Calcium regulates the permeability of cellular membrane. It is a structural part of the chromosomes in which it binds the DNA with protein. It is required by a number of enzymes for their proper functioning *viz.* lipase, phosphatase D, £ Amylase and Apyrase. It makes the stems stiff and thereby reduces lodging in cereals. It also neutralizes the organic acids formed within the plant body and eliminates their toxic effects. Calcium accelerates nitrogen fixation in legumes and helps in boosting nitrogen uptake by plants.

Magnesium. Being constituent part of polyribosomes, it helps in protein synthesis in the plants. Mg is also a constituent part of chromosomes and chlorophyll. It plays a catalytic role of numerous enzymes concerning carbohydrate metabolism, phosphate transfer and decarboxilations. It is involved in photosynthesis and organic acid metabolism. Mg helps in synthesis of fat and increases oil content in oilseed crops when it combines with sulphur.

Sulphur. It helps in synthesis of protein and amino acids like cystein, methionine, vitamins (thiamine and biotine), lipoic acid, acetyl coenzyme A, ferredoxin and glutathione. It forms active sulphate- 3 phosphoadenosine-5 phosphosulphate which synthesizes glucosides in mustard oil, pungency in onion, radish etc. It is required in conversion of nitrogen into protein in symbiotic nitrogen fixing legumes. It is involved in activating enzymes participating in the dark reactions of photosynthesis and carbohydrate metabolism of plants. It increases oil content in soybean, groundnut and linseed.

Iron. It forms cytochromes, heam and metalloproteins like ferredoxin and heamoglobin in plants. These cytochromes play a vital role in oxidative and photophosphorylations during respiratory electron transport and photosynthesis, respectively. The ferredoxin helps in reduction of carbon dioxide, sulphate and of atmospheric nitrogen. It synthesizes chlorophyll precursor (protoporphyrin-9), which forms chlorophyll in green plants. Its specific requirement has been identified in synthesis of enzymes like oxido-reductase, sulphate oxidase, catalase, peroxidise and aconitase etc. Being a constituent part of metabolically active compounds, iron is responsible for all major metabolic processes in plants.

Manganese. Being a part of nitrite reductase and hydroxylamine reductase, it helps in the nitrogen assimilation. It activates several enzymes related to oxidation-reductions (oxidoreductase), hydrolysis (hydrolases), breakdown of phosphates bonds in ATP or ligases. It activates photosynthesis and nitrogen metabolism. It also accelerates enzyme participating in calvin cycle, helps in chlorophyll and chloroplast synthesis for boosting photosynthetic rates.

Copper. It helps in oxidation-reduction process in plants. The compounds containing copper like plastoquinones and plastocyanins help in electron transport from chlorophyll to NADP and from water to chlorophyll during photosynthesis.

Zinc. It regulates the auxin concentration in plants and helps in synthesis of protein, carotein and chlorophyll etc.

Molybdenum. It helps in protein and amino acid synthesis. It accelerates nitrogen-fixing efficiency of aerobic (Azotobacter), anaerobic (Clostridium), blue-green algae, Azolla and symbiotic bacteria. It regulates the carbohydrate metabolism in plants.

Boron. It regulates development and differentiation of vascular tissues formation and lignification of cell-wall. It is associated with reproductive phase in plants and under imbalanced nutrition it causes sterility and malformation in reproductive organs. It is involved in carbohydrate metabolism, particularly in translocation of photosynthates. It boosts nodulation in legumes, regulates water absorption and is essential for synthesis of ATP, DNA, RNA and pectins.

Chlorine. During photosynthesis it helps in evolution of oxygen. It is a part of anthocyanin and affects protein synthesis. It increases turgor pressure.

Cobalt. It is required for symbiotic and non-symbiotic nitrogen fixation. It is a part of vitamin B-12.

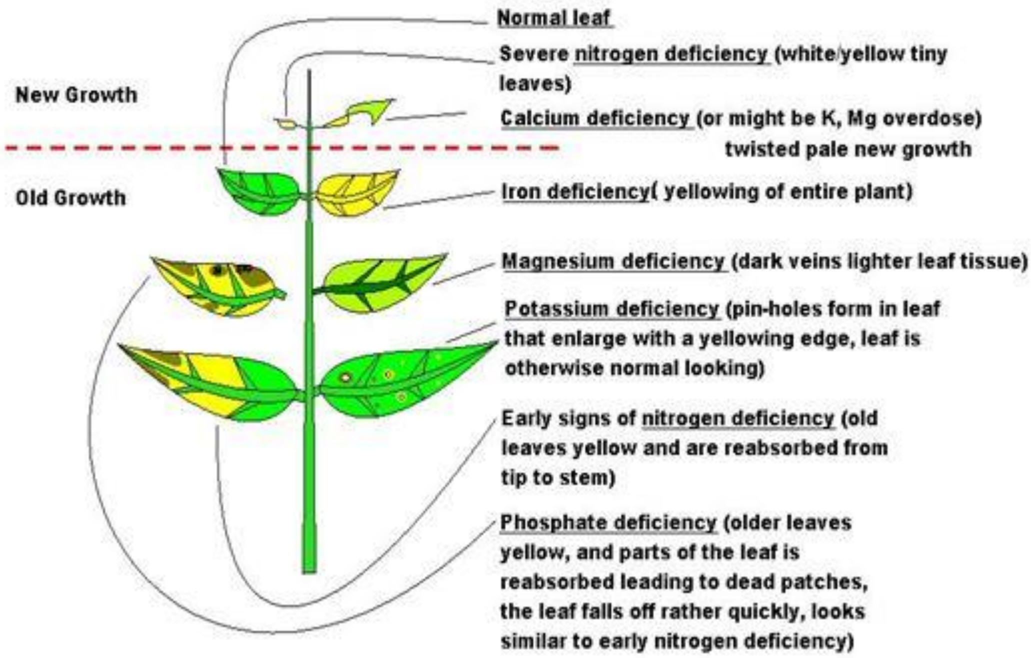
Sodium. It maintains the osmotic pressure. It also regulates water uptake by plants. Plants take sodium as a substitute for potash under deficient potash supply.

Lecture-3: Plant nutrients – Deficiency symptoms and correction measures

NUTRIENT DEFICIENCY

In the absence of any particular element, plants show certain morphological changes. These morphological changes are indicative of certain element deficiencies and are called deficiency symptoms. The deficiency symptoms vary from element to element and they disappear when the deficient mineral nutrient is provided to the plant. However, if deprivation continues, it may eventually lead to the death of the plant. The parts of the plants that show the deficiency symptoms also depend on the mobility of the element in the plant. For elements that are actively mobilised within the plants and exported to young developing tissues, the deficiency symptoms tend to appear first in the older tissues. For example, the deficiency symptoms of nitrogen, potassium and magnesium are visible first in the senescent leaves. In the older leaves, biomolecules containing these elements are broken down, making these elements available for mobilize younger leaves.

The deficiency symptoms tend to appear first in the young tissues whenever the elements are relatively immobile and are not transported out of the mature organs, for example, elements like sulphur and calcium are a part of the structural component of the cell and hence are not easily released. This aspect of mineral nutrition of plants is of a great significance and importance to agriculture and horticulture.



Identification of deficiency symptoms

The deficiency symptoms can be distinguished based on the (1) region of occurrence (2) presence or absence of dead spots, and (3) chlorosis of entire leaf or intervienal chlorosis. The region of appearance of deficiency symptoms depends on mobility of nutrient in plants.

The nutrient deficiency symptoms of N, P, K, Mg and Mo appear in lower leaves because of their mobility inside the plants. These nutrients move from lower leaves to growing leaves thus causing deficiency symptoms in lower leaves.

Zinc is moderately mobile in plants and deficiency symptoms, therefore, appear in middle leaves. The deficiency symptoms of less mobile elements (S, Fe, Mn and Cu) appear on new leaves. Since Ca and B are immobile in plants, deficiency symptoms appear on terminal buds. Chlorine deficiency is less common in crops.

Deficiency symptoms on old leaves

The symptoms that appear on old leaves can be further distinguished based on the presence or absence of dead spots.

Without dead spots. The characteristic deficiency symptom of nitrogen is uniform yellowing of the leaves including the veins. The leaves become stiff and erect especially in cereals. The leaf may detach after a little forceful pull in extreme deficiency in dicotyledonous crops. Cereal crops show characteristic 'V' shaped yellowing at the tip of lower leaves. In phosphorus deficiency, leaves are small, erect, unusually dark green with a greenish red, greenish brown or purplish tinge. The rear side develops bronzy appearance. Magnesium deficiency also causes yellowing, but differs from that of nitrogen. The yellowing takes place in between the veins and the veins remain green. The leaf is not erect. The leaf detaches very easily and may be shed by blowing wind. Necrosis (death of tissues) occurs in extreme cases only in the margins.

With dead spots. In potassium deficiency, yellowing starts from tips or margins of leaves extending to the centre of leaf base. These yellow parts become necrotic (dead spots) very soon. There is sharp difference between green and yellow and yellow and necrotic portions. The dead spots appear particularly on margins and tips. .Molybdenum deficiency causes translucent spots of irregular shape in between the veins of leaves. These spots are light green, yellow or brown in colour. The affected spots are impregnated with resinous gum which exudes from rear side of the leaf from the reddish brown spots. Defficiency diseases of Mo

***Whip tail*:** The deficient plants show chlorotic mottling between the veins in older and middle leaves. Under severe deficiency the leaves show scorching and withering which start from the margins and spreads over entire lamina except petiole. It gradually extends to young leaves, if the deficiency continues. The affected young leaves fail to expand, growing point becomes necrotic and growth of the plant is arrested. These symptoms are termed as *"whip tail"* in cauliflower and other *Brassica spp.*

***Scald*:** The tomato leaves show chlorotic mottling and inward curling of leaf margins. The older leaves of radish show interveinal yellowish green mottling, they become papery, bleached and have downward cupping. Similar symptoms appear in beans, which are called as 'Scald'.

***Yellow spot of citrus*:** In cereals the middle leaves becomes golden yellow at the tip during ear head emergence stage. Affected leaves become dry and papery while younger leaves become spirally twisted. Similar symptoms appear in citrus and the deficiency disease is called as "yellow spot of citrus".

Deficiency symptoms on new leaves

These symptoms may be spread over entire leaf or the veins may remain green.

Veins Remaining Green. Veins remain green in iron and manganese deficiency. In iron deficiency, the principal veins remain conspicuously green and other portions of the leaf turn yellow tending towards whiteness. Under severe deficiency, most part of the leaf becomes white. In manganese deficiency, the principal veins as well as the smaller veins are green. The interveinal portion is yellowish, not tending towards whiteness. Dead spots also appear at a later stage. There is a chequered appearance to the leaf. Manganese deficiency diseases:

Grey spec of oats: Middle and old leaves of oats develop small grey or buff coloured patches which are prominent near the margins and come upto slightly above the base. These patches convert into brown streaks of necrotic areas and leaves wither. The growth of both top and roots is stunted and grain yield becomes miserably poor.
Speckled yellows of sugar beet: In this interveinal areas of sugar beet develop yellowish green chlorotic mottled areas. The chlorotic areas turn into necrotic ones resulting into breaking of lamina. The leaf margins of such leaves roll upwards and turn into triangular or an arrow shaped outline which remain upright.
Marsh spot of peas: When plants of garden peas and other beans are affected with Mn deficiency at fruiting stage, the central part of the cotyledons become brown and necrotic which disintegrate and become hollow at later stages.
Pahala blight of sugarcane**:** The interveinal space of middle and young leaves of the affected sugarcane plants develop chlorotic tripes which first turn into necrotic spots and later into red stripes. These leaves split and dry later.
Frenching of tung trees: Manganese deficiency causes chlorotic mottling between the veins, which later turn into necrotic spots and affected leaves shed prematurely.
Veins not Remaining Green. The leaf becomes yellowish due to sulphur deficiency, but looks like nitrogen deficient leaf. The leaf is small and the veins are paler than interveinal portion.No dead spots appear. Plant does not lose the lower leaves as in the case of N deficiency.
In copper deficiency, leaf. is yellowish tending towards whiteness. In extreme deficiency, chlorosis of veins occur and leaf loses lustre. Leaf is unable to retain its turgidity and hence, wilting occurs. Leaf detaches due to water soaked conditions of the .base of petiole. .

Terminal buds

The deficiency symptoms of Ca and B are many times seen on new leaves. However, it is easy to recognize their deficiency symptoms on the terminal buds or growing points than on new leaves. In calcium deficiency, the bud leaf becomes chlorotic white with the base remaining green. About one-third chlorotic portion of the tip hooks downward and becomes brittle. Death of terminal bud occurs in extreme cases. Boron deficiency causes yellowing or chlorosis which starts from the base to tip. The tip becomes very much elongated into a whip like structure and becomes brownish or blackish brown. Death of the terminal bud occurs in extreme cases.

Boron deficiency diseases:

Heart-rot of sugar beet and marigold. *The* young central leaves of the crown do not expand and become severely curled. The petiole and the basal part of the midrib turn brown or black and become very brittle. Older leaves turn yellow with scorched or withered appearance. The entire crown becomes necrotic and starts decaying.
Browning or hollow stem of cauliflower. Leaf margins becomes chlorotic and curled and lamina becomes brittle. The curd enlarges, turns brown, necrotic and starts decaying. The pith becomes hollow, necrotic and forms a large cavity.
Top sickness of tobacco. The youngest leaves fail to open and remain pale green for some time which afterwards turn necrotic and disintegrate. The older leaves become thicker and very brittle. The auxiliary buds sprout and show same symptoms.

Lecture 4: Nutrient management (corrective measures)

Nutrient deficiency can be correct by (i) addition of nutrient through fertilizer in soil as well as foliar application and (ii) addition of organic manure as per fertilizer recommendation.

Deficiency of Nutrient	Corrective measures
N	(1) Use of nitrogen fertilizer in the soil. (2) Foliar spray of urea.
P	Application of phosphatic fertilizer in the soil e.g., DAP, super phosphate
K	Use of potassic fertilizer in the soil e.g., muriate of potash.
Ca	Use of calcium carbonate or calcium hydroxide in the soil.
Mg	Soil or foliar application of magnesium sulphate.
S	Soil or foliar application of sulphur or sulphate.
Fe	Soil or foliar spray of ferrous sulphate.
Mn	Soil or foliar spray of manganese sulphate.
Zn	Soil or foliar application of zinc sulphate
B	Soil or foliar spray of boric acid or borax
Cu	Soil or foliar spray of copper sulphate
Mo	Soil or foliar application of sodium molybdate or ammonium molybdate.

NUTRIENT TOXICITY AND MANAGEMENT

The requirement of micronutrients is always in low amounts while their moderate decrease causes the deficiency symptoms and a moderate increase causes toxicity. In other words, there is a narrow range of concentration at which the elements are optimum. Any mineral ion concentration in tissues that reduces the dry weight of tissues by about 10 per cent is considered toxic. Such critical concentrations vary widely among different micronutrients. The toxicity symptoms are difficult to identify. Toxicity levels for any element also vary for different plants. Many a times, excess of an element may inhibit the uptake of another element.

Nutrient toxicities in crops are more frequent for manganese (Mn) and boron (B) than for other nutrients.

Manganese toxicity is found on acid soils. It is important to know that manganese competes with iron and magnesium for uptake and with magnesium for binding with enzymes. Manganese also inhibits calcium translocation in shoot apex. Therefore, excess of manganese may, induce deficiencies of iron, magnesium and calcium. Thus, what appears as symptoms of manganese toxicity may actually be the deficiency symptoms of iron, magnesium and calcium.

Boron toxicities occur in irrigated regions where the well or irrigation waters are exceptionally high in B. Most other nutrient toxicities occur when large amounts of nutrients in question have been added in waste, e.g., sewage sludge. Crops grown near mines and smelters are prone to nutrient toxicities. Generally, the symptoms of toxicity in crops occur as burning, Chlorosis and yellowing of leaves. Toxicities can result in decreased yield and/or impaired crop quality.

Prevention of toxicity

(1) With the exception of Mo, toxicity of other nutrients can be reduced by liming.

(2) Following recommended rates of fertilizers and the safe and controlled use of waste materials, such as sewage sludge and coal fly ash, should reduce metal loading and nutrient toxicity in crops.

(3) Use of crop species and genotypes less susceptible to toxicity are recommended where toxicity is suspected.

(4) Provided sufficient drainage because availability of nutrients like Fe and Mn is increases up to toxicity level under water logged condition.

(5) Ground water must be monitored regularly, if content of B and Cl is too high stop to applied water or applied with dilution.

(6) Addition of sufficient amount of organic matter binds some of the toxic elements.

(7) Ploughing in dry soil so increase the infiltration rate and leach the toxic element with rain water.

Lecture 5: Sources of nutrients - Fertilizers and their classification

Fertilizers are industrially manufactured chemicals containing plant nutrients. Nutrient content is higher in fertilizers than in organic manures. The nutrients are released almost immediately.

Classification of fertilizers

Fertilizers are classified into straight, complex and mixed fertilizers. Straight fertilizers are those which supply only one primary plant nutrient, namely nitrogen or phosphorus or potassium. Urea, ammonium sulphate, potassium chloride, potassium sulphate are some of the straight fertilizers. Complex fertilizers contain two or three primary plant nutrients of which two primary nutrients are in chemical combination. These fertilizers are usually produced in granular form. When the fertilizer contains only two of the primary nutrients, it is designated as incomplete complex fertilizer, while the one containing all three primary nutrients, (N, P_2O_5 and K_2O) is designated as complete complex fertilizers.

In contrast to the straight fertilizers complex fertilizers are much more desirable for balanced treatment of the soil. Commercial complex fertilizers being manufactured in India are:

1. Nitrophosphates also known as nitric-phosphates, and
2. Ammonium phosphate sulphate, Diammonium phosphate and Urea ammonium phosphate.

Mixed fertilizers are physical mixtures of straight fertilizers. They contain two or three primary plant nutrients. Mixed fertilizers are made by thoroughly mixing the ingredients either mechanically or Manually. Sometimes, complex fertilizers containing two plant nutrients are also used in formulating fertilizer mixtures. The 'complete fertilizer' is one that contains three major plant nutrients, namely nitrogen, phosphoric acid and potash. The experimental results obtained in recent years indicate that for certain soils and crops a complete fertilizer should also carry other plant nutrients like calcium, magnesium, sulphur, copper, zinc, etc., while for certain regions only one or two nutrients would be required. In other words, a complete fertilizer irrespective of the number of nutrients, should meet the nutritional requirements of the soil and crops.

Types of Fertilizer Mixtures

Open-formula fertilizer mixtures: The formulae of such fertilizers in terms of kinds and quantity of the ingredients mixed are disclosed by the manufacturers. Knowing the formula, cultivator or the extension man is able to judge the type and quality of the nutrients and their suitability for specific soils and crops, and is able to determine roughly the quantity of sand or other inert material contained in any fertilizer mixture. Closed-formula fertilizer mixtures: The ingredients or straight fertilizers used in such mixtures are not disclosed. So these mixtures have the disadvantage that the farmer cannot know the type and quality of the nutrients in them. Fertilizers can also be classified based on physical form: solid and liquid fertilizers. Most of the fertilizers are in solid form. The solid fertilizers are in several forms *viz.* dust (single superphosphate), crystals (ammonium sulphate), prills (urea, diammonium phosphate, superphosphate), granules (Holland granules), super granules (urea super granules) and briquettes (urea briquettes). Some of the fertilizers are in liquid form for applying with irrigation water or for direct application. Ease of handling, less labour requirement and possibility of mixing with herbicides have made the liquid fertilizers more acceptable to farmers. Liquid fertilizers are of two types: (1) clear liquid fertilizers and (2) suspension liquid fertilizers. When the nitrogenous, phosphatic, potassic and other fertilizer materials are completely dissolved in water, these are called clear liquid fertilizers.

Suspension liquid fertilizers are those in which some of the fertilizer materials are suspended as fine particles.

Every fertilizer mixture is sold with a declared 'fertilizer grade' which refers to the guaranteed analysis of its plant nutrients. The word analysis, as applied to fertilizers, is used to designate the percentage composition of the product expressed in terms of N, P_2O_5 and K_2O. A 5-10-10 fertilizer mixture is guaranteed to contain 5 per cent total nitrogen, 10 per cent available P_2O_5, 10 per cent water-soluble K_2O.

Types of Fertilizer Mixtures

Open-formula fertilizer mixtures: The formulae of such fertilizers in terms of kinds and quantity of the ingredients mixed are disclosed by the manufacturers. Knowing the formula, cultivator or the extension man is able to judge the type and quality of the nutrients and their suitability for specific soils and crops, and is able to determine roughly the quantity of sand or other inert material contained in any fertilizer mixture.

Closed-formula fertilizer mixtures: The ingredients or straight fertilizers used in such mixtures are not disclosed. So these mixtures have the disadvantage that the farmer cannot know the type and quality of the nutrients in them.

Fertilizers can also be classified based on physical form: solid and liquid fertilizers. Most of the fertilizers are in solid form. The solid fertilizers are in several forms *viz.* dust (single superphosphate), crystals (ammonium sulphate), prills (urea, diammonium phosphate, superphosphate), granules (Holland granules), super granules (urea super granules) and briquettes (urea briquettes). Some of the fertilizers are in liquid form for applying with irrigation water or for direct application. Ease of handling, less labour requirement and possibility of mixing with herbicides have made the liquid fertilizers more acceptable to farmers. Liquid fertilizers are of two types: (1) clear liquid fertilizers and (2) suspension liquid fertilizers. When the nitrogenous, phosphatic, potassic and other fertilizer materials are completely dissolved in water, these are called clear liquid fertilizers. Suspension liquid fertilizers are those in which some of the fertilizer materials are suspended as fine particles.

Fertilizers are grouped based on the nutrient present in the fertilizers namely, nitrogenous fertilizer, phosphatic fertilizer, potassic fertilizer, boron fertilizer etc.

Acidity and Basicity of Fertilizers

Application of fertilizers increases acidity or basicity of soils depending on the nature of fertilizers. Fertilizers which leave an acid residue in the soil are called acid-forming fertilizers. The amount of calcium carbonate required to neutralize the acid residue is referred to as its equivalent acidity.

Equivalent basicity of basic fertilizers	
Fertilizer	Equivalent basicity
Sodium nitrate	29
Calcium nitrate	21
Calcium cynaide	63
Dicalcium phosphate	25

Lecture 6: Nitrogenous, Phosphatic and Potassic fertilizers

NITROGENOUS FERTILIZERS

The fertilizer materials containing N are called nitrogenous fertilizers. They may contain secondary nutrients like calcium and sulphur. Nitrogenous fertilizers are classified into four groups based on the chemical form of N in the fertilizer. Fertilizers containing N in the form of nitrate (NO_3) are called nitrate fertilizers. Examples of nitrate fertilizers are: sodium nitrate ($NaNO_3$) and calcium nitrate $Ca(NO_3)_3$. The general characteristics of nitrate fertilizers are: (1) they are highly mobile in soils and are, therefore, suitable for top dressing, (2) highly soluble and subjected to leaching, (3) subjected to denitrification in waterlogged soils, and (4) increase alkalinity as they are basic in their residual effect. Fertilizers containing nitrogen in the form of ammonium are called ammoniacal fertilizers.

The general characteristics of these fertilizers are:

(1) easily available to plants as they are readily soluble in water, (2) leaching losses are less as ammonium ions are adsorbed on clay complex, and (3) reduce alkalinity as they are acidic in their residual effect on the soils. These fertilizers are well suited to submerged soils. Some ammoniacal fertilizers are: ammonium sulphate $(NH_4)_2SO_4$ (20% N), ammonium chloride NH_4Cl (24 to 26% N), anhydrous ammonia NH_3 (82% N). Nitrate and ammoniacal fertilizers contain N in the form of both nitrate and ammonium. These are acidic in nature. Leaching losses are less. Nitrate N is readily available to plants for rapid growth and ammoniacal nitrogen is available at a later stage of the crop. Example of nitrate-ammoniacal fertilizers are: Ammonium nitrate, NH_4NO_3 (33 to 34% N) and calcium ammonium nitrate, $CaNH_4NO_3$ (20% N).

Amide fertilizers contain nitrogen in the form of amide. These fertilizers are also known as organic fertilizers since they contain carbon atoms. Though plants can take nitrogen in amide form, it is converted into ammoniacal and nitrate form in the soil which plants generally utilize. The two amide fertilizers are: urea, $CO(NH)_2$ (46% N) and calcium cyanide $CaCN_2$ (21 % N).

Slow Release Nitrogenous Fertilizers

Nitrogenous fertilizers are highly soluble in water and are, therefore, subjected to leaching.Since rice is grown with standing water, percolation losses are 60 to 70 per cent of total water requirement. To overcome this problem of leaching, the solubility of nitrogen fertilizers are reduced by: (1) synthesizing compounds which are inherently less soluble, e.g. isobutylidenediurea (IBDU) 32.2% N, crotonilidene diurea (CDU) 32.5% N and (2) coating barriers to the presently available fertilizers, e.g. sulphur coated urea, shellac coated urea, neem coated urea.

Nitrification Inhibitors

During the process of mineralization, ammonium is converted into nitrate by *Nitrosomonas* bacteria. Nitrates are subjected to leaching and denitrification losses, especially in submerged soils. These losses can be reduced by inhibiting nitrification with chemicals which are known asnitrification inhibitors. Some of them are: nitrapyrin, N serve, AM, thiourea, dicyan diamide, S T etc.

PHOSPIIATIC FERTILIZERS

Phosphorus content in fertilizers is expressed in oxidized form (P2O5), while its content in soil and plant is expressed in elemental form. The conversion factors for elemental to oxidized form and vice-versa are 2.29 and 0.43, respectively.

Phosphatic fertilizers can be classified into three groups based on their availability to crops and solubility.

Phosphatic Fertilizers Containing Water Soluble Phosphoric Acid. These fertilizers are available in the form of monocalcium phosphate or ammonium phosphate. They are: (I) single superphosphate or ordinary superphosphate-16% P_2O_5 (2) double superphosphate-32% P_2O_5, (3) triple superphosphae-46 to 48% P_2O_5 (4) ammonium phosphate-20% P_2O_5 and 20 per cent N, (5) monoammonium phosphate-48 per cent P_2O_5 and 11 per cent N and (6) ammonium phosphatesulphate-20 per cent P_2O_5 and 16 per cent N.

Phosphorus is easily available to plants from these fertilizers. These fertilizers are most suitable for neutral and alkaline soils. However, they form insoluble iron and aluminium phosphates in acid soils. These fertilizers are used when crop requires quick start and for short duration crops like wheat, sorghum, pulses etc.

Phosphatic Fertilizers Containing Citric Acid Soluble Phosphoric Acid. These fertilizers contain citrate soluble phosphoric acid or dicalcium phosphate. They are converted into monocalcium phosphate in acid soil. As they are basic in reaction and contain calcium they are suitable for acidic soils. These fertilizers are used for long duration crops like sugarcane, tapioca, tea, coffee and also for lowland rice. Phosphatic fertilizers belonging to this group are basic slag (14-18% P_2O_5) and dicalcium phosphate (34-39% P_2O_5).

Phosphatic Fertilizers Containing Phosphoric Acid not Soluble in Water or Citric Acid. Phosphatic fertilizers like rock-phosphate (20-40% P_2O_5), raw bone-meal (20-25% P_2O_5), steamed bone-meal (22% P_2O_5) contain phosphoric acid not soluble in water or Citric acid. These fertilizers are suitable for strongly acidic or organic soils. The availability of phosphorus from these fertilizers can be increased by ploughing in along with green manures. These are suitable for plantation crops like tea, coffee, rubber, cocoa, coconut etc.

POTASSIC FERTILIZERS

Potassic or potash or potassium fertilizers are grouped into two: chloride form and nonchloride form. Potassium chloride belongs to the first group and potassium sulphate, potassium magnesium sulphate, potassium nitrate etc., belong to the second group. From the potassium nutrition point of view, all these fertilizers are equally efficient, but the accompanying anions do make some difference. Presence of chloride in the fertilizer makes it unsuitable for sugar crops, tobacco and potato. In nonchloride fertilizers, sulphate or nitrate anions add to the nutrition of the plant, but they are considered as costly per unit of K_2O. Potassium in the fertilizer is expressed as K_2O (potassium oxide). The conversion factor to express in elemental form (K) is 0.83 and oxide form 1.2. Potassium chloride or muriate of potash is the most common and cheap fertilizer among potassic fertilizers. It contains 58-60 per cent K_2O. It is suitable for most of the crops except sugarcane, sugar beet, potato and tobacco. In sugar crops, accumulation of sugar is affected due to chloride ion present in the fertilizers. Higher content of chloride in tobacco leaf reduces its burning quality. This fertilizer is suitable for acidic and heavy soils but not for alkaline soils.

Potassium sulphate contains 48 to 50 cent K_2O in addition to 17.5 per cent sulphur. It can be safely applied to any crop including sugarcane, sugar beet and tobacco. Potassium magnesium sulphate is a double salt of potassium sulphate and magnesium sulphate and contains 22 per cent K_2O and 11 per cent magnesium and 22 per cent sulphur. Potassium nitrate *or* salt petre or nitre contains 13 per cent N and 44 per cent K_2O. It is an excel1ent source of potassium and nitrogen and is mainly used for fruit trees and crops such as tobacco and vegetables. Potassium polyphosphate contains 56 per cent P_2O_5 and 24, per cent K_2O. It can be produced both as liquid and solid fertilizer.

Lecture 7: secondary nutrients: calcium, magnesium and sulphur fertilizers

Calcium, magnesium and sulphur are supplied to the plants incidentally by the application of N P K fertilizers and as such, fertilizers are not manufactured to supply these nutrients.

Ca, Mg and S contents of different fertilizer materials

Fertilizer	Nutrient content (%)			
	Ca	Mg	S	Others
Calcium nitrate	19.4	-	-	-
Gypsum	29.2	-	18.6	-
Rock phosphate	33.1	-	-	25.2 (P_2O_5)
Single superphosphate	19.5	-	12.5	16 (P_2O_5)
Triple superphosphate	14.0	-	1.0	43.5 (P_2O_5)
Epsom salt	-	9.6	13.0	-
Potassium magnesium sulphate	-	11.1	22.3	31 (K_2O)
Potassium sulphate	-	-	17.5	48(K_2O)
Ammonium sulphate	-	-	24.2	21 (N)
Ammonium sulphate nitrate	-	-	12.1	26 (N)
Basic slag	-	-	3.0	15.6 (P_2O_5)
Copper sulphate	-	-	11.4	21(Cu)
Ferrous ammonium sulphate	-	-	16.0	6 (N) 16 (Fe)
Ferrous sulphate	-	-	18.8	32.8 (Fe)
Elemental sulphur	-	-	100.0	-
Urea-gypsum	4.6	-	0.6	36.8(N)
Urea-sulphur	-	-	10.0	40(N)
Zinc sulphate	-	-	17.8	36.4 (Zn)

a. Magnesium fertilizers

These are chemical substances containing the nutrient magnesium in the form of magnesium cations (Mg2+).

Magnesium Sulphate (MgSO4)

The utilization rate of magnesium fertilizers decreases w,ith incr,easing potassium supplies.

b. Calcium fertilizers

1. These are the chemical substances containing the nutrient calcium in absorbable calcium cations ('Ca2+) form.
2. The raw material of calcium fertilizers is lime found in nature.

Calcium Chloride (CaCl2 6H2O)

1. It contains at least 15 per cent calcium.

2. It is highly water soluble and can, therefore, be dissolved for application as a foliar nutrient.

c. Sulphate Fertilizers

1. These are chemical substances containing the nutrient sulphur in the form of absorbable sulphate anions (SO42-).
2. The sulphur requirements of plants are about two third of their phosphorus requirements.
3. Substantial sulphur supplies occur as minor constituents of various N, P and K fertilizers.
4. Fertilization with sulphur becomes necessary with increasing removal from the soil with rising agricultural production especially in plants with high sulphur requirements. e.g. mustard

Lecture 8: **Micronutrient fertilizers**

Of the sixteen elements essential for plant growth, six nutrients are required in much smaller quantities and they are referred to as micronutrients. They are: Fe, Mn, B, Zn, Cu and Mo. Several micronutrient salts are highly reactive and soluble rendering them unavailable to plants. Micronutrient salts are fused with special type of glass and shattered into small bits which are called frits. When these frits are applied to the soil, the glass slowly dissolves and releases the nutrient salts. Frits extend period of nutrient availability by reducing the reactivity and solubility.

Borosilicate glass, manganese ammonium frits, zinc frits, and copper frits are available. Some of the metallic micronutrient salts when applied to the soil are transformed into non-available forms due to their high reactivity. Organic compounds like EDTA (Ethylene diamine tetraacetic acid), DTPA (Diethylene triamine pentaacetic acid), CDTA (Cyclohexane diamine tetraacetic acid) have the ability to chelate or loosely hold metallic ions in their cyclic structure and these metalorganic complexes are called metal chelates. Metal chelates are soluble in water, but they do not ionize in soil solution. Metal ions, therefore, do not react with soil constituents. Chelate forms of nutrients are more available than those from ordinary salts. Iron, copper, zinc and manganese fertilizers are available in chelated forms.

Iron Fertilizers

Ferrous sulphate is the most commonly used fertilizer which is sprayed on the crop to control iron chlorosis. When it is applied to the soil, it is oxidized to ferric sulphate which is not readily available to plants. To overcome this, problem, iron chelates are used both for soil and foliar application. Iron frits which contain around 22 per cent iron can be used for acid soils.

Manganese Fertilizers

Manganese sulphate is the most popular manganese fertilizer which contains 26 per cent manganese. Manganese chelate (12 per cent Mn) and manganese frit (10 to 25 per cent Mn) are the other sources of manganese. Manganese oxide which is insoluble, can be applied to the soil.

Molybdenum Fertilizers

Some of the molybdenum fertilizers are ammonium molybdate, sodium molybdate and molybdate trioxide. Molybdenum fertilizers can be mixed with N P K fertilizer and applied to the soil. They can also be applied as foliar spray or used for soaking the seed.

Zinc Fertilizers

Zinc sulphate which contains 36 per cent zinc is the most commonly used zinc fertilizer. Zinc sulphate is applied both to soil (at 30-50 kg per hectare) and plant (0.5 per cent as spray). Zinc oxide containing 78 per cent zinc is used for seed treatment.

Organic compounds have also been used successfully to correct deficiency of zinc.These include several zinc chelates like EDTA type or zinc polyflavanoid or ligninsulfonate types. Soil application of the various zinc compounds is the suitable way of overcoming zinc deficiency. Foliar application is a temporary measure.

Boron Fertilizers

Borax is the most commonly used boron fertilizer which is white compound containing 11 per cent boron.

Because of its high solubility in water, it is lost by leaching. To avoid this loss, boron frits are developed which contain 2 to 6 per cent boron. Borosilicate glass is one such material and it is advantageous to apply this than borax in sandy soils under high rainfall conditions, Boric acid and solub or (a soluble commercial borate) are boron fertilizers for foliar application.

Copper Fertilizers

Copper can be applied by spraying soluble salts on crops or by applying copper fertilizer material to the soil. Copper sulphate is commonly used for both the purposes. It contains 25.5 percent copper.

Copper ammonium phosphate can also be used either for soil application or as a foliar spray. It is slightly soluble in water, but can be suspended in water for spraying. Copper chelates are also available for correcting copper deficiency symptoms.

Crop response to different nutrients, residual effects and fertilizer use efficiency. agronomic, chemical and physiological methods of estimating

Crop response to nutrients

In a well-drained acidic soil (pH 4.5-5) and low in organic carbon, upland rice can utilize only 4.3%, 4.5%, and 24.5% from soil source and 23.3% 13.5% and 93.6% from fertilizer source as N, P, and K, espectively (Table). In general,5-10% N, 28-30% P_2O_5 and 70-75% K2O under un-irrigated conditions and 10-15% N, 50% P_2O_5 and 25% K_2O under irrigated conditions are the contributions from soil source.

In either case response to N is more than that to P & K worldwide. In rainfed condition response margin is less than that in irrigated conditions. Crop requirement varies. They remove different quantities of nutrients. It is not that the crop absorbs the nutrient, as it requires rather absorption is as per availability of the nutrient in the medium. For example -absorption of K is usually more than requirement and such consumption is called luxury consumption.

In sandy loam oxisols response of medium-land- irrigated-rice crop to one kg N is 14-16 kg grains in summer and 8-10 kg in wet season. Response to P and K is less than that to N and is 5 kg grain to 1 kg P and 4-5 kg grain to 1 kg K. Response to P & K in wet seasons is also less than that in summer. Crop response varies with the soils type too, the order being red and yellow soil>alluvial soil> laterite soil. Crop responses are determined from field experiments applying different quantities of nutrients either single or in combination (N, P, K, NP, NK, NPK, etc.) and recording yields obtained under each treatment.

Besides, nature of fertilizer (acidic, neutral, alkaline), solubility analysis (high or low grade),particle size (granular, powder), etc. are to be considered. With same range of fertilizer nutrient application nature of response is different in different seasons. If the nutrient supply is moderately high the response may be quadratic in wet season but linear in dry season. At lower levels, in both the seasons response may be linear but the slope of the curve (b in the response equation) may be different. Response is more conspicuous in case of N than in P or K.

Response of Rice to Nitrogen

Investigations in India, as a result of long series of experiments, have come to the conclusion that rice in all circumstances responds to the application of nitrogen. Several factors influence response of rice to applied nitrogen. High yielding varieties are more responsive to applied nitrogen than traditional varieties. Response to nitrogen is higher during dry season than monsoon season due to greater number of sunny days during the period from flowering to maturity. Grain yield per unit area increases with decrease in spacing up to certain extent, after which there is no change or a decrease depending on the variety. Optimum spacing at a low nitrogen level is closer than that at higher levels. Response to nitrogen is more pronounced at wide spacing than at close spacing and is more prominent is dry season than in rainy season. Low responsive varieties have a wider optimum spacing than high responsive varieties. Upland rice receives little or no fertilizer because of the risk involved in input investment.

Traditional varieties are unresponsive to nitrogen, which tend to increase dry matter production without increasing grain production. However, many experiments with improved varieties have shown response to increased nitrogen supply. In general, application of 40-60 kg N ha^{-1} in three splits is optimum both for rainfed upland and rainfed lowland situations during monsoon season.

Irrigated rice responds to higher levels of nitrogen since drought or deep flooding are not the problems either during monsoon season or dry season. Response to nitrogen, in general, varies from 40-60 kg ha^{-1} in fertile soils of delta areas to 80-100 kg ha^{-1} in light soils of low fertility during *kharif*. In dry season, optimum rate of application, in general, is 100 and 120 kg N ha^{-1} for short duration varieties and medium and long duration varieties, respectively. In delta areas, optimum rate is 80-100 kg ha^{-1}. There are instances of latest medium and long duration varieties responding up to 200 kg ha^{-1} or even higher in the recent past. As such there is need for revising fertilizer recommendations based on the location specific responses. On equal nitrogen basis all the fertilizers are equally effective in increasing the yield, provided losses from applied fertilizers are minimized.

Response of Rice to Phosphorus

Many investigations around the world report that lowland rice fails to respond to phosphatic fertilizers even though upland rice grown on the same soil show positive response, since flooding usually increases the availability of soil phosphorus as discussed already.

Application of 30-40 kg P_2O_5 ha^{-1} is the general recommendation for rainfed rice. For irrigated rice, the recommended rate is 40-60 kg P_2O_5 ha^{-1} depending on the rate of nitrogen application.

Response of Rice to Potassium

Generally, response of rice to added potassium is not marked as for nitrogen and phosphorus. Most rice soils in Asia do not need potassium as much as N or P and only small andvariable increase in yield is obtained with added potassium fertilizer. Rice soils in high rainfall areas that are deficient in potassium may respond addition of potassium fertilizers. In India, highest response to added potassium (about 1.5 t ha^{-1}) has been obtained with 60 kg K_2O ha^{-1} in sandy soils. As of now, application of potassium fertilizers is on insurance or balancing principle in several instances.

Response of Rice to Sulphur

Though, sulphur deficiency seldom encountered in acute form, it has been observed in some areas and a moderate deficiency may possibly be more wide spread than is commonly thought, since it is added to soil through irrigation water, atmosphere and precipitation in appreciable quantities. A little less than 2.0 kg ha^{-1} is required to produce 1.0 t of rice. Soils deficient in sulphur respond to applications ranging from 20 to 50 kg S ha^{-1} depending on the levels of deficiencies.

Residual Effect of fertilizers

The extent of residues left over in the soil depends on the type of fertilizer used. Because of their mobility and solubility, nitrogenous fertilizers leave no residues after the crop is harvested. 15N studies have shown that only 1 to 2 per cent of nitrogen applied to maize was taken up the following wheat crop. However, residues of nitrogen occur only when previous crop yields are poor. Phosphatic fertilizers and farmyard manure leave considerable residue in the soil which is useful for subsequent crops. Farmyard manure applied to the previous crops: used only 50 per cent of its nutrients and rest was available for subsequent crops. The residues left by potassium fertilizers are marginal.

Lecture 9:Midsemester

Lecture 10: Fertilizer use efficiency

Fertilizers are applied to supplement nutrient requirement of the crop. It should not be looked as a substitute to organic sources. After determination of nutrient requirement of a crop for a given yield and contribution of nutrients from different sources, particularly, from the soil source, it is necessary to supplement the balance from the inorganic sources. These are determined by field experimentation supplemented by pot-culture, laboratory and green house studies, if necessary.

When a fertilizer is applied all of its nutrient(s) are not absorbed by the crop. The interactions between soil-crop-season and other factors are quite significant. Only a fraction of the nutrient(s) is utilized by the crop.

Efficiency in any system is an expression of obtainable output with the addition of unit amount of input. The ratio of energy intake and energy of the produced biomass i.e. of input and output is called ecological efficiency. This can be studied at any trophic level. Fertilizer use efficiency is the output of any crop per unit of the nutrient applied under a specified set of soil and climatic conditions.

The NUE/FUE can be expressed in several ways. Mosier *et al*. (2004) described four agronomic indices to describe NUE: partial factor productivity (PFP, kg crop yield per kg input applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Crop removal efficiency (removal of nutrient in harvested crop as % of nutrient applied) is also commonly used to explain nutrient efficiency. According to Barker (1977), fertilizer efficiency is increase in yield per unit of fertilizer nutrient applied; the agronomic efficiency.

The partial factor productivity (PFP) from applied nutrients is a useful measure of nutrient use efficiency because it provides an integrative index that quantifies total economic output relative to utilization of all nutrient resources in the system. For a given yield level, optimum factor productivity from applied nutrients is achieved when the use of indigenous soil nutrients is maximum and the efficiency of applied nutrients in producing economic yield is high. In the long term, specification of optimum factor productivity must also consider nutrient balance so that the depletion of nutrient stocks below critical threshold levels does not lead to increased requirements for applied nutrients to maintain yield levels.

Nutrient Recovery (NR) refers to the actual amount of Nutrient taken up from the fertilizers.

Quantity of the nutrient of fertilizer taken up by the crop x I00

FUE in terms of NR (%) = Quantity of nutrient applied through fertilizer

NR could be best known through isotopic studies. For practical purposes, however, it is worked out as follows:

$$NR = \frac{\text{Nutrient uptake in fertilized plots} - \text{Nutrient uptake in unfertilized plots}}{\text{Amount of nutrient added}} \times 100$$

The NR exhibits a diminishing trend with the increasing amounts of nutrients.

Agronomists usually express the efficiency of fertilizer nutrient in kg of grain yield produced kg-l of applied nutrient, Agronomic efficiency (AE). It refers to the additional produce obtained in kg per kg of an applied nutrient.

It is calculated as follows:

$$AE = \frac{\text{Yield from fertilized plot in kg} - \text{yield without fertilizer in kg}}{\text{Amount of fertilizer nutrient applied in kg}} \times 100$$

The AE like NR generally decreases with the increase in nutrient supply.

Physiologists, define the efficiency of nutrient utilization in kg of grain yield produced kg^{-l} of nutrient absorbed. These two efficiencies (Agronomic and physiological) can be related by introducing, percentage of nutrient recovery (a third parameter worked out as above).

Efficiency of Percentage of nutrient Efficiency of fertilizer nutrient = recovery (kg absorbed nutrient x utilization (kg yield (kg yield kg^{-l} nutrient applied) kg-l applied nutrient) kg-l nutrient absorbed)

The percentage nitrogen recovery varies with soil properties; methods, amounts and timing of fertilizer application and other management practices. It usually ranges from 30 to 50 per cent

One of the central themes in plant nutrition is to find the particular growth stage when supply of a particular nutrient leads to highest yield per unit amount of the absorbed. Partial productive efficiency of nitrogen for grain production is defined as:

$$\text{Partial productive efficiency of nitrogen absorbed at period (n-l) to (n)} = \frac{Y(n) - Y(n-1)}{N(n) - N(n-1)}$$

where,

Y (n) = grain weight of the treatment corresponding to period (n)

Y (n-l) = grain weight of the treatment corresponding to period (n-1)

N (n) = total nitrogen uptake of the treatment corresponding to period (n)

N (n-l) = total nitrogen uptake of the treatment correspol1ding to period (n-l).

In other words, partial productive efficiency is the amount of grain production per unit of nitrogen absorbed at a particular growth stage (Yoshida 1981). The greater the value of partial productive efficiency, the higher the efficiency of nitrogen absorbed to produce grain. Solution culture technique provides a convenient means to study partial productive efficiency since the nutrient supply can be controlled easily. From the classical work by Kimura and Chiba (1943), the following important conclusions were drawn:

Principles and Practices of Soil Fertility and Nutrient Management (Agron 502) – 2011-12 67

- Nitrogen absorbed at early stages is used to produce more straw than grain.
- Nitrogen absorbed at later stages is used to produce more gain than straw.
- Partial productive efficiency for both grain and straw is higher when the nitrogen supply is lower.
- There are two peaks for partial productive efficiency for grain: the first around 20-25 days after planting when the nitrogen concentration in the culture solution is high and the second around twenty to ten days before heading when the nitrogen concentration is moderate.
- When the nitrogen concentration is high, there is no second peak. Thus, the most efficient time to supply nitrogen for grain production varies with the level of nitrogen supply.

If very limited nitrogen should be applied at about 20 days before heading, when the supply is moderate, nitrogen may be given twice-around 20 days after planting and again at about 20 days before heading. When nitrogen is abundant, application at early growth stage is relatively more efficient for grain production. The capacity of soil to hold applied nitrogen is an important consideration in determining the efficiency of basal versus split application of nitrogen fertilizers. Soils with montmorillonite clays have higher nitrogen retaining capacity than those with kaolinite or allophone. For soils with low nitrogen holding capacity, split application. Of fertilizer should result in high nitrogen recovery and hence higher yield than a/basal application. On the other hand, split applications may not be better than a basal application in soils when the applied ammonia is held by clay.

Lecture 11: MANURES

Manures are plant and animal wastes that are used as sources of plant nutrients. They release nutrients after their decomposition. Manures can be grouped into bulky organic manures and concentrated organic manures based on concentration of the nutrients.

BULKY ORGANIC MANURES

Bulky organic manures contain small percentage of nutrients and they are applied in huge antities. Farmyard manure (FYM), compost and green manure are the most important and widely used bulky organic manures. Use of bulky organic manures have several advantages: (1) they supply plant nutrients including micronutrients, (2) they improve soil physical properties like structure, water holding capacity etc., (3) they increase the availability of nutrients, (4) carbon dioxide released during decomposition acts as a CO2 fertilizer, and (5) plant parasitic nematodes and fungi are controlled to some extent by altering the balance of microorganisms in the soil.

Farmyard Manure

Farmyard manure refers to the decomposed mixture of dung and urine of farm animals along with litter and left over material from roughages or fodder fed to the cattle. On an average well decomposed farmyard manure contains 0.5 per cent N, 0.2 per cent P2O5 and 0.5 percent K_2O. The present method of preparing farmyard manure by the farmers is defective. Urine, which is wasted, contains 1% N and 1.35% K. Nitrogen present in urine is mostly in the form of urea which is subjected to volatilization losses. Even during storage, nutrients are lost due to leaching and volatilization. However, it is practically impossible to avoid losses altogether, but can be reduced by following improved method of preparation of farmyard manure. Trenches of size 6 m to 7.5 m length, 1.5 m to 2.0 m width and 1.0 m deep are dug. All available litter and refuse is mixed with soil and spread in the shed so as to absorb urine. The next morning, urine soaked refuse along with dung is collected and placed in the trench. A section of the trench from one end should be taken up for filling with daily collection. When the section is filled up to a height of 45 cm to 60 cm above the ground level, the top of the heap is made into a dome and plastered with cow dung earth slurry. The process is continued and when the first trench is completely filled, second trench is prepared. The manure becomes ready for use in about four to five months after plastering.

If urine is not collected in the bedding, it can be collected along with washings of the cattle shed in a cemented pit from which it is later added to the farmyard manure pit. Chemical preservatives can also be used to reduce losses and enrich farmyard manure. The commonly used chemicals are gypsum and superphosphate. Gypsum is spread in the cattle shed which absorbs urine and prevents volatilization loss of urea present in the urine and also adds calcium and sulphur. Superphosphate also acts similarly in reducing losses and also increases phosphorus content. Partially rotten farmyard manure has to be applied three to four weeks before sowing while well rotten manure can be applied immediately before sowing. Generally 10 to 20 t/ha is applied, but more than 20 t/ha is applied to fodder grasses and vegetables. In such cases farmyard manure should be applied at least 15 days in advance to avoid immobilization of nitrogen. The existing practice of leaving manure in small heaps scattered in the field for a very long period leads to loss of nutrients. These losses can be reduced by spreading and incorporating by ploughing immediately after application. Vegetable crops like potato, tomato, sweet-potato, carrot, radish, onion etc., respond well to the farmyard manure. The other responsive crops are sugarcane, rice, Napier grass and orchard crops like oranges, banana, mango and plantation crop like coconut. The entire amount of nutrients present in farmyard manure is not available immediately. About 30% N, 60-70% P and 70% K are available to the first crop.

Compost

A mass of rotted organic matter made from waste is called compost. The compost made from farm waste like sugarcane trash, paddy straw, weeds and other plants and other waste is called farm compost. The average nutrient content of farm compost is 0.5 per cent N, 0.15 per cent P2O5 and 0.5 per cent K2O. The nutrient value of farm compost can be increased by application of superphosphate or rock phosphate at 10 to 15 kg/t of raw material at the initial stage of filling the compost pit. The compost made from town refuses like night soil, street sweepings and dustbin refuse is called town compost. It contains 1.4 per cent N, 1.00 per cent P_2O_5 and 1.4 per cent K_2O. Farm compost is made by placing farm wastes in trenches of suitable size, say, 4.5 m to 5.0 m long, 1.5 m to 2.0 m wide and 1.0 m to 2.0 m deep. Farm waste is placed in the trenches layer by layer. Each layer is well moistened by sprinkling cow-dung slurry or water. Trenches are filled up to a height of 0.5 m above the ground. The compost is ready for application within five to six months.

Green Manure

Green un-decomposed plant material used as manure is called green manure. It is obtained in two ways: by growing green manure crops or by collecting green leaf (along with twigs) from plants grown in wastelands, field bunds and forest. Green manuring is growing in the field plants usually belonging to leguminous family and incorporating into the soil after sufficient growth. The plants that are grown for green manure are known as green manure crops. The most important green manure crops are sunnhemp, dhaincha, *pillipesara*, clusterbeans and *Sesbania rostrata* (Table below). Nitrogen fixation by leguminous green manure crops can be increased by application of phosphatic fertilizers. This phosphorus is available to succeeding crop after mineralization of the incorporated green manure crop.

Application to the field, green leaves and twigs of trees, shrubs and herbs collected from elsewhere is known as green-leaf manuring. Forest tree leaves are the main sources for green-leaf manure. Plants growing in wastelands, field bunds etc., are another source of green-leaf manure. The important plant species useful for green-leaf manure are neem, mahua, wild indigo, glyricidia, Karanji *(Pongamia glabra)* calotropis, avise *(Sesbania grandiflora)*, subabul and other shrubs.

Vermicompost

Soil fauna including protozoa to mammals though not considered major is the important source of nutrients. Among the soil fauna earthworms have attracted more attention than others because of their importance in agriculture. Earthworm gut is the site of production of genuine humic acids which are distinct from the polysaccharide-gum humic acids. About half of the gums secreted by earthworm are in form of mucoproteins that help stabilizing pore space distribution. The earthworm soil casts are richer in available plant nutrients (nitrate nitrogen, exchangeable Ca, Mg, K and P) and organic matter. The earthworms through their casts and dead tissues supply about 60-90 kg N to the soil. Earthworm eats on fungal mycelia. Earthworms convert farm waste and organic residues into high quality compost. For this, *Eisenia foetida*, *Perionyx exacavatus*, *Eudrillus euginiae* and *Lumbrius rubellus* are important. These species can be cultured on organic wastes and dung. The technique of culturing them is called vermiculture and using these for decomposing residue to make compost is called vermicomposting. About 1000 adult earthworms can convert 5 kg waste into compost per day. The earthworm assimilate 5-10% of the substrate and rest passes through the alimentary canal and is excreted as cast. Earthworm cast contains nutrients, vitamins, hormones and antibiotics.

Night Soil

Night soil is human excreta, both solid and liquid. It is richer in N, P and K than farmyard manure and compost. Night soil contains on an average 5.5 per cent N, 4.0 per cent P2O5 and 2.0 per cent K2O.

Sewage and Sludge

In the modern system of sanitation adopted in cities and towns, human excreta is flushed out with water which is called sewage. The solid portion in the sewage is called sludge and liquid portion is sewage water. Both the components of sewage are separated and are given a preliminary fermentation and oxidation treatments to reduce bacterial contamination and offensive smell.

Sheep and Goat Manure

The dropping of sheep and goats contain higher nutrients than farmyardmanure and compost On an average, the manure contains 3 per cent N, 1 per cent P_2O_5 and 2 per cent K_2O. It is applied to the field in two ways. The sweeping of sheep or goat sheds are placed in pits for decomposition and it is applied later to the field. The nutrients present in the urine are wasted in this method. The second method is sheep penning, wherein sheep and goats are allowed to stay overnight in the field and urine and fecal matter is added to the soil which is incorporated to a shallow depth by running blade harrow or cultivator.

Poultry Manure

The excreta of birds ferments very quickly. If left exposed, 50 per cent of its nitrogen is lost within 30 days. Poultry manure contains higher nitrogen and phosphorus compared to other bulky organic manures. The average nutrient content is 3.03 per cent N, 2.63 per cent P_2O_5 and 1.4 per cent K_2O.

CONCENTRATED ORGANIC MANURES

Concentrated organic manures have higher nutrient content than bulky organic manure.The important concentrated organic manures are oilcakes, bloodmeal, fish manure etc. These are also known as organic nitrogen fertilizer. Before their organic nitrogen is used by the crops, it is converted through bacterial action into readily usable ammoniacal nitrogen and nitrate nitrogen. These organic fertilizers are, therefore, relatively slow acting, but they supply available nitrogen for a longer period.

Oil-cakes

Average nutrient contents of oil-cakes

Oil cakes	Nutrient content (%)		
	N	P_2O_5	K_2O
Non-edible oil-cakes			
Castor cake	4.3	1.8	1.3
Cotton seed cake (un-decorticated)	3.9	1.8	1.6
Karanj cake	3.9	0.9	1.2
Mahua cake			
Safflower cake (un-decorticated)			
Edible oil-cakes			
Coconut cake	3.0	1.9	1.8
Cotton seed cake (Decorticated)	6.4	2.9	2.2
Groundnut cake	7.3	1.5	1.3

Linseed cake	4.9	1.4	1.3
Niger cake	4.7	1.8	1.3
Sesamum cake	6.2	2.0	1.2

Other Concentrated Organic Manures

Organic manure Nutrient content (%)	N	P_2O_5	K_2O
Blood-meal	10-12	1-2	1.0
Meat-meal	10.5	2.5	0.5
Fish-meal	4-10	3-9 0.	3-15
Horn and hoof meal	13	...	…
Raw bone-meal	3-4	20-25	…
Steamed bone meal	1-2	25-30	…

Importance of manures in soil fertility management

Organic manure forms a very small but an important portion and it is obtained from dead plant roots, crop residues, various organic manures like farmyard manure,compost and green manure, fungi, bacteria, worms and insects.

Function of organic matter

Organic matter improves the physical condition of the soil, particularly the structure.

1. Decaying organic matter acts as a food material for bacteria , fungai and other organisms.
2. Presence of organic matter dissolves many insoluble soil minerals and make them available to plants.
3. It plays an important role in the nutrient supplying power of soil as it has got high cation exchange capacity (CEC).
4. It increases the water holding capacity of the soil, particularly in soil
5. It improves aeration and infiltration in heavy soil.
6. It reduces loss of soil by water and wind erosion.
7. It regulate soil temperature.
8. It serves as important sources of certain plant of food element (N, P, S etc).
9. The buffering nature of the organic matter is considered to be advantageous in the residue management of pesticides, herbicides, and other heavy metals.

Lecture12:Techniques of increasing fertilizer use efficiency

To increase the fertilizer use efficiency the nutrient must be available at the time of its requirement by the crop, in right form and quantity. On application there occur certain inevitable/evitable losses of nutrients that reduce the efficiency.

The losses are due to: (i) leaching, (ii) volatilization, (iii) immobilization, (iv) chemical reaction between various components in the mixture, (v) change in capacity to supply nutrients, and (vi) unfavourable effects associated with fertilizer application.

Each component of loss can be reduced to a great extent by management of the soil fertilizer crop system. This requires knowledge and experience on (i) how much of the fertilizer to be applied, (ii) what/which (type of fertilizer) to be applied, (iii) when to be applied (time of application), (iv) how (method of application), (v) where (placement of fertilizer) and (vi) other considerations (cost, availability of fertilizer, labour, ease of application, awareness on benefits of fertilizer use, etc.).

How Much

Inorganic source is a supplement to other sources of nutrients. Among other sources, the most important one is soil source. Availability of nutrients from soil and fertilizer sources can be estimated from field experiments involving response to fertilizers and tracer techniques (using radio-active isotopes).

What and Which (Type of fertilizer)

Fertilizers vary with respect to their solubility besides their grade. Choice of fertilizer is location specific and needs to be found out by field experimentation. The choice is more with respect to nitrogen and phosphatic fertilizers than for potassic. Studies on crop response is also more for N than for P or K fertilizers because leaching loss is more in nitrogenous fertilizer and its residual effect is nil or negligible. In case of P, its indirect, residual and cumulative effects are more important.Nitrogen in form of NO_3^- is subject to more leaching. Leaching loss is also more in wet *(kharif)* than in summer and in sandy soils than in clayey soils. Losses can be minimized by choosing suitable time and method of application.

When to apply

It necessarily means time of application. The objective of time of application is to get maximum benefit from the fertilizer nutrient. If the nutrient is applied too earlier than the time of requirement, it is lost in different ways or is absorbed more than required. If applied late it is either not absorbed or if absorbed not utilized for the purpose and only gets accumulated in plant parts. Some amendments need to be applied before commencement of crop season so that it reacts well with the soil and becomes available to the crop after sowing/planting (Example – application of press mud, other liming materials, bone-meal, Ferrochrome slags-bhusakti, etc).

Where to apply (placements)

The objective of placement of fertilizer is to make the nutrient available easily to the crop. It should be near to the roots. Application may be surface broadcast, at furrow bottom, placed deep at or slightly below the root zone, top dressed, side dressed or to foliage. This depends on type of crop, rooting pattern, feeding area and ease of application. The choice of method of application depends on soil-crop-fertilizer interaction too.

Other considerations

- Proper control of pests and diseases is must for realizing maximum effectiveness from fertilizers.
- Weeds, if not controlled effectively particularly during early stages (7-21 days) of crop growth in kharif season, take away about 25 to 30 per cent of the applied plant nutrients. Therefore, the weed control, particularly during early stages of crop growth is essential.

• When the soils are acidic or saline or alkali, appropriate amendments viz. lime, gypsum etc. should be applied before using fertilizers. In alkali soils 3 to 5 tonnes of gypsum per acre (8 to 12 t/ha) should be applied broadcast only once and mixed with the top 10 cm of the soil layer.

• Rock phosphates can be profitably used in acid soils and in low land rice and legumes.

• Deficiency of Zn is becoming increasingly widespread. In such cases 25-50 kg zinc sulphate should be applied through soil as basal application. If symptoms of zinc deficiency appear in standing crop, it should be sprayed with 0.3 to 0.5 per cent solution of zinc sulphate mixed with 0.3 percent solution of lime for quick recovery.

• Under adverse soil and climatic conditions e.g. light permeable soils, rainfed conditions or where the crop is grown under deep standing water, application of fertilizers (particularly N) through foliage along with insecticides and pesticides (if needed will lead to higher utilization efficiency by plants.

• For rice crop, wherever possible, mix urea with available nitrification inhibitors such as neem cake and karanj cake (1 kg of cake blend with 5 kg of urea). This will reduce N losses from the soil Curing urea with soil for top-dressing reduces N loss. Mixing one part of urea with 5 to 10 parts of moist soil thoroughly and keeping it for 24 hours can cure urea for its better efficiency.

• Fertilizer recommendations should preferably be based on crop sequence for multiple cropping. Application of FYM and phosphate should preferably be made in wet and dry season, respectively. Intercropping with green gram, blackgram, soybean, onion and groundnut prove highly remunerative in wide row crops like cotton and red gram as compared to pure crop stand and need no extra fertilizers.

• Balanced fertilization should be practiced based on the soil test.

• To the extent possible, using just enough water at different physiological growth stages as recommended for the crop being grown controls irrigation rate. It is better to give priority to irrigated fields as compared to un-irrigated fields/crops as irrigated crops respond better to fertilizers.

• The introduction of leguminous crops in diverse rotational and inter-cropping sequence and use of bacterial and algal cultures play a very important role in meeting the fertilizer need of the crop.

• To the extent possible, green manuring with daincha (*Sesbania aculeata*) or sunhemp (*Crotalaria juncea*) should be practiced in low land paddy cultivation.

• For the compost made from straw and leaves having wide C:N ratio, add small quantity of N to increase N availability to young crop. Incorporation of finely ground rock phosphate or super phosphate with organic manures will make the manure more balanced.

• It is desirable to properly conserve and use organic waste. They should be incorporated 3-4 weeks before sowing the crop. It is preferable to apply FYM in kharif.

• Ensure proper plant spacing.

• Plant/sow the crop timely to get maximum benefit from fertilizers.

• Higher yielding varieties should be preferred over local varieties. Most responsive and best-suited crops should be selected to get maximum benefits of the limited quantity of fertilizers.

Compatability of herbicides with other agrochemicals

Simultaneous or sequential application of herbicides, insecticides, fungicides, antidotes, fertilizers etc., is followed in a single cropping season. These chemicals may undergo a change in physical and chemical characters, which could lead to enhancement or reduction in the efficacy of one or more compounds. The interaction effects were seen much later in the growing season or in the next season due to build-up of persistent chemicals or their residues in the soil. Knowledge on the interactions of various chemicals can be helpful in the formulation and adoption of a sound and effective plant protection programme. It can also help to exploit the synergistic and antagonistic interactions between various pesticides for an effective eradication of weed and other pest problems. When two or more chemicals accumulate in the plant, they may interact and bring out responses. These responses are classified as additive, synergistic, antagonistic, independent and enhancement effects.

i) Additive effect: It is the total effect of a combination, which is equal to the sum of the effects of the components taken independently.

ii) Synergistic effect: The total effect of a combination is greater or more prolonged than the sum of the effects of the two taken independently e.g. The mixture of 2,4-D and Chlorpropham is synergistic on monocot species generally resistant to 2,4-D. Similarly, low rates of 2,4-D and Picloram have synergistic response on Convolvulus arvensis. Atrazine and Alachlor combination, which shows synergism is widely used for an effective control in corn.

iii) Antagonistic effect: The total effect of a combination is smaller than the effect of the most active component applied alone e.g. Combination of EPTC with 2,4-D, 2,4,5-T or dicamba have antagonistic responses in sorghum and giant foxtail. Similarly, chlorpropham and 2,4-D have antagonism. When simazine or atrazine is added to glyphosate solution and sprayed the glyphosate activity is reduced. This is due to the physical binding within the spray solution rather than from biological interactions within the plant.

iv) Independent effect: The total effect of a combination is equal to the effect of the most active component applied alone

v) Enhancement effect: The effect of a herbicide and non-toxic adjuvant applied in combination on a plant is said to have an enhancement effect if the response is greater than that obtained when the herbicide is used at the same rates without the adjuvant e.g. Mixing Ammonium sulphate with Glyphosate.

Herbicide-moisture interaction

Soil applied herbicides fail when there is a dry spell of 10-15 days after their application. Pre-emergence herbicides may be lost by photo-decomposition, volatilization and wind blowing while some amount of water is desirable to activate the soil applied herbicides, excess of it may leach the herbicide to the crop seed and root zone. This may injure the crops and on other side, results in poor weed control. Heavy showers may wash down herbicides from the foliage.

Continuous wet weather may induce herbicide injury in certain crops by turning them highly succulent e.g. Maize plants are normally tolerant to Atrazine but they become susceptible in wet weather, particularly when air temperature is low. Extra succulence has been found to increase atrazine absorption and low temperature decreases its metabolism inside the plants. Quality of water used may also determine herbicide action. Dusty water reduces action of paraquat. Calcium chloride rich water reduces glyphoste phytotoxicity.

Herbicide-insecticide interaction

These chemicals are usually not harmful at recommended rates. The tolerance of plants to a herbicide may be altered in the presence of an insecticide and vice versa. The phyto-toxicity of monuron and diuron on cotton and oats is increased when applied with phorate. Phorate interacts antagonistically with trifluralin to increase cotton yield, by stimulating secondary roots in the zone of pesticide incorporation.

Propanil interacts with certain carbamate and phosphate insecticides used as seed treatments on rice. But chlorinated hydrocarbon insecticides as seed treatment have not interacted with propanil. When propanil is applied at intervals between 7 and 56 days after carbofuron treatment, it results in greater injury to rice vegetatively.

Herbicide-pathogens / fungicides interaction

Herbicides interact with fungicides also. In sterilized soil, chloroxuron is not causing any apparent injury to pea plants, while in the presence of *Rhizoctonia solani i*n unsterilized soil it causes injury. Oxadiazon reduces the incidence of stem rot caused by the soil borne pathogen *Sclerotium rolfsii* L. in groundnut. Diuron and triazine which inhibit photosynthesis may make the plants more susceptible to tobacco mosaic virus. On the other hand, diuron may decrease the incidence of root rot in wheat.

Herbicide-fertilizer interaction

Herbicides have been found to interact with fertilizers in fields e.g., fast growing weeds that are getting ample nitrogen show great susceptibility to 2,4-D, glyphosate than slow growing weeds on poor fertility lands. The activity of glyphosate is increased when ammonium sulphate is tank mixed. Nitrogen invigorate (put life and energy in to) the meristamatic activity in crops so much that they susceptible to herbicides. High rates of atrazine are more toxic to maize and sorghum when applied with high rates of phosphorus.

Herbicide-microbes interaction

Microorganisms play a major role in the persistence behaviour of herbicides in the soil. The soil microorganisms have the capacity to detoxify and inactivate the herbicides present in the soil. Some groups of herbicides more easily degrade through microbes than others. The difference lies in the molecular configuration of the herbicide. The microorganisms involved in herbicide degradation include bacteria, fungi, algae, moulds etc. Of these, bacteria predominates and include the members of the genera *Agrobacterium*, *Arthrobacter*, *Achromobacterium. Bacillus, Pseudomonas, Streptomyces*, *Flavobacterium*, *Rhizobium*etc. The fungi include those of the genera *Fusarium*, *Penicillium* etc.

Lecture13:Bio fertilizers – Methods of application and their importance in nutrient availability.

Atmosphere contains 78 per cent nitrogen and 0.03 per cent carbon dioxide. Plants are able to assimilate carbon dioxide through photosynthesis even when carbon dioxide content is less, but most of the plants cannot fix atmospheric nitrogen though it is abundant. Some microorganisms are capable of fixing nitrogen, while some can increase the availability of nitrogen and phosphorus.

SAPROPHYTES

Microorganisms that are capable of decomposing organic matter at a faster rate can be used as a fertilizer for quick release of nutrients. *Aspergillus*, *Penicillium*, *Trichoderma* are cellulolytic fungi which break down cellulose of plant material. The natural process of decomposition is accelerated and composting time is reduced by 4 to 6 weeks by the use of inoculants of these organisms.

The ultimate source of nitrogen is atmosphere and immediate and important source of nitrogen is soil organic matter. Plant materials and microorganisms are the source of soil organic matter. Plant materials contain nitrogenous and non-nitrogenous compounds. The nitrogenous compounds are amino acids, amino sugars, nucleoproteins, nucleic acids, amides, purins, pyrimedines, alkaloids etc. The non-nitrogenous compounds are cellulose, hemicellulose, starch, sugar, gum, lignins, tanins, fats, oils, waxes, resins and pigments. Among them, cellulose and hemicellulose are more abundant and constitute 30 to 60 per cent of dry matter.

Bacteria belonging to the genus *Rhizobium* are capable of fixing atmospheric nitrogen in association with leguminous crops. Different species of *Rhizobium* are used for treating the leguminous crops (Table). *Rhizobium* species enter the roots of host plants and form nodules on the root surface. The bacteria depend on the host plant for carbohydrates and water while *Rhizobium* supplies nitrogen to the host. Nitrogen fixed by the *Rhizobium* is translocated through xylem vessels of the host plant mainly in the form of aspergine and to some extent as gluatamine. *Rhizobium* species suitable for different crops are multiplied on a peat base in laboratories. This inoculum can be applied in three ways and among them, seed treatment is the best.

Seed Treatment. Depending on the seed rate, the required quantity of jaggary is boiled in water and cooled. *Rhizobium* inoculum (1.5 kg/ha) is mixed in the jaggary solution and sprinkled over the seeds. Then the seeds are thoroughly mixed to spread the inoculum over the entire surface of the seeds. Seeds are then shade dried.

Soil Treatment. The *Rhizobium* inoculum is mixed with soil and spread over the field.

Soil Application. If *Rhizobium* inoculum is not available, 200 kg of surface soil (2 to 10 cm depth) can be collected from the fields where that 'particular leguminous crop is grown luxuriantly and this soil can be broadcasted over the field where crop is grown for the first time.

FREE LIVING ORGANISMS

The important free living organisms that can fix atmospheric nitrogen are blue green algae (BGA), *Azolla*, *Azotobacter* and *Rhizospirillum*. Among them, BGA and *Azolla* can survive only in lowland conditions. Small quantity of inoculum of BGA and AzolIa can be obtained from laboratories and they can be multiplied in the farmers' fields for subsequent application.

Blue-green Algae (BGA)

Several species of blue-green algae can fix atmospheric nitrogen. The most important species are *Anabaena* and *Nostoc*. The amount of nitrogen fixed by blue-green algae ranges from 15 to 45 kg N/ha. Standing water of 2 to 10 cm in the field is a prerequisite for the growth of blue-green algae. It can grow in a temperature range of 25 to 45°C. Bright sunshine increases the growth rate while rains' and cloudiness slows growth rate. It grows well in a pH range of 7 to 8 and in soils with high organic matter.

Blue-green algae inoculum is multiplied in iron trays of 2 m x 2 m x 0.25 m size. These trays are lined with polythene sheet. Each tray is filled with 20 kg of soil and 400 g of superphosphate. Blue-green algae inoculum is sprinkled in the tray and water is let in. Standing water of 5 to 10 cm is maintained continuously. Within a week, a thick algal scum is formed. At this stage, water is drained out and soil is allowed to dry. The dried flakes of blue green algae are collected and stored for application in the main field. Blue green algae inoculum is applied after transplantation of rice crop in the main field. The inoculum required is 10 kg/ha. For higher nitrogen fixation, 3 to 4 t/ha of farmyard manure and 200 kg/ha of superphosphate are applied.

Azolla. Azolla is a free floating fresh water fern. *Azolla pinnata* is the most common species occurring in India. It fixes nitrogen due to *Anabaena* species of blue-green algae present in the lobes of Azolla leaves. A thick mat of Azolla supplies 30 to 40 kg N/ha. Unlike blue-green algae, it thrives well at low temperature. Normal growth of Azolla occurs in the temperature range of 20 to 30°C. It grows better during monsoon season with frequent rains and cloudiness. Suitable soil pH is 5.5 to 7.0.

Nursery area should be under the shade of trees. Small plots of 4 m x 2 m with bunds of 30 to 40 cm height all around are prepared. The bunds may be lined with polythene sheets to avoid leakage of water from plots. Water is let into the plots and Azolla is applied at 0.1 to 0.5 kg/m2. For faster growth of nursery, superphosphate at the rate of 2.5 g/m2 is applied. Carbofuran granules at 1.2 g/m2 are applied to control leaf eating caterpillars and other pests.

Azolla is applied to the main field as a green manure crop and as a dual crop. As green manure crop, AzolIa is allowed to grow on the flooded fields for 2 to 3 weeks before transplanting. Later water is drained and Azolla is incorporated by ploughing in. As a dual crop, 1,000 to 5,000 kg/ha of Azolla is applied to the soil one week after transplanting. When a thick mat forms, it is incorporated by trampling. The left over Azolla develops again which is trampled in as a second crop. For better growth of Azolla, 25 to 50 kg/ha of superphosphate is applied and standing water of 5 to 10 cm is maintained continuously in the rice fields.

Application of 5 t/ha of FYM helps in better growth of *Azotobacter*. *Azotobacter* can be used for rice, cotton and sugarcane. *Azospirillum* inoculum is used for sorghum.

Mycorrhiza and Phospho-micro Organisms

Phosphorus availability and fertilizer phosphorous use efficiency can be increased with mycorrhiza, phosphate solubilizing bacteria and fungi. Mycorrhiza inhabits roots of several crops and solubilises soil phosphates. Inoculation of mycorrhiza increases the pod yield of groundnut. Some microorganisms like *Psuedomonas striate*. *Aspergillus awaneorii* and *Bacillus polymyxa* are capable of solubilising phosphates. The inoculum of these microorganisms is applied to increase the availability of phosphorus.

Lecture 14: PLANT GROWTH REGULATORS

Plant growth regulators or phytohormones are organic substances produced naturally in higher plants, controlling growth or other physiological functions at a site remote from its place of production and active in minute amounts. Thimmann (1948) proposed the term *Phyto hormone* as these hormones are synthesized in plants. *Plant growth regulators* include auxins, gibberellins, cytokinins, ethylene, growth retardants and growth inhibitors. Auxins are the hormones first discovered in plants and later gibberellins and cytokinins were also discovered.

Hormone

An endogenous compound, which is synthesized at one site and transported to another site where it exerts a physiological effect in very low concentration. But ethylene (gaseous nature), exert a physiological effect only at a near a site where it is synthesized. Classified definition of a hormone does not apply to ethylene.

Plant growth regulators

• Defined as organic compounds other than nutrients, that affects the physiological processes of growth and development in plants when applied in low concentrations.

• Defined as either natural or synthetic compounds that are applied directly to a target plant to alter its life processes or its structure to improve quality, increase yields, or facilitate harvesting.

Plant Hormone

When correctly used, is restricted to naturally occurring plant substances, there fall into five classes. Auxin, Gibberellins, Cytokinin, ABA and ethylene. Plant growth regulator includes synthetic compounds as well as naturally occurring hormones.

Plant Growth Hormone

The primary site of action of plant growth hormones at the molecular level remains unresolved.

Reasons

• Each hormone produces a great variety of physiological responses.

• Several of these responses to different hormones frequently are similar.

• The response of a plant or a plant part to plant growth regulators may vary with the variety of the plant.

• Even a single variety may respond differently depending on its age, environmental conditions and physiological state of development (especially its natural hormone content) and state of nutrition. There are always exceptions for a general rule suggesting the action of a specific growth regulator on plants.

• There are several proposed modes of action in each class of plant hormone, with substantial arguments for and against each mode.

Hormone groups

Auxin - Substances generally resembles IAA and has the ability to stimulate the elongation of coleoptiles.

Gibberellins - are diterpenoids, which have the ability to elongate the stem of green seedlings especially certain dwarf and rosette types.

Cytokinin - Usually substituted Adenines, which resembles zeatin (Naturally occurring cytokinin in *Zea mays*) and have the ability to stimulate cytokinensis in cultures of tobacco cells.
Ethylene - Gaseous regulator that stimulate is diametric growth in the apices of dicot seedlings.
Inhibitors - are regulators of growth, which originally depress the

Auxins
Auxins are a group of phytohormones produced in the shoot and root apices and they migrate from the apex to the zone of elongation. Auxins promote the growth along the longitudinal axis of the plant and hence the name (auxeing : to grow). The term, auxin was introduced by Kogl and Haagen- Smit (1931). Went (1928) isolated auxin from the Avena coleoptile tips by a method called *Avena coleoptile or curvature test* and concluded that no growth can occur without auxin. Auxins are widely distributed through out the plant however, abundant in the growing tips such as coleoptile tip, buds, root tips and leaves. Indole Acetic Acid (IAA) is the only naturally occurring auxin in plants. The synthetic auxins include,

Physiological effects of auxin
1. Cell division and elongation
The primary physiological effects of auxin are cell division and cell elongation in the shoots. It is important in the secondary growth of stem and differentiation of xylem and phloem tissues.
2. Apical dominance
In many plants, if the terminal bud is intact and growing, the growth of lateral buds just below it remains suppressed. Removal of the apical bud results in the rapid growth of lateral buds. This phenomenon in which the apical bud dominates over the lateral buds and does not allow the lateral buds to grow is known as *apical dominance*. Skoog and Thimmann (1948) pointed out that the apical dominance might be under the control of auxin produced at the terminal bud and which is transported downward through the stem to the lateral buds and hinders the growth. They removed the apical bud and replaced it with *agar* block. This resulted in rapid growth of lateral buds. But when they replaced the apical bud with agar block containing auxin, the lateral buds remained suppressed and did not grow.

3. Root initiation
In contrast to stem, the higher concentration of auxin inhibits the elongation of roots but the number of lateral roots is considerably increased i.e., higher concentration of auxin induces more lateral branch roots. Application of IAA in lanolin paste (lanolin is a soft fat prepared from wool and is good solvent for auxin) to the cut end of a young stem results in an early and extensive rooting. This fact is of great practical importance and has been widely utilized to promote root formation in economically useful plants which are propagated by cuttings.
4. Prevention of abscission
Natural auxins prevent the formation of abscission layer which may otherwise result in the fall of leaves, flowers and fruits.
5. Parthenocarpy

Auxin can induce the formation of parthenocarpic fruits (fruit formation without pollination and fertilization). In parthenocarpic fruits, the concentration of auxin in the ovaries is higher than in the ovaries of plants which produce fruits only after fertilization. In the later cases, the concentration of the auxin in ovaries increases after pollination and fertilization.

6. Respiration

Auxin stimulates respiration and there is a correlation between auxin induced growth and respiration. Auxin may increase the rate of respiration indirectly through increased supply of ADP by rapidly utilizing ATP in the expanding cells.

7. Callus formation

Besides cell elongation, auxin may also be active in cell division. In many tissue cultures, where the callus growth is quite normal, the continued growth of such callus takes place only after the addition of auxin.

8. Eradication of weeds

Some synthetic auxins especially 2, 4- D and 2, 4, 5-T are useful in eradication of weeds at higher concentrations.

9. Flowering and sex expression

Auxins generally inhibit flowering but in pine apple and lettuce it promotes uniform flowering.

Distribution of auxin in plants

In plants, auxin (IAA) is synthesized in growing tips or meristematic regions from where; it is transported to other plant parts. Hence, the highest concentration of IAA is found in growing shoot tips, young leaves and developing auxiliary shoots. In monocot seedling, the highest concentration of auxin is found in coleoptile tip which decreases progressively towards its base. In dicot seedlings, the highest concentration is found in growing regions of shoot, young leaves and developing auxiliary shoots. Within the plants, auxin may present in two forms. i.e., *free auxins* and *bound auxins*. Free auxins are those which are easily extracted by various organic solvents such as diethyl ether. Bound auxins on the other hand, need more drastic methods such as hydrolysis, autolysis, enzymolysis etc. for extraction of auxin. Bound auxins occur in plants as complexes with carbohydrates such as glucose, arabionse or sugar alcohols or proteins or amino acids such as aspartate, glutamate or with inositol.

Biosynthesis of auxin (IAA) in plants

Thimann (1935) found that an amino acid, tryptophan is converted into Indole 3 acetic acid. Tryptophan is the primary precursor of IAA in plants. IAA can be formed from tryptophan by two different pathways.

1. By deamination of tryptophan to form indole-3-pyruvic acid followed by decarboxylation to from indole-3-acetaldehyde. The enzymes involved are tryptophan deamintion and indole pyruvate decarboxylase respectively.
2. By decarboxylation of tryptophan to form tryptamine followed by deamination to form indole-3-acetaldehyde and the enzymes involved are tryptophan decarboxylase and tryptamine oxidase respectively. Indole 3-acetaldehyde can readily be oxidized to indole 3-acetic acid (IAA) in the presence of indole 3-acetaldehyde dehydrogenase.

Transport of auxin in plant

The transport of auxin is predominantly polar. In stems, polar transport of auxin is basipetal i.e., it takes place from apex towards base. Polar transport of auxin is inhibited by 2, 3, 5 Triiodobenzoic acid (TIBA) and Naphthyl thalamic acid (NPA). The substances are called as antiauxins.

Destruction / Inactivation of auxin in plants

Auxin is destructed by the enzyme IAA oxidase in the presence of O2 by oxidation.

IAA Oxidase

IAA + H2O2 + O2 3-methylene oxindole + H2O + CO2

Rapid inactivation may also occur by irradiation with x-rays and gamma rays. UV light also reduces auxin levels in plants. Inactivation or decomposition of IAA by light has been called as photo oxidation.

Mechanism of Action

IAA increases the plasticity of cell walls so that the cells stretch easily in response to turgor pressure. It has been suggested that IAA acts upon DNA to influence the production of mRNA. The mRNA codes for specific enzymes responsible for expansion of cell walls. Recent evidences indicate that IAA increases oxidative phosphorylation in respiration and enhanced oxygen uptake. The growth stimulation might be due to increased energy supply and it is also demonstrated that auxin induces production of ethylene in plants.

Gibberellins

Discovery

A Japanese scientist Kurosawa found that the rice seedlings infected by the fungus *Gibberella fujikuroi* grow taller and turned very thin and pale. An active substance was isolated from the infected seedlings and named as Gibberellin.

Biosynthesis of gibberellins in plants

The primary precursor for the formation of gibberellins is acetate.

Acetate + COA → Acetyl COA → Mevalonic acid → MA pyrophosphate →

Isopentanyl pyrophosphate → Geranyl pyrophosphate → GGPP → Kaurene → Gibberellins.

Physiological effects of gibberellins

1. Seed germination

Certain light sensitive seeds eg. Lettuce and tobacco show poor germination in dark. Germination starts vigorously if these seeds are exposed to light or red light. This requirement of light is overcome if the seeds are treated with gibberellic acid in dark.

2. Dormancy of buds

In temperature regions the buds formed in autumn remain dormant until next spring due to severe cold. This dormancy of buds can be broken by gibberellin treatments. In potato also, there is a dormant period after harvest, but the application of gibberellin sprouts the refer vigorously.

3. Root growth

Gibberellins have little or no effect on root growth. At higher concentration, some inhibition of root growth may occur. The initiation of roots is markedly inhibited by gibberellins in isolated cuttings.

4. Elongation of internodes

The most pronounced effect of gibberellins on the plant growth is the elongation of the internodes. Therefore in many plants such as dwarf pea, dwarf maize etc gibberellins overcome the genetic dwarfism.

5. Bolting and flowering

In many herbaceous plants, the early period of growth shows rosette habit with short stem and small leaves. Under short days, the rosette habit is retained while under long days bolting occurs i.e. the stem elongates rapidly and is converted into polar axis bearing flower primordia. This bolting can also be induced in such plants by the application of gibberellins even under non-inductive short days.

In *Hyoscyamus niger* (a long day plant) gibberellin treatment causes bolting and flowering under non-inductive short days. While in long day plants the gibberellin treatment usually results in early flowering. In short day plants, its effects are quite variable. It may either have no effect or inhibit or may activate flowering.

6. Parthenocarpy

Germination of the pollen grains is stimulated by gibberellins; likewise, the growth of the fruit and the formation of parthenocarpic fruits can be induced by gibberellin treatment.

In many cases, eg. pome and stone fruits where auxins have failed to induce parthenocarpy, the gibberellins have proven to be successful. Seedless and fleshly tomatoes and large sized seedless grapes are produced by gibberellin treatments on commercial scale.

7. Synthesis of the enzyme α - amylase

One important function of gibberellins is to cause the synthesis of the enzyme α - amylase in the aleurone layer of the endosperm of cereal grains during germination. This enzyme brings about hydrolysis of starch to form simple sugars which are then translocated to growing embryo to provide energy source.

Distribution of gibberellins in plant

Gibberellins are found in all parts of higher plants including shoots, roots, leaves, flower, petals, anthers and seeds. In general, reproductive parts contain much higher concentrations of gibberellins than the negative parts. Immature seeds are especially rich in gibberellins (10-100 mg per g fresh weight). In plants, gibberellins occur in two forms free gibberellins and bound gibberellins. Bound gibberellins usually occur as gibberellin – glycosides.

CYTOKININS (Kinetin)

Kinetin was discovered by Skoog and Miller (1950) from the tobacco pith callus and the chemical substance was identified as 6-furfuryl aminopurine. Because of its specific effect on *cytokinesis* (cell division), it was called as cytokinins or kinetin. The term, cytokinin was proposed by Letham (1963). Fairley and Kingour (1966) used the term, *phytokinins* for cytokinins because of their plant origin. Chemically cytokinins are kinins and they are purine derivatives.

Cytokinins, besides their main effect on cell division, also regulate growth and hence they are considered as natural plant growth hormones. Some of the very important and commonly known naturally occurring cytokinins are Coconut milk factor and Zeatin. It was also identified that cytokinin as a constituent of t-RNA.

Naturally occurring cytokinins

Cytokinins can be extracted from coconut milk (liquid endosperm of coconut), tomato juice, flowers and fruits of *Pyrus malus*; fruits of *Pyrus communis* (Pear), *Prunus cerasiferae* (plum) and *Lycopersicum esculentum* (bhendi); Cambial tissues of *Pinus radiata*, *Eucalyptus regnans* and *Nicotiana tabacum*; immature fruits of *Zea mays*, *Juglans* sp. and *Musa* sp; female gametophytes of *Ginkgo biloba*; fruitlets, embryo and endosperms of *Prunus persica*; seedling of *Pisum sativum*; root exudates of *Helianthus annuus* and tumour tissues of yg7futobacco. According to Skoog and Armstrong (1970), at least seven well established types of cytokinins have been reported from the plants.

Biosynthesis

It is assumed that cytokinins are synthesised as in the case of purines in plants (nucleic acid synthesis). Root tip is an important site of its synthesis. However, developing seeds and cambial tissues are also the site of cytokinin biosynthesis. Kende (1965) reported that cytokinins move upwards perhaps in the xylem stream. However, basipetal movement in petiole and isolated stems are also observed. Seth *et al* (1966) found that auxin enhances kinetin movement (translocation) in bean stems.

Physiological effects of cytokinins

1. Cell division

The most important biological effect of kinetin on plants is to induce cell division especially in tobacco pith callus, carrot root tissue, soybean cotyledon, pea callus etc.

2. Cell enlargement Like auxins and gibberellins, the kinetin may also induce cell enlargement. Significant cell enlargement has been observed in the leaves of *Phaseolus vulgaris*, pumpkin cotyledons, tobacco pith culture, cortical cells of tobacco roots etc.

3. Concentration of apical dominance External application of cytokinin promotes the growth of lateral buds and hence counteracts the effect of apical dominance

4. Dormancy of seeds Like gibberellins, the dormancy of certain light sensitive seeds such as lettuce and tobacco can also be broken by kinetin treatment.

5. Delay of senescence (Richmand - Lang effect) The senescence of leaves usually accompanies with loss of chlorophyll and rapid breakdown of proteins. Senescence can be postponed to several days by kinetin treatment by improving RNA synthesis followed by protein synthesis. Richmand and Lang (1957) while working on detached leaves of *Xanthium* found that kinetin was able to postpone the senescence for a number of days.

6. Flower induction Cytokinins can be employed successfully to induce flowering in short day plants.

7. Morphogenesis It has been shown that high auxin and low kinetin produced only roots whereas high kinetin and low auxin could promote formation of shoot buds.

8. Accumulation and translocation of solutes Plants accumulate solutes very actively with the help of Cytokinin and also help in solute translocation in phloem.

9. Protein synthesis Osborne (1962) demonstrated the increased rate of protein synthesis due to translocation bys kinetin treatment.

10. Other effects

Cytokinins provide resistance to high temperature, cold and diseases in some plants. They also help in flowering by substituting the photoperiodic requirements. In some cases, they stimulate synthesis of several enzymes involved in photosynthesis.

11. Commercial applications

Cytokinins have been used for increasing shelf life of fruits, quickening of root induction and producing efficient root system, increasing yield and oil contents of oil seeds like ground nut.

Ethylene

Ethylene is the only natural plant growth hormone exists in gaseous form.

Important physiological elects

1. The main role of ethylene is it hastens the ripening of fleshy fruits eg. Banana, apples, pears, tomatoes, citrus etc.
2. It stimulates senescence and abscission of leaves
3. It is effective in inducing flowering in pine apple
4. It causes inhibition of root growth
5. It stimulates the formation of adventitious roots
6. It stimulates fading of flowers
7. It stimulates epinasty of leaves.

Abscisic acid

Addicott (1963) isolated a substance strongly antagonistic to growth from young cotton fruits and named Abscissin II. Later on this name was changed to Abscisic acid. This substance also induces dormancy of buds therefore it also named as Dormin. Abscisic acid is a naturally occurring growth inhibitor.

Physiological effects

The two main physiological effects are
1. Geotropism in roots
2. Stomatal closing
3. Besides other effects
1. Geotropism in roots
Geotropic curvature of root is mainly due to translocation of ABA in basipetal direction towards the root tip.
2. Stomatal closing
ABA is synthesized and stored in mesophyll chloroplast. In respond to water stress, the permeability of chloroplast membrane is lost which resulted is diffusion of ABA out of chloroplast into the cytoplasm of the mesophyll cells. From mesophyll cells it diffuses into guard cells where it causes closing of stomata.
3. Other effects
i. Including bud dormancy and seed dormancy
ii. Includes tuberisation
iii. Induces senescence of leaves fruit ripening, abscission of leaves, flowers and fruits
iv. Increasing the resistance of temperate zone plants to frost injury.
Growth retardants
There is no. of synthesis compounds which prevent the gibberellins from exhibiting their usual responses in plants such as cell enlargement or stem elongation. So they are called as anti gibberellins or growth retardants. They are
1. Cycocel (2- chloroethyl trimethyl ammonium chloride (CCC)
2. Phosphon D – (2, 4 – dichlorobenzyl – tributyl phosphonium chloride)
3. AMO – 1618
4. Morphactins
5. Maleic hydrazide

Lecture 15:Integrated nutrient management

Soil health degradation with regard to reduced organic carbon (OC) as a result of imbalance use of fertilizers and multi-nutritional deficiencies (P, K, S, Zn, Fe, Mn, Cu, and B) has emerged as a major factor responsible for stagnation in agricultural production. Arresting the decline of soil OC by use of organic sources is the most potent weapon in fighting unabated soil degradation. Organic matter helps in improving soil quality to sustain biological productivity,maintain environmental quality and promote plant and animal health. But the organic sources alone are not sufficient to meet the nutritional needs for higher productivity. As early as 1974 the need for integrated nutrient management (INM) was elucidated. The INM philosophy combines economic and efficient traditional and improved technologies from the symbiosis and synergy of crop-soil environment bio-interactions. The approach is flexible and minimizes use of chemicals but maximizes use efficiency. Therefore, INM is the most logical way for managing long term soil fertility and productivity. Integrated use of organic manures and chemical fertilizers has been found promising in arresting the decline in productivity through increase FUE and correcting marginal deficiencies of secondary and micronutrients and their beneficial influences on the physical and biological properties of the soil. Integrated nutrient management can bring about equilibrium between degenerative and restorative activities in the soil environment. In literature three terminologies are used to convey the same meaning – Integrated Plant Nutrition Systems (IPNS), Integrated Plant Nutrient Supply Systems (IPNS Systems) and Integrated Nutrient Management (INM). Although these terminologies may look the same, yet they convey somewhat different connotations.

IPNS Systems means the supply of nutrients to the plants from various sources of nutrients- 1) nutrient reserves in the soil, 2) organic sources – FYM, compost, green manure, crop residues and other organic fertilizers and 3) fertilizers; IPNS is a concept "which aims at 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 benefit from all possible sources of plant nutrients in an integrated manner (Roy and Ange, 1991). Thus 'IPNS system' is only a method to achieve the objective of IPNS. In the latter is embedded a philosophy with social, economic and technological components while the former provides a strategy to achieve the said objective. INM is actually the technical and managerial component of achieving the technical objectives of IPNS under farm situations. It takes into account all factors of soil and crop management including management of all other inputs such as water, agrochemicals etc, besides nutrients. The main objective of IPNS is to efficiently utilize all the sources of plant nutrients.

The IPNS approach aims to:

1. Enhance crop and soil productivity through a balanced use of mineral fertilizers combined with organic and biological sources of plant nutrients to ensure sustainability of the production systems.
2. Improve the capital stock of plant nutrients in the soil and
3. Improve the efficiency of plant nutrients use, limiting losses of N and P to the environment and promoting environmental security.

The necessity of promoting and adopting the wider concept of IPNS management arises from past mineral fertilization-based practices and their lessons and thus results in paradigm shifts in several aspects of farming as given below (adapted from Finck, 1995):

- from individual crop nutrient requirements to optimum use of nutrient sources;
- from static nutrient balances to nutrient flows (fluxes) and nutrient cycles;

- from least concern for environmental impact to due attention to the unwanted side effects of fertilization (on soils, weed growth, crop diseases etc.; pollution of water and air);
- from first year's nutrient effects to long -term effects (residual nutritive effects, fate of non - used nutrients, storage, carry-over);
- from the narrow concern for yield effects to resistance of crops against stress conditions (dry, cold, salty, alkaline, toxicity, pollution);
- from the assumption of ideal growth conditions to an awareness of not or hardly controllable growth limiting factors and production risks;
- from exploitation of soil fertility to its improvement or maintenance;
- from the neglect of protective restrictions to awareness against dangerous or even toxic elements;
- from productivity to productivity and sustainability;
- from quantitative nutrient use to both quantitative and qualitative aspects of economy and efficiency in nutrient use;
- from fertilizer use promotion to knowledge intensive nutrient management; and
- from emphasis on direct effect of fertilizers to emphasis on synergy, and interactive effects of crop-water-nutrient

Key concept of IPNS

IPNS enhances soil productivity through a balanced use of soil nutrients, chemical fertilizers, combined with organic sources of plant nutrients, including bio-inoculants and nutrient transfer through agro-forestry systems and has adaptation to farming systems in both irrigated and rainfed agriculture.

IPNS incorporates the underlying relationships between use of plant nutrients, economic feasibility and maintenance of environmental quality. Operationally it focuses first on the seasonal or annual cropping system rather than on an individual crop, secondly on the management of nutrients in the whole farming system and thirdly on the concept of village or community areas and watersheds rather than individual fields through use of nutrient budgeting approach, soil fertility maps and analysis of practices which may be contributing to nutrient losses or inefficient plant nutrient management and their remedy.

The following key concepts are fundamental to IPNS and should be built into the strategy and techniques recommended for promoting IPNS as one of the tenets of sustainable agricultural production.

1. Loss of soil productivity is of greater concern than loss of soil fertility.
2. Adoption of soil conservation practices and improved organic matter management practices are crucial for maintaining soil productivity.
3. Inclusion of legume species in the cropping system and rotations as grain, forage or green manure crop.
4. Nutrient management cannot be dealt with in isolation but should be managed as an integral part of a productive farming system.
5. The synergy between best water management practices (rainwater under rainfed dryland conditions and irrigation water under irrigated conditions) and best nutrient management practices must be optimized.
6. The full benefits from the supply of plant nutrients can be realized by farmers only after they have made improvements in the biological, physical and hydrological properties of the soils and removed soil related constraints.
7. It is necessary to identify the socio-economic constraints in the adoption of IPNS at community level and devise appropriate policy interventions and improvements.

8. Promotion of IPNS must be bottom-up rather than top-down in orientation, planning and implementation with the full involvement and participation of the farmers and local communities.

Veritable Nutrient Sources

Various combinations of the following nutrient sources (adapted from Finck, 1995) can be used based on recommendations arising out of field experimental results specific to different cropping systems from the National Research and Extension system.

A. Internal (farm) nutrient sources

- soil (available and reserve nutrients in the rooting zone)
- subsoil and parent material (nutrient reserves)
- legume plants and microbes (N-fixation by crops, green manure, free-living microorganisms, BG algae, azolla, VA mycorrhiza, P solubilizing microbes)
- crop residues (nutrients in straw, leaves, roots, etc)
- green manure (for nutrient storage and saving, etc)
- animal manure (nutrients in stable manure or sludge)
- compost, ashes, etc. (organic or mineral nutrients)

B. External nutrient sources (from farm surroundings)

- weeds, silt and mud from tanks, rivers, lakes, swamps, seaweed
- litter and bark from forest

Principles and Practices of Soil Fertility and Nutrient Management (Agron 502) – 2011-12 100

- organic top soil layer from forests (peat, humus)
- animal manure collected: for burning (ash), biogas, composting
- fodder collected for livestock (nutrients utilized as manure)
- other nutrient-containing substances (ashes, etc)
- atmospheric sources (rain, etc)

C. Imported nutrient sources (usually bought)

- organic fertilizers from waste products or by-products of plant or animal processing factories
- communal waste products (town compost, sewage sludge)
- mineral fertilizers
- fodder

Lecture 16: Soil fertility evaluation approaches

Interactions among plant nutrients are often overlooked even though they can have considerable influence on plant growth. The interplay of plant nutrients is best studied in factorial experiments that test each nutrient at three or more rates.

Two or more growth factors are said to interact when their influence individually is modified by the presence of one or more of the others. An interaction takes place when the response of two or more inputs used in combination is unequal to the sum of their individual responses. There can be both positive and negative interactions in soil fertility studies (Fig. below). In addition, there can be circumstances where there is no interaction, with the action of factors being only additive.In negative interactions, the two nutrients combined increase yields less than when they are applied separately. This kind of interaction can be the result of substitution for and/or interference of one treatment with the other. Lime x P, lime x Mo, Mo x P, and Na x K are common negative interactions involving apparent substitution effects. Changes in soil pH will result in numerous interactions where one ion or nutrient interferes with or competes with the uptake and utilization of other nutrients by plants. Positive interactions are in accordance with Liebig's law of the minimum. If two factors are limiting, or nearly so, addition of one will have little effect on growth, whereas provision of both together will have a much greater influence. In severe deficiencies of two or more nutrients, all fertilizer responses will result in strong positive interactions.Yield increases from an application of one nutrient can reduce the concentration of a second nutrient, but the higher yields result in greater uptake of the second nutrient. This is a dilution effect, which should be distinguished from an antagonistic effect.

In addition to interactions between two or more nutrients, there are numerous opportunities for other kinds of interactions: for example, nutrients and disease, nutrients and cultural practice, nutrients and crop species, nutrients and hybrid or variety, nutrients and seeding date, nutrients and plant population or spacing, and nutrients and environmental conditions.

Interactions between Nutrients

N-K and N-P interactions are commonly observed. For example, under low yield conditions when other nutrients are limiting or management practices are inadequate, plant growth is slow, and unless K is seriously limiting, some soils will release K at a rate adequate to meet the needs of the crop. With adequate N and P and improved management practices, there is more rapid growth and the potential response to K, S, and other nutrients is greater. With 30 kg/ha of N there was little response by rice to K; however, when 90 kg/ha of N was applied, the response to K was linear up to the highest rate applied.Interactions with micronutrients can be dramatic. On a low-P, low-Zn soil leveled for irrigation, adding P or Zn separately decreased corn yields. When both were applied a substantial positive interaction occurred.

The effect of soil pH on the response of corn to P_2O_5 banded beside the row shown that with a pH of 6.1 there was little response to P, but at pH 5.1 there was about a 20-bu response to 70 Ib/a of P_2O_5. Liming alone also increased yields substantially

Crop response to N is greatly reduced when P is limiting. The data in Figure 13.20 on irrigated corn illustrate that the N rate required for an optimum yield is considerably higher with 40 Ib/a of P_20_5 (160 lb/a of N) compared with no added P (80 lb/a of N). When both N and P were adequate, crop recovery of fertilizer N was approximately 75% compared to about 40% without adequate P fertilization. Maximizing crop recovery of fertilizer N reduces the quantity of profile NO_3 – after harvesting. The rooting depth is about 6 ft; thus, a significant quantity of fertilizer N moved below the root zone and could potentially reach the groundwater. Thus, adequate N and P fertilization will optimize yield and profitability and maximize the fertilizer N recovered while minimizing the environmental impact of fertilizer

N use. The positive interaction of N and P also has been shown in wheat with N-P placement in the same band compared to separate placement.

Many nutrient interactions occur in soils; only a few examples have been provided. The most probable nutrient interactions in a given cropping system involve those nutrients that are deficient or marginally deficient. For example, N-P or P-Zn interactions frequently occur on soils marginally deficient in P or Zn, respectively. Therefore, a good soil testing program will enable the grower or consultant to anticipate potential nutrient interactions.

Time and Methods of manures and fertilizer application

To obtain the maximum benefit from fertilizers, it is most essential that fertilizers are applied at the proper time and proper place. The fertilizers to be applied possess different qualities with regard to solubility in water and movement into the soil solution. Similarly soils are of different nature, sandy to clayey. The nature of soil governs the movement of applied fertilizer. The requirement of plants for different plant nutrients varies in relation to their stage of growth. Thus the time and method of application will vary in relation to the nature of the fertilizer, soil type and difference in nutrient requirement and nature of field crops.

TIME OF APPLICATION

The correct time of application is aimed at providing nutrients in sufficient quantities to meet the crop demand and at the same time avoiding excess availability and leaching losses. The time of application mainly depends on crop uptake pattern, soil properties, nature of the fertilizer material and utilization of carbohydrates.

Crop uptake Nitrogen, phosphorus and potassium are taken in large quantities in early stages of crop growth. For example: 95, 86 and 68 per cent of N, P, K uptake is completed by panicle initiation stage in finger millet. Nitrogen is necessary for the synthesis of proteins which are essential for the development of tissues. After flowering, most of the crops, especially cereals, contain lesser percentage of nitrogen due to greater accumulation of carbohydrates. The uptake of nitrogen is slow at the later stages, which is generally met from the soil by mineralization. Legumes require nitrogen until root nodules are formed. Potassium is taken gradually throughout the growth and development of the crop.

Soil properties and nature of fertilizers Nitrogenous fertilizers are soluble and highly mobile in soil. Nitrogenous fertilizers are lost into deeper layers beyond root zone if the entire quantity of fertilizer is applied especially in light textured soils. Phosphatic fertilizers which are highly reactive are fixed in the soil and become immobile. Potassium fertilizers are less mobile since they are adsorbed on the clay complex. The entire quantity of phosphatic and potassium fertilizers are, therefore, applied in one dose at the time of sowing. Utilization of carbohydrates The level of carbohydrates and nitrogen in the plants are inversely related. When large quantities of nitrogenous fertilizers are applied, the level of carbohydrates in the plants decreases. With less nitrogen in plants, carbohydrate level in the plants increases. Under a sufficient level of nitrogen in the plant, carbohydrates are utilized for the synthesis of proteins. The assimilation of nitrogen requires energy which is obtained either from light or the breakdown of carbohydrates. The time of application of nitrogen, therefore, depends on the end product of the crop. In fodder crops, leafy succulent crop with higher level of proteins are preferred compared to fibrous crop with higher carbohydrates. Hence, application of nitrogen in several splits is necessary. If Principles and Practices of Soil Fertility and Nutrient Management (Agron 502) – 2011-12 82 the fodder crop is grown for silage, it should have higher carbohydrates just before cutting for better quality silage. Application of nitrogen should be curtailed in the last stage. Similarly, nitrogen should not be applied for sugarcane during maturation as the economic product is carbohydrate (sugar). Basal application Application of fertilizers before or at the time of sowing is known as basal application. A portion of a recommended dose of nitrogen and entire quantity of phosphatic and potassium fertilizers are applied as basal. Modified forms of urea like urea super granules, sulphur-coated urea, neem-coated urea etc. are used for basal application.

Application of recommended dose of fertilizers in two or three splits during crop period is known as split application of fertilizers.
Application of fertilizers in the standing crop is known as top dressing. The number of split applications has to be more in light soils and less in heavy soils. Nitrogen is applied in more splits for long duration crops.
The stage of application is also important. In cereals, nitrogen is applied at tillering and panicle initiation stages in addition to basal application. Basal application is sufficient in pulses while for sugarcane, it is not necessary. Nitrogen is applied at 60, 90 and 120 days after sowing for sugarcane. Fertilizers are applied by different methods mainly for three purposes: (1) to make the nutrients easily available to crops (2) to reduce fertilizer losses, and (3) for ease of application.

Factors influencing methods of application

Suitable method for a particular situation depends on the nature of the soil, crop and fertilizer material.Nature of the Soil, Soil properties like texture, pH, CEC, nutrient and moisture status are important factors to be considered for selecting suitable method of application. Soil texture influences the mobility of the fertilizer material. Soil pH increases volatilization of ammoniacal fertilizers when it is more than 8 pH. The soils with high CEC retain the cations present in the fertilizer material and thus reduce leaching tosses. In soils low in phosphorus status, band placement of phosphatic fertilizer reduces fixation, while in soils of medium phosphorus status, incorporation of phosphorus fertilizer after broadcasting is better for higher availability. For crops grown on residual moisture, deep placement of fertilizer in the moist zone is essential and when it is not possible foliar application is resorted to Nature of the Crop.
Depending on the type of root system and spacing adopted for the crop, different methods of fertilizer application are practiced. In crops with fibrous root system and those grown with closer spacing, most of top layer of the soil is occupied by the root system. In such a situation, broadcasting of fertilizer is resorted to followed by irrigation. In widely spaced crops with initial slow growth, point placement is adopted instead of broadcasting over the entire field.

Nature of the fertilizer

Suitable method of fertilizer application depends on the properties of fertilizers such as physical form, solubility and mobility. Mud-ball urea, pellets and briquetts of urea are amenable for placement with hand. Granules and prills can be drilled while granules, prills and powders can be broadcasted. Liquid fertilizers are applied with irrigation water alone or mixed with herbicide sprays. Soluble fertilizers can be applied as foliar application. Fertilizers containing plant nutrients which are immobile or less mobile are applied in the root zone. Fertilizers which are subject to volatilization and denitrification losses are incorporated into the soil.

Different methods

Soil Application *Broadcasting* .Application of fertilizer uniformly on the soil surface is known as broadcasting of fertilizer. This is done either before sowing of the crop or in the standing crop (top dressing). Broadcasting is the most widely practiced method in India due to ease in application.

Broadcasting is advantageous with solid and soluble fertilizers.

Broadcasting and Incorporation. Generally, the entire dose of a phosphatic and potassium fertilizer is applied by broadcasting before sowing. Because of their low mobility in soil, these fertilizers are incorporated into the rooting zone.

Band Placement. Application of fertilizers in narrow bands beneath and by the side of the crop rows is known as band placement of fertilizers. Band placement is done under the following situations: (I) when the crop needs initial good start, (2) when soil fertility is low, (3) when fertilizer materials react with soil constituents leading to fixation, and (4) where volatilization losses are high. Depending on the root system, fertilizer band is placed directly beneath the seed or by the side of the row. For crops like castor, redgram, cotton etc., with tap root system, fertilizer band can be 5 cm below the seed. In cereals and millets, which produce fibrous rootsystem, it is advantageous to place fertilizers 5 cm away from the seed row and 5 cm deeper than the seed placement.

Point Placement. Placement of fertilizers near the plant either in a hole or in a depression followed by closing or covering with soil is known as point placement of fertilizers. It is adopted for top dressing of nitrogenous fertilizers in widely spaced crops. In sugarcane, two or three holes are made around the clump and nitrogenous fertilizers are placed in the holes and closed. Similarly, soil near tobacco plants is scooped and fertilizers are placed and covered with soil. This method is adopted to get high recovery of fertilizer nitrogen. Since the crop roots occupy only a small fraction of soil in the early stages, it is not advisable to apply to the entire field by broadcasting. Urea supergranules and urea briquetts are placed in the reduced zone by pressing them into the mud in between the hills of rice plants.

Sub-soil Placement. It refers to the placement of fertilizers in the subsoil with the help of high power machinery. This method is recommended in humid and subhumid regions where sub-soils are acidic.

Fertigation. Application of fertilizers with irrigation water is known as fertigation. Straight an mixed fertilizers containing N, P and K easily soluble in water, are allowed to dissolve in the irrigation stream. The nutrients are thus carried into the soil in solution. This saves the application cost and allows the utilization of relatively inexpensive water soluble fertilizers. Usually nitrogenous fertilizers are most commonly applied through irrigation water. It is generally followed with drip irrigation.

Application to plant*Root Dipping.* The roots of the seedlings are dipped in nutrient solution before transplanting. In soils deficient in phosphorus, roots of rice seedlings are dipped in phosphorus slurry before planting.

Foliar application. Application of fertilizers to foliage of the crop as spray solution is known as foliar spray of fertilizers. It is also called non-root feeding. These solutions may be prepared in a low concentration to apply any one of plant nutrient or a combination of nutrients. This method is suitable for application of small quantities of fertilizers, especially micronutrients. Major nutrients can also be applied by this method when there is not adequate moisture in the top layer of soil. Among the nutrients N is most frequently foliarly applied. Absorption of N by foliage I more rapid and nearly 80% of the spray material is absorbed by most of the crops within 24 hours of application. Spray of urea 4-6% solution, is common in many cereals excluding maize which is very susceptible to foliar injury. Some thick-cuticle leaf fruit crops can also be sprayed with urea concentration as high as 15-20%. For feed crops foliar application to be effective need to be sprayed at low concentration (2-4%) when LAI is high to retain the spray. Foliar application of urea just before flowering or at flowering increases grain quality and leaf area duration (LAD). It should be preferably sprayed during evening hours to reduce failure of fertility and grain sterility.

Foliar feeding is an efficient method of fertilization supplementary to soil feeding. It is not a substitute for soil application, but only a supplement to it. Precautions are taken to avoid scorching. Stickers can be mixed for retaining fertilizers on the foliage. To avoid any injury or to increase absorption wetting agent like teepol (1.0%) can be used.

Foliar application of P is less frequent than nitrogen partly due to the fact that almost agricultural crops require P early in the growth period and foliage canopy is very mall to retain the spray and partly that most of the phosphatic fertilizers are of low solubility. Single super phosphate can be soaked in water for 2 days before spray. Supernatant liquid is strained carefully, dilute and sprayed.

Potassium is less frequently applied in spray as single nutrient but more frequently in complex fertilizer spray.

To determine the choice of fertilizer, it dose and method and time of application valid for wide variety of soil and climatic situations. Conduct of multilocational trials over seasons and collection of first hand data are more important than statistical analysis. The soil - plant system in so far as crop nutrition is concerned should be treated as continuum, a sequence of physicochemical processes that follow physic-chemical laws in which concentration of reactants and reaction rate constant can be manipulated so that nutrient (in solution) nutrient (in plant root) nutrient in plant (top) is maintained.

It has been well established that all plant nutrients are absorbed through the leaves of plants and this absorption is remarkably rapid and complete for some nutrients. Absorption of sprayed nutrient is both by cuticle an stomata, in the long run cuticular absorption being more than stomatal. It has been observed that the effects of nutrient sprays are usually about the same as of soil application, and rarely more than two or three times greater. Therefore, foliar application does not result in a great saving of fertilizer, but may be preferable to soil application when

1. The soil conditions (moisture or uneven topography) or a competitive crop makes nutrients from soil dressings unavailable, like late application of nitrogen to crops raised under rainfed conditions;
2. An accurately timed response to fertilizers is required, e.g., changes in the season or higher fertilizer economy is desired;
3. Routine applications are made of insecticidal or herbicidal sprays to which nutrients can be added.
4. The growth of the crop prevents application of fertilizers to the soil but permits its application to the leaves from a high clearance sprayer or from a helicopter.

There are certain difficulties associated with the foliar application of nutrients. These are: i) marginal leaf burn or scorching may occur if strong solution are used ii) as solutions of low concentrations (usually three to six percent) are to be used, only small quantities of nutrients can be applied in one single spray, iii) several applications are needed for moderate to high fertilizer rates, and hence iv) foliar spraying of fertilizers is costly compared to soil application, unless combined with other spraying operations taken up for weeds, insect or disease control

Soil Test Crop Response (STCR) Approach

This approach takes into account the soil contribution and yield level for recommending fertilizer dose for a particular crop. This approach is also called as rationalized fertilizer prescription or prescription based fertilizer recommendations. It is specific to a given type of soil,n crop and climatic situation. The requirement of nutrients is different for different crops. Then efficiency of soil available nutrients and those added through fertilizers is also different for different type of soils under a particular set of climatic conditions. Therefore, following three basic parameters are worked out for the specific crop and area for the development of prescription based fertilizer recommendations:

1. Nutrient requirement (kg/q) =Total uptake of nutrient (kg/ha)
Grain yield (q/ha)
2.Efficiency of soil available
nutrients (CS %)
=
Uptake in control plot (kg/ha)
x 100
Soil test value (STV) of nutrient (kg/ha) in control plots
3.Efficiency of fertilizer nutrient
(CF %)
=
Total uptake of nutrient in fertilized plots –
(STV in fertilized plot x CS)
x 100
Nutrient applied through fertilizer (kg/ha)

After calculating these three basic parameters from the yield and uptake data from the well conducted test crop experiment, these basic parameters, in turn, are transformed into workable
fertilizer adjust equations as below,
Fertilizer nutrient dose (kg/ha) =
NR
x 100 x T -
CS%
x STV
CF% CF%

Thus equations for nitrogen, phosphorus and potassium are of the type
FN = X T - Y SN
F P2O5 = Xi T - Yi SP
F K2O = Xj T - Yj SK

Where SN is soil nitrogen (N kg/ha); SP soil phosphorus (P kg/ha); SK soil potassium (K kg/ha); FN fertilizer N to be applied (N kg/ha); FP fertilizer P2O5 to be applied (P2O5 kg/ha); K2O
fertilizer K2O to be applied (K2O kg/ha) and T is targeted yield (q/ha).

Based on this approach, fertilizer recommendations are developed for different regions (Table 2).One such equation developed to recommend N, P, K fertilizers for rice is given below:
FN = 4.39 T - 0.6723 SN
F P2O5 = 2.83 T - 6.110 SP
F K2O = 1.41 T - 0.329 SK

It is to be remembered that in the equations, soil phosphorus and potassium are considered in elemental form while fertilizer phosphorus and potassium are in oxidized form (P2O5 and K2O). The prescription based fertilizer recommendations method avoid wide variation in soil rating limits used in the previous method as it substitutes the exact values for soil available N, P and K. This method ensures the balanced nutrition of crops besides the maintenance of soil fertility.

The drawbacks of STCR approach are that these equations are not available for different crops and regions and development of these involves cost and time. These equations are suitable when available N P and K are estimated by potassium permanganate, Olson and ammonium acetate methods, respectively.

Using fertilizer adjustment equations

The fertilizer adjustment equations are very simple and easy to use for calculating the fertilizer doses for different yield targets. But before these equations are used, the following points must be taken into account:

1. Proper procedure must be followed in the collection and preparation of the representative soil sample.
2. Farmer should be asked about the choice of the crop he is interested to grow and money he can spent on fertilizers.
3. Depending upon the above 2, the proper yield target should be fixed.
4. Chemical analysis of the soil sample should be very accurate.
5. Present the soil analysis values of N, P and K in kg/ha. Use these values in kg/ha in the fertilizer adjustment equation in place of SN, SP and SK, respectively.
6. Once the nutrient doses (kg/ha) are calculated for a specific yield target, they should be converted into their respective fertilizer equivalents.
7. Follow all the standard agronomic practices during the entire crop growth period.

Problem 1: Recommend fertilizer dose for rice using soil-test crop response equation from the data given below:

Let the prescription equations be

FN = 4.39 T - 0.6723 SN

F P_2O_5 = 2.83 T - 6.110 SP

F K_2O = 1.41 T - 0.329 SK

Assume that soil available N (potassium permanganate method) is 250 kg/ha, soil available P_2O_5 (Olson's method) 35 kg P_2O_5 per ha, soil available K_2O (ammonium acetate method) 350 kg K_2O per ha and targeted yield is 5 t/ha.

Convert P_2O_5 and K_2O into P and K respectively as soil phosphorus and potassium are considered in elemental form in the equation.

Soil P = 35 x 0.43 = 15.05

Soil K = 350 x 0.83 = 290.5

Targeted yield = 5 t/ha = 50 q/ha.

Substitute T, SN, SP and SK in the equation

FN = 4.39 T - 0.6723 SN = (4.39 x 50) - (0.6723 x 250) = 219.50 - 168.07 = 51.43 kg N/ha

F P_2O_5 = 2.83 T - 6.11 SP = (2.83 x 50) - (6.11 x 15.05) = 141.50 -91.95 = 49.55 kg P_2O_5/ha F K_2O = (1.41 x 50) - (0.329 x 290.5) = 70.50 - 95.57 = - 25.07 kg K_2O /ha

Thus for a 5 t crop of rice, with soil test values of 250 kg N/ha, 35 kg P_2O_5/ha and 350 kg K_2O/ha, the fertilizer recommended dose is 51.43 kg N, 49.55 kg P_2O_5 and zero K_2O hectare as soil contains sufficient quantities of K in the soil. If the recommendation is compared with blanket recommendation of 100: 60: 60 kg N, P_2O_5 and K_2O/ha, lot of fertilizers are applied unnecessarily for a 5 t crop by blanket recommendation approach.

Problem 2:

Prescription equations:

FN = 5.46 T - 0.32 SN

F P_2O_5 = 2.58 T – 2.67 SP
F K_2O = 2.82 T - 0.68 SK
Yield target= 45 q/ha
Available N, P and K are 450, 20 and 175 kg/ha, respectively
Sol: FN (kg/ha) = 5.46 x 45 – 0.32 x 450 = 245.7 – 144.0 = 101.7 say 102 kg N/ha
FP_2O_5 (kg/ha) = 2.58 x 45 – 2.67 x 20 = 126.1 – 53.4 = 62.7 or 63.0 kg P_2O_5/ha
FK_2O (kg/ha) = 2.82 x 45 – 0.68 x 175 = 126.9 – 119 = 7.9 or 8.0 kg K_2O/ha

DRIS Approach

Recently Diagnosis and Recommendation Integration System (DRIS) approach is suggested for fertilizer recommendation. In this approach, plant samples are analyzed for nutrient content and they are expressed as ratios of nutrients with others. Suitable ratios of nutrients are established for higher yields from experiments and plant samples collected from farmer's fields.

The nutrients whose ratios are not optimum for high yields are supplemented by top dressing.
This approach is generally suitable for long duration crops, but it is being tested for short duration crops like soybean, wheat etc.

Modeling Approach

This approach is particularly suitable for recommendation of nitrogenous fertilizers where soils are rich in organic matter as in temperate regions. The soil contribution is estimated based on the fact that mineralization depends on soil temperature.

Relative performance of organic and inorganic manures

Organic cannot meet nutrient requirement of crops. For example a 5 t grain yielding rice crop removes about 98 kg N, 45 kg P_2O_5 and 150 kg K_2O and 55 kg Ca. Assuming that the farm yard manure (FYM) contains 0.5% N, 0.2% P_2O_5 and 0.5% K_2O (contents vary with source, method of production etc) such a crop will need 19.6 t FYM per ha. Quantities of nutrients contained in organics are not completely available in the first year offeature and may therefore, be ignored. However, whenever secondary produce has a commercial value, it should be positively considered while working out economics of fertilizer use. As regard the value of the additional produce, it is an over-simplification to work out the same at the support/market price without taking into account the variable cost of production of the crop.

Regarding expenses (E') it is to be noted that the application of fertilizer to a crop usually entails additional expenses by way of extra irrigation, extra interculture, additional plant protection measures etc. it would also be correct to say that the additional yield consequent to the use of fertilizer is the combined result of the effect of fertilizer and these additional inputs. Any attempt to properly evaluate the economics of fertilizers only should deduct the increase due to other associated inputs.Cost of production of a crop has two well recognized components viz. Fixed costs (the cost which does not vary with the level of yield or output like cost of seed, preparatory tillage operations, post sowing inter-cultivations etc. and Variable cost (the cost which varies directly with the level of produce, like cost of harvesting, threshing, winnowing, marketing etc.When cost-benefit ratio (CBR) is worked out without considering value of secondary produce and variable cost of cultivation, it is known as gross CBR and when value of secondary produce and variable cost are considered, the ratio is known as net CBR. One cost benefit ratio represents the break-even point where the extra yield just pays for fertilizer cost (a no profit no loss situation). A CBR 2 means 200% gross return or 100% net return over investment.CBR or fertilizer application (economics of fertilizer use) is a variable factor, changing directly with value of extra main and secondary produce and fertilizer cost. Another ratio commonly used in working out economics of fertilizer use is incremental cost benefit ratio (ICBR). In this analysis, the incremental costs of applying fertilizers and the incremental benefits through additional farm output are compared. As per FAO standard, the value of net ICBR should be better than 1:2.5.