COURSE NO.: AG.CHEM.3.2

TITLE: MANURES, FERTILIZERS AND SOIL FERTILITY MANAGEMENT (2+1)

CONTENTS

Reference Books

1. Manures and Fertilizes (1992), Seventh Edition by K. S. Yawalkar, J. P. Agarwal and S. Bokde
2. Soil Fertility, theory and practice (1976) by J. S. Kanwar
3. Soil Fertility and Fertilizers (1985) by S.L. Tisdale, W.L. Nelson and J. D. Beaton
4. Fundamentals of Soil (1999) by V. N. Sahai
5. Introductory Soil Science (1999) by D. K. Das.

CHAPTER- I: ORGANIC MANURES

The manures are organic in nature, plant or animal origin and contain organic matter in large proportion and plant nutrients in small quantities and used to improve soil productivity by correcting soil physical, chemical and biological properties. Manure is organic matter used as organic fertilizer in agriculture. Manures contribute to the fertility of the soil by adding organic matter and nutrients, such as nitrogen, that are trapped by bacteria in the soil. Higher organisms then feed on the fungi and bacteria in a chain of life that comprises the soil food web.

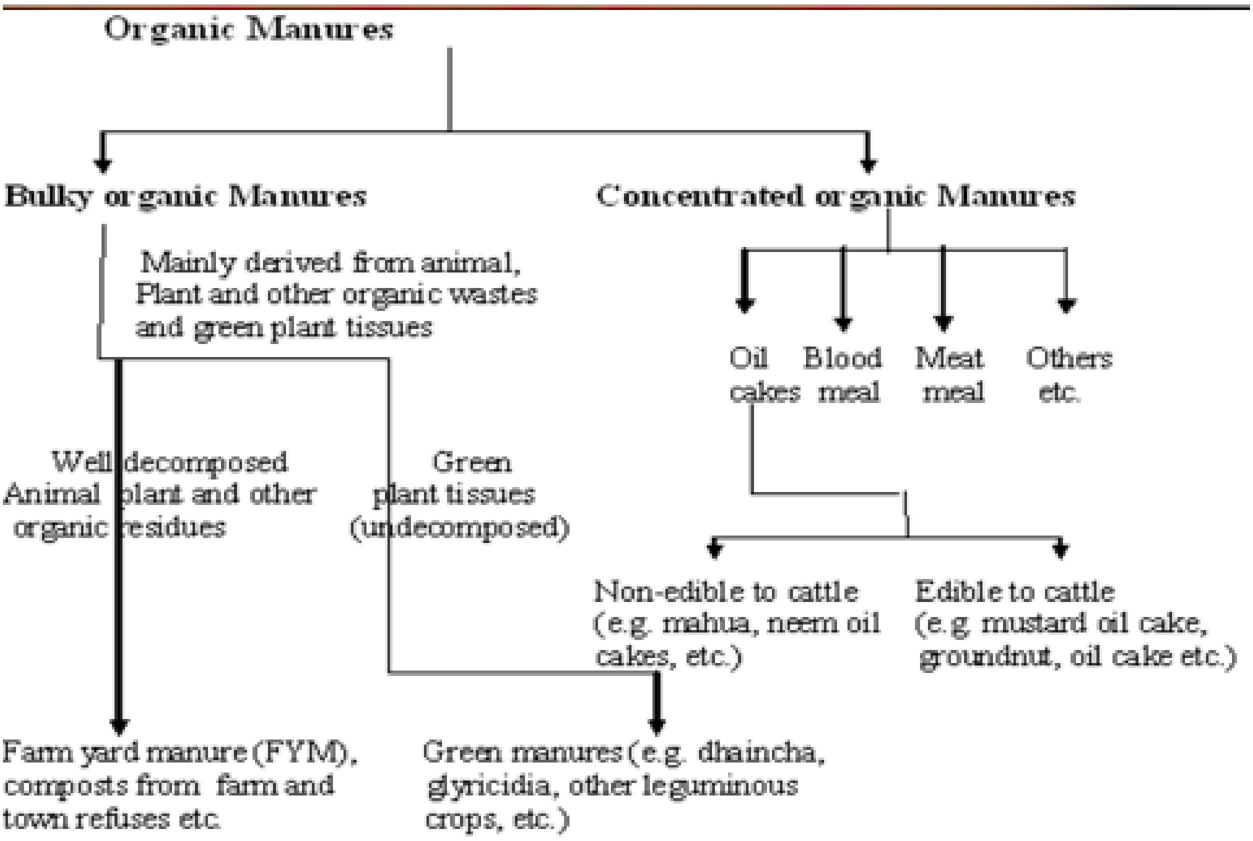
Difference between manures and fertilizers:

Manure	Fertilizer
1. Contains O.M. and hence improves soil physical properties	1. Do not contain O.M. and cannot improve soil physical properties
2. Improves soil fertility as well as productivity	2. Improves soil fertility
3. Contains all plant nutrients but small in concentration	3. Contains one or more plant nutrients but in higher concentration
4. Required in large quantity bulky and costly	4. Required in less quantity concentrated and cheaper
5. Nutrients are slowly available upon decomposition	5. Nutrients are readily available.
6. Long lasting effect on soil and crop	6. Very less residual effect
7. No salt effect	7. Salt effect is high
8. No adverse effect	8. Adverse effects are observed when not applied in time and in proper proportion.

1.1 Bulky Organic Manures:

Bulky organic manures include farm yard manure (FYM) or farm manure, farm compost, town compost, night soil, sludge, green manures and other bulky sources of organic matter. All these manures are bulky in nature and supply (i) plant nutrients in small quantities and (ii) organic matter in large quantities. Of the various bulky organic manures, farm yard manure, compost and green manure are by far most important and most widely used.

Classification of organic manures



Effect of bulky organic manures on soil:

i) Direct effect on plant growth

ii) Increase organic matter content and improve physical properties of soil. Increase humus content of soil and consequently WHC of sandy soil is increased and the drainage of clayey soil is improved.

iii) Provide food for soil microorganisms. This increases activity of microbes which in turn helps in converting unavailable plant nutrients into available forms.

Farm Yard Manure (FYM):

It refers to the decomposed mixture of dung and urine of farm animals along with litter (bedding material) and left over material from roughages or fodder fed to the cattle.

On an average well-rotted FYM contains 0.5% N_s 0.2% P_20_5 and 0.5% K_20.

FYM is one of the most important agricultural by products. Unfortunately, however nearly 50 per cent of the cattle dung production in India today is utilized as fuel and is thus lost to agriculture.

Average percentage of N, P_20_5 and K_2O in the fresh excreta of farm animals:

Excreta of		N (%)	P_2O_5 (%)	K_2O (%)
Cows and bullocks	Dung	0.40	0.20	0.10
	Urine	1.00	Traces	1.35
Sheep and goat	Dung	0.75	0.50	045
	Urine	1.35	0.05	2.10
Buffalo	Dung	0.26	0.18	0.17
	Urine	0.62	Traces	1.61
Poultry	-	1.46	1.17	0.62

i) Poultry manure is the richest of all

ii) Urine of all animals contains more percentage of N and K_2O compared to the dung portion.

Factors Affecting Nutritional Buildup of FYM:

The following factors affect the composition of FYM:

1. **Age of animal:** Growing animals and cows producing milk retain in their system nitrogen and phosphorus required for productive purposes like making growth and producing milk and the excreta do not contain all the ingredients of plant food given in the feed. Old animals on the downgrade waste their body tissues and excrete more than what they do ingest.
2. **Feed:** When the feed is rich in plant food ingredients, the excreta produced is correspondingly enriched.
3. **Nature of Litter Used:** Cereal straw and leguminous plant refuse used as litter enriched the manure with nitrogen.
4. **Ageing of Manure:** The manure gets richer and less bulky with ageing.
5. **Manner of Making and Storage:** In making and storage losses are in various ways. (see ‘Losses in FYM).

Losses during handling and storage of FYM:

(I) Losses during handling:

FYM consists of two original components the solid or dung and liquid or urine. Both the components contain N, P_2O_5 and K_2O the distribution of these nutrients in the dung and urine is shown in figure below:

Approximately half of N and K_2O is in the dung and the other half in urine. By contrast, nearly all of the P_2O_5 (96%) is in the solid portion. To conserve N, P_2O_5 and K_2O, it is most essential that both the parts of cattle manure are properly handled and stored.

i) Loss of liquid portion or urine

Under Indian conditions the floor of the cattle shed is usually un-cemented or Kachha. As such the urine passed by animals during night gets soaked into the Kachha floor. When the animals, particularly bullocks, are kept in the fields during the summer season, urine gets soaked into soil. But during remaining period cattle are kept in a covered shed and therefore the Kachha floor soaks the urine every day. Large quantities of nitrogen are thus lost through the formation of gaseous NH_3. The following reactions take place:

$$NH_2CONH_2 + 2H_2O \longrightarrow (NH_4)_2CO_3$$

Urea in urine **Ammonium carbonate**

$$(NH_4)_2CO_3 + 2H_2O \longrightarrow 2NH_4OH + H_2CO_3$$

$$NH_4OH \longrightarrow NH_3\uparrow + H_2O$$

Gaseous Ammonia

The smell of NH_3 in the cattle shed clearly indicates the loss of N.

No special efforts are made in India to collect the liquid portion of the manure.

ii) Loss of solid portion or dung

It is often said that 2/3 of the manure is either utilized for making cakes or is lost during grazing, the remaining manure is applied to the soil after collecting in heaps. Firstly, the most serious loss of dung is through cakes for burning or for use as Fuel-Secondly, when milch animals go out for grazing, no efforts are made to collect the dung dropped by them, nor is this practicable, unless all milch animals are allowed to graze only in enclosed small size pastures.

(II) Loss during storage:

Mostly, cattle dung and waste from fodder are collected daily in the morning by the cultivators and put in manure heaps in an open space outside the village. The manure remains exposed to the sun and rain. During such type of storage, nutrients are lost in the following ways:

i) By leaching:

Losses by leaching will vary with the intensity of rainfall and the slope of land on which manure is heaped. About half of portion of N and P_2O_5 of FYM and nearly 90% of K are water soluble. These water soluble nutrients are liable to get washed off by rain water.

ii) By Volatilization:

During storage considerable amount of NH_3 is produced in the manure heap from

i) the decomposition of urea and other nitrogenous compounds of the urine and
ii) the much slower decomposition of the nitrogenous organic compounds of the dung. As the rotting proceeds, more and more quantity of ammonia is formed. This NH_3 combines with carbonic acid to form ammonium carbonate and bicarbonate. These ammonium compounds are unstable and gaseous NH_3 may be liberated as indicated below:

1. Urea and other nitrogenous compounds in urine and dung $\xrightarrow[\text{decomposition}]{\text{microbial}}$ $NH_3 \uparrow$
2. $2NH_3 + H_2CO_3 \longrightarrow (NH_4)_2 CO_3$
3. $(NH_4)_2 CO_3 + 2H_2O \longrightarrow 2NH_4 OH + H_2CO_3$
4. $NH_4OH \longrightarrow NH_3 + H_2O \uparrow$

Loss of NH_3 increases with

i) the increase in the concentration of ammonium carbonate
ii) increase in the temperature and
iii) air movement

Improved Methods of Handling FYM:

It is practically impossible to check completely the losses of plant nutrients and organic matter during handling and storage of FYM. However, improved methods could be adopted to reduce such losses considerably.

Among these methods are described here under:

i) Trench method of preparing FYM

ii) Use of gobar gas-compost plant

iii) Proper field management of FYM

iv) Use of chemical preservatives

ii) Use of gobar gas compost plant:

Methane gas is generated due to anaerobic fermentation of the most common organic materials such as cattle dung, grass, vegetable waste and human excreta. Gobar gas and manure both are useful on farms as well as in homes. A few advantages of this method are given below:

1) The methane gas generated can be used for heating, lighting and motive power.

2) The methane gas can be used for running oil engines and generators

3) The manure which comes out from the plant after decomposition is quite rich in nutrients. N -1.5%, P_2O_5- 0.5%, K_2O- 2.0%

4) Gobar gas manure is extremely cheap and is made by locally available materials.

Superiority of gobar gas compost plant over traditional method:

1000 Kg fresh dung manure obtained by

Sr. No.	Particulars	Traditional method	Gobar gas plant
1.	Loss of OM	500 Kg	270 Kg
2.	Loss of N	1.25 Kg	Nil
3.	Final manure	**500 Kg**	730 Kg
4.	% N	0.5%	1.5%
5.	Additional advantage	-	2000 C.ft. gas for cooking

iii) Proper field management of FYM:

Under field conditions, most of the cultivators unload FYM in small piles in the field before spreading. The manure is left in piles for a month or more before it is spread. Plant nutrients are lost through heating and drying. To derive maximum benefit from FYM, it is most essential that it should not be kept in small piles in the field before spreading, but it should be spread evenly and mixed with the soil immediately.

iv) Use of Chemical Preservatives:

Chemical preservatives are added to the FYM to decrease N losses. To be most effective, the preservatives are applied in the cattle yard to permit direct contact with the liquid portion of excreta or urine. This has to be done because the loss of N from urine starts immediately. The commonly used chemical preservatives are I) Gypsum and ii) Super phosphate. The value of gypsum in preserving the N of manure has been known and it has been used for many years in foreign countries. The reaction of gypsum with ammonium carbonate (intermediate product from decomposition of urea present in urine) is :

$$(NH_4)_2 CO_3 + CaSO_4 \longrightarrow CaCO_3 + (NH_4)_2 SO_4$$

As long as the manure is moist, no loss of NH_3 will occur, but if the manure becomes dry, the chemical reaction is reversed and the loss of NH_3 may occur. As such, under Indian conditions, use of gypsum to decrease N losses, does not offer a practical solution.

Superphosphate has been extensively used as a manure preservative:

$$2CaSO_4 + Ca (H_2PO_4)_2 + 2 (NH_4)_2 CO_3 \longrightarrow Ca_3(PO_4)_2 + 2 (NH_4)_2 SO_4 + 2H_2O + 2CO_2$$

In this reaction, tricalcium phosphate is formed which does not react with ammonium sulphate, when manure becomes dry. As such, there is no loss of NH_3.

Since FYM becomes dry due to high temperature under Indian conditions, the use of superphosphate will be safely recommended as a preservative to decrease N losses. **Use of superphosphate as a chemical preservative will have three advantages**:

1. It will reduce loss of N as ammonium from FYM.
2. It will increase the percentage of P in manure thus making it a balanced one.
3. Since, tricalcium phosphate produced with the application of superphosphate to the FYM is in inorganic form, which is readily available to the plants, it will increase the efficiency of phosphorus.

It is recommended that one or two pounds of SSP should be applied per day per animal in the cattle shed where animal pass urine.

Supply of plant nutrients through FYM:

On an average, FYM applied to various crops by the cultivators contains the following nutrients:

% N : 0.5 % P_2O_5 : 0.2 % K_2O : 0.5

Based on this analysis, an average dressing of 10 tones of FYM supplies about

50 Kg N 20 Kg P_2O_5 50 Kg K_2O

All of these quantities are not available to crops in the year of application, particularly N which is very slow acting. Only 1/3 of the N is likely to be useful to crops in the first year. About 2/3 of the phosphate may be effective and most of the potash will be available. This effect of FYM application on the yield of first crop is known as the direct effect of application. The remaining amount of plant food becomes available to the second, third and to a small extent to the fourth crop raised on the same piece of land. This phenomenon is known as the residual effect of FYM.

When FYM is applied every year, the crop yield goes on increasing due to direct plus residual effect on every succeeding crop. The beneficial effect is also known as cumulative effect.

Compost:

Compost (pronounced /ˈkɒmpɒst/ or /ˈkɒmpoʊst/) is composed of organic materials derived from plant and animal matter that has been decomposed largely through aerobic decomposition. The process of **composting** is simple and practiced by individuals in their homes, farmers on their land, and industrially by industries and cities. Composting is largely a bio-chemical process in which microorganisms both aerobic and anaerobic decompose organic residue and lower the C : N ratio. The final product of composting is well rotted manure known as compost.

Rural compost: Compost from farm litters, weeds, straw, leaves, husk, crop stubble, bhusa or straw, litter from cattle shed, waste fodder, etc. is called rural compost.

Urban compost: Compost from town refuse, night soil and street dustbin refuse, etc is called urban compost.

Composition of town compost:

Nitrogen	Phosphorus	**Potassium**
(%N)	(%P_2O_5)	(%K_2O)
1.4	1.0	1.4

Compared to FYM, town compost prepared from Katchara and night soil is richer in fertilizer value.

Mechanical Composting Plants:

Mechanical composting plants with capacities of 500 – 1000 tonnes per day of city garbage could be installed in big cities in India and 250 tonnes per day plants in the small towns. Refined mechanical compost contains generally about 40% mineral matter and 40% organic materials with organic carbon around 15%. The composition would vary depending on the feed but typically the nutrient content is about 0.7% N, 0.5% P_2O_5 and 0.4% K_2O. There are trace elements like Mn, B, Zn and Cu and the material has C : N ratio of nearly 15-17.

Decomposition:

The animal excreta and litter are not suitable for direct use as manure, as most of its manurial ingredients are present in an unavailable form. However, urine, if collected separately, can be used directly. The dung and litter have to be fermented or decomposed before they become fit for use. Hence, the material is usually stored in heaps or pits, where it is allowed to decompose. Under suitable conditions of water supply, air, temperature, food supply and reaction, the microorganisms decompose the material. The decomposition is partly aerobic and partly anaerobic. During decomposition the usual yellow or green colour of the litter is changed to brown and ultimately to dark brown or black colour; its structural form is converted into a colloidal, slimy more or less homogenous material, commonly known as **humus.**

Factors controlling process of decomposition:

1) Food supply to micro-organisms and C : N ratio:

The suitable ratio of carbonaceous to nitrogenous materials is 40, if it is wider than this, the decomposition takes place very slowly and when narrow it is quick. C:N ratio of the dung of farm animals varies from 20 to 25, urine 1 to 2, poultry manure 5-10, litters-cereals straw 50, and legume refuse 20.

2) Moisture:

About 60-70 per cent moisture is considered to be the optimum requirement to start decomposition and with the advance in decomposition, it diminishes gradually being 30-40 per cent in the final product. Excess of moisture prevents the temperature form rising high and retards decomposition, resulting in loss of a part of the soluble plant nutrients through leaching and drainage.

3) Aeration:

Most of the microbial processes are oxidative and hence a free supply of oxygen is necessary.

Reasons for poor aeration in pit/heap

i) Excessive watering

ii) Compaction

iii) Use of large quantities of fine and green material as litters

iv) High and big heaps or deep pits.

4) Temperature:

Under the optimum conditions of air moisture and food supply, there is a rapid increase in the temperature in the manure heap or pit. The temperature usually rises to 50º–60ºC and even to 70ºC. The high temperature destroys weed seeds, worms, pathogenic bacteria, *etc,* which prevents fly breeding and makes the manure safe from hygienic point of view.

5) Reaction:

The microorganisms liberate certain organic acids during the course of decomposition, which, if allowed to accumulate, retards fermentation and sometime even stop it completely. Hence, it is necessary to control the reaction of the material.

A neutral or slightly alkaline reaction between pH 7.0 and 7.5 is considered the most suitable. The addition of alkaline substances like lime and wood ashes neutralized the excess acidity. Since in the preparation of FYM it is a common practice to add household ashes to the manure pit, it is not necessary to add additional alkaline substances.

Heap *V/S* Pit decomposition:

Heap	Pit
1. Aerobic	1. Anaerobic
2. Turning is required	2. No turning is required
3. Physical disintegration	3. Very little physical disintegration
4. Quick oxidation	4. Slow rate of decomposition
5. High temp. 60º – 70ºC. Kill weed seeds and pathogenic	5. High temp. is not developed but weed seeds and MO destroyed

	organisms		due to toxic products of decomposition.
6.	Loss of OM is about 50%	6.	Loss is about 25%
7.	If not properly protected, moisture loss is high. Watering is necessary	7.	Moisture loss is minimized. No watering is necessary
8.	If rainfall is high, leaching takes place	8.	Protected from leaching but anaerobic condition occurs.

Vermicomposting:

Vermicompost is the product of composting utilizing various species of worms, usually red wigglers, white worms, and earthworms to create a heterogeneous mixture of decomposing vegetable or food waste, bedding materials, and vermicast. Vermicast is also known as worm castings, worm humus or worm manure, is the end-product of the breakdown of organic matter by species of earthworm. The earthworm species (or **composting worms**) most often used are Red Wigglers (*Eisenia foetida* or *Eisenia andrei*), though European night crawlers (*Eisenia hortensis*) could also be used. Users refer to European night crawlers by a variety of other names, including *dendrobaenas*, *dendras*, and Belgian night crawlers. Containing water-soluble nutrients, vermicompost is a nutrient-rich organic fertilizer and soil conditioner.

Vermiculture means artificial rearing or cultivation of worms (Earthworms) and the technology is the scientific process of using them for the betterment of human beings. Vermicompost is the excreta of earthworm, which is rich in humus. Earthworms eat cow dung or farm yard manure along with other farm wastes and pass it through their body and in the process convert it into vermicompost. The municipal wastes; non-toxic solid and liquid waste of the industries and household garbage's can also be converted into vermicompost in the same manner. Earthworms not only convert garbage into valuable manure but keep the environment healthy.

Method of preparation of Vermicompost Large/community Scale:

A thatched roof shed preferably open from all sides with unpaved (*katcha*) floor is erected in East-West direction length wise to protect the site from direct sunlight. A shed area of 12'X12' is sufficient to accommodate three vermibeds of 10'X3' each having 1' space in between for treatment of 9-12 quintals of waste in a cycle of 40-45 days. The length of shed can be increased/decreased depending upon the quantity of waste to be treated and availability of space. The height of thatched roof is kept at 8 feet from the centre and 6 feet from the sides. The base of the site is raised at least 6 inches above ground to protect it from flooding during the rains. The vermibeds are laid over the raised ground as per the procedure given below. The site marked for vermibeds on the raised ground is watered and a 4”-6” layer of any slowly biodegradable agricultural residue such as dried leaves/straw/sugarcane trash etc. is laid over it after soaking with water. This is followed by 1” layer of Vermicompost or farm yard manure.

Earthworms are released on each vermibed at the following rates:

For treatment of cowdung/agriwaste: 1.0 kg. per

For treatment of household garbage: 1.5 kg. per

The frequency and limits of loading the waste can vary as below depending upon the convenience of the user

Frequency	Loading
Daily	2" /bed/day
In Bulk	12-15"(3-4q/bed/cycle of 45 days)

The loaded waste is finally covered with a Jute Mat to protect earthworms from birds and insects. Water is sprinkled on the vermibeds daily according to requirement and season to keep them moist. The waste is turned upside down fortnightly without disturbing the basal layer (vermibed). The appearance of black granular crumbly powder on top of vermibeds indicate harvest stage of the compost. Watering is stopped for atleast 5 days at this stage. The earthworms go down and the compost is collected from the top without disturbing the lower layers (vermibed). The first lot of Vermicompost is ready for harvesting after 2-2 ½ months and the subsequent lots can be harvested after every 6 weeks of loading. The vermibed is loaded for the next treatment cycle.

Multiplication of worms in large scale:

Prepare a mixture of cow dung and dried leaves in 1:1 proportion. Release earthworm @ 50 numbers/10 kg. Of mixture and mix dried grass/leaves or husk and keep it in shade. Sprinkle water over it time to time to maintain moisture level. By this process, earthworms multiply 300 times within one to two months. These earthworms can be used to prepare Vermicompost.

Advantages of Vermicomposting:

- Vermicompost is an ecofriendly natural fertilizer prepared from biodegradable organic wastes and is free from chemical inputs.
- It does not have any adverse effect on soil, plant and environment.
- It improves soil aeration, texture and tilth thereby reducing soil compaction.
- It improves water retention capacity of soil because of its high organic matter content.
- It promotes better root growth and nutrient absorption.
- It improves nutrient status of soil-both macro-nutrients and micro-nutrients.

Precautions during vermicomposting:

- Vermicompost pit should be protected from direct sun light.
- To maintain moisture level, spray water on the pit as an when required.
- Protect the worms from ant, rat and bird

Nutrient Profile of Vermicompost and Farm Yard Manure:

Nutrient	Vermicompost	Farm Yard Manure
N (%)	1.6	0.5
P (%)	0.7	0.2
K (%)	0.8	0.5
Ca (%)	0.5	0.9
Mg (%)	0.2	0.2
Fe (ppm)	175.0	146.5
Mn (ppm)	96.5	69.0
Zn (ppm)	24.5	14.5
Cu (ppm)	5.0	2.8
C:N ratio	15.5	31.3

Night Soil:

Night soil is human excrement i.e. solid and liquid. Night soil is richer in N, P_2O_5 and K_2O as compared to FYM or compost. On oven dry basis, it has an average chemical composition of:

N%	P_2O_5%	K_2O%
5.5.	4.0	2.0

In India it is applied to a limited extent directly to the soil. Pits or trenches of 10 to 12 ft. long, 2 to 3 ft. wide and 9 inches to 1 foot deep are made. In these pits, night soil is deposited and covered over on top with a layers of earth or Katchara. This is known as the **Poudrette System**. Since the material formed in the above trenches after they become dry, is known as **poudrette.**

Improved methods of handling night soil:

Since night soil is an important bulky organic manure, supplying a good deal of organic matter and plant nutrients to the soil, it is important that night soil is used by the following improved methods:

1. Night soil should be protected from flies and fly breeding should be controlled.
2. It should be stored in such a way that it does not pollute the supply of drinking water.
3. Pathogens, protozoa, cysts, worms and eggs should be destroyed before the night soil is applied to the land.
4. Attempts should be made to compost the night soil with other refuse in urban centres by municipal or town authorities and in rural areas by the farmer himself.

Sewage and Sludge:

In the modern system of sanitation adopted in cities, water is used for the removal of human excreta and other wastes. This is called the sewage system of sanitation. In this system, there is a considerable dilution of the material in solution and in dispersion in fact, water is the main constituent of sewage, amounting often to 99.0%.

In general sewage has two components, namely

(i) Solid portion, technically known as sludge and

(ii) Liquid portion, commonly known as sewage water.

Both the components are used in increasing crop production as they contain plant nutrients. Both components of sewage as separated and are given a preliminary fermentation and oxidation treatments to reduce the bacterial contamination, the offensive smell and also to narrow down the C: N ratio of the solid portion.

(i) Sludges:

In the modern system of sewage utilization, solid portion or sludge is separated out to a considerable extent and given a preliminary treatment (i.e. fermentation and oxidation) before its use as manure. Such oxidized sludge is also called **activated sludge** which is of inoffensive smell and on dry weight basis contains up to 3 to 6 per cent N, about 2 per cent P_2O_5 and 1 per cent K_2O in a form that can become readily available when applied to soil.

(ii) Sewage irrigation:

When raw sewage is treated to remove the solid portion or sludge the water, technically known as **treated effluent**, is used for irrigation purpose. Such a system of irrigation is known as sewage irrigation. Thus, both the activated sludge and the effluent can be used with safely for manuring and irrigating all field crops except the vegetables which are eaten raw or uncooked.

CONCENTRATED ORGANIC MANURES

Concentrated organic manures are those that are organic in nature and contain higher percentages of major plant nutrients like N, P_2O_5 and K_2O compared to bulky organic manures like FYM and compost. These concentrated manures are made from raw materials of animal or plant origin. The common concentrated organic manures are oil cakes, blood meal, fish manure, meat meal and wool waste.

Oil cake:

Oil cake is the residue left after the oil is extracted from oil bearing seeds. It contains varying quantities of oil depending upon the process of manufacture employed in treating the oil seed as shown below:

Process of manufacture	Oil (per cent)
Country ghani	10-15
Hydraulic press	8-10
Expeller	5-8
Solvent	1-2

Oil cakes are of two types:

1) Edible Oil cake
2) Non Edible Oil cake

Edible oil cakes are valued more as cattle feed and seldom used as manure, except when it becomes mouldy or rancid and unfit for feeding to cattle. Non edible oil cakes are used as manure.

Characteristics:

1. Quick acting organic manures as C:N ratio is usually narrow (5-15)
2. Oil prevents rapid conversion of N
3. Nearly 50-80% of its N is made available in 2-3 months and rate of availability varies with the type of cake and nature of soil.

4. Castor cake contain **Ricin**, Mahuva cake contains **Saponin** and Neem cake contains **Nimbidin** which are responsible for slow nitrification of their N due to effects of alkaloids on soil microorganisms
5. Castor cake has also good vermicidal effect against white ants
6. Groundnut cake has the highest nitrification rate.
7. Mahua cake is very poor in N and takes a long time to nitrify. When used as manure it has got to be applied to the soil two to three months before sowing/planting of crop.

Average nutrient contents of principal oil cakes

Name of the oil cake	Percentage composition		
	N	P_2O_5	K_2O
Non edible oil cakes			
Castor cake	4.3	1.8	1.3
Cotton seed cake [Undecorticated]	3.9	1.8	1.6
Karanj cake	3.9	0.9	1.2
Mahua cake	2.5	0.8	1.8
Neem cake	5.2	1.0	1.4
Safflower cake [Undecorticated]	4.9	1.4	1.2
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
Rape seed cake	5.2	1.8	1.2
Safflower cake(decorticated)	7.9	2.2	1.9
Sesame or til cake	6.2	2.0	1.2

Precautions in using oil cakes:

1. It should be powdered before use.
2. Apply during last ploughing in short duration crop.
3. It is best used as a topdressing after the plants have established themselves.
4. Use only when there is sufficient moisture in the soil.
5. If Mahua cake is to be used, apply before 2-3 months before planting or decompose in a pit and then apply or treat with ammonium sulphate.

Blood meal:

Dried blood or blood meal contains 10-12% N and 1-2% P_2O_5. Blood meal is prepared from the blood collected from slaughter house treating with copper sulphate, dried, powdered and bagged and sold as blood meal. Blood meal is a quick acting manure and is effective for all crops on all soils. It should be applied like oil cakes.

Meat meal:

Bones and meat are cooked in special type of pan for 2-3 hours. Bones are separated and meat is dried and powdered. It is quick acting and used like oil cakes. It contains 10.50% N and 2.5% P_2O_5.

Fish manure:

Fish and fish waste is dried and powdered. It is quick acting organic manure and used like oil cakes for all crops on all types of soils. Fish manure or fish meal contains 4 to 10% N, 3 to 9% P_2O_5 and 0.3 to 1.5% K_2O.

Horn and hoof meal:

Horn and hoof cooked in bone digester, dried and powdered. It contains 13% N.

Green Manuring:

Practice of incorporating undecomposed green plant tissues into the soil for the purpose of improving physical structure as well as fertility of the soil.

In agriculture, a **green manure** is a type of cover crop grown primarily to add nutrients and organic matter to the soil. Typically, a green manure crop is grown for a specific period, and then plowed under and incorporated into the soil. Green manures usually perform multiple functions that include soil improvement and soil protection:

- Leguminous green manures such as clover and vetch contain nitrogen-fixing symbiotic bacteria in root nodules that fix atmospheric nitrogen in a form that plants can use.
- Green manures increase the percentage of organic matter (biomass) in the soil, thereby improving water retention, aeration, and other soil characteristics.
- The root systems of some varieties of green manure grow deep in the soil and bring up nutrient resources unavailable to shallower-rooted crops.

- Common cover crop functions of weed suppression and prevention of soil erosion and compaction are often also taken into account when selecting and using green manures.
- Some green manure crops, when allowed to flower, provide forage for pollinating insects.

Historically, the practice of green manuring can be traced back to the fallow cycle of crop rotation, which was used to allow soils to recover.

Types of green manuring:

Broadly two types of green manuring can be differentiated. I) Green manuring *in situ* and ii) Green leaf manuring

i) Green manuring in situ:

In this system green manure crops are grown and buried in the same field, either as a pure crop or as intercrop with the main crop. The most common green manure crops grown under this system are Sanhemp, Dhaincha and guar.

ii) Green leaf manuring:

Green leaf manuring refers to turning into the soil green leaves and tender green twigs collected from shrubs and trees grown on bunds, waste lands and nearby forest areas. The common shrubs and trees used are Glyricidia, Sesbania (wild dhaincha), Karanj, *etc.*

The former system is followed in northern India, while the latter is common in eastern and central India.

Advantages of Green Manuring:

1. It adds organic matter to the soil. This stimulates the activity of soil micro-organisms.
2. The green manure crops return to the upper top soil, plant nutrients taken up by the crop from deeper layers.
3. It improves the structure of the soil.
4. It facilitates the penetration of rain water thus decreasing run off and erosion.
5. The green manure crops hold plant nutrients that would otherwise be lost by leaching.

6. When leguminous plants, like sannhemp and dhaincha are used as green manure crops, they add nitrogen to the soil for the succeeding crop.
7. It increases the availability of certain plant nutrients like phosphorus, calcium, potassium, magnesium and iron.

Disadvantages of green manuring:

When the proper technique of green manuring is not followed or when weather conditions become unfavorable, the following disadvantages are likely to become evident.

1. Under rainfed conditions, it is feared that proper decomposition of the green manure crop and satisfactory germination of the succeeding crop may not take place, if sufficient rainfall is not received after burying the green manure crop. This particularly applies to the wheat regions of India.
2. Since green manuring for wheat means loss of *Kharif* crop, the practice of green manuring may not be always economical. This applies to regions where irrigation facilities are available for raising *Kharif* crop along with easy availability of fertilizers.
3. In case the main advantage of green manuring is to be derived from addition of nitrogen, the cost of growing green manure crops may be more than the cost of commercial nitrogenous fertilizers.
4. An increase of diseases, insects and nematodes is possible.
5. A risk is involved in obtaining a satisfactory stand and growth of the green manure crops, if sufficient rainfall is not available.

Green manure crops:

Leguminous	Non-leguminous
1. Sannhemp	1. Bhang
2. Dhaincha	2. Jowar
3. Mung	3. Maize
4. Cowpea	4. Sunflower
5. Guar	
6. Senji	
7. Khesari	
8. Berseem	

Selection of Green manure crops *in situ*:

Certain green manure crops are suitable for certain parts of the country. Suitability and regional distribution of important green manure crops are given below:

Sannhemp: This is the most outstanding green manure crop. It is well suited to almost all parts of the country, provided that the area receives sufficient rainfall or has an assured irrigation. It is extensively used with sugarcane, potatoes, garden crops, second crop of paddy in South India and irrigated wheat in Northern India.

Dhaincha: It occupies the second place next to sannhemp for green manuring. It has the advantage of growing under adverse conditions of drought, water-logging, salinity and acidity. It is in wide use in Assam, West Bengal, Bihar and Chennai with sugarcane, Potatoes and paddy.

Guar: It is well suited in areas of low rainfall and poor fertility. It is the most common green manure crop in Rajasthan, North Gujarat and Punjab.

Technique of Green Manuring *in situ*:

The maximum benefit from green manuring cannot be obtained without knowing

(i) When the green manure crops should be grown,

(ii) When they should be buried in the soil and

(iii) How much times should be given between the burying of a green manure crop and the sowing of the next crop.

(i) Time of sowing:

The normal practice usually adopted is to begin sowing immediately after the first monsoon rains. Green manure crops usually can be sown/broadcast preferably giving somewhat higher seed rate.

(ii) Stage of burying green manure crop:

From the results of various experiments conducted on different green manure crops, it can be generalized that a green manure crop may be turned in soil at the stage of flowering. The majority of the green manure crops take about six to eight weeks from the time of sowing to attain the flowering stage. The basic principle which governs the proper stage of turning in the green manure crops, should aim at maximum succulent green matter at burying.

(iii) Time interval between burying of green manure crop and sowing of next crop.

Following two factors which affect the time interval between burring of green manure crop and sowing of next crop.

1. Weather conditions
2. Nature of the buried green material

In paddy tracts the weather is humid due to the high rainfall and high temperature. These favour rapid decomposition. If the green material to be buried is succulent, there is no harm in transplanting paddy immediately after turning in the green manure crop. When the green manure crop is woody, sufficient time should be allowed for its proper decomposition before planting the paddy.

Regions not suitable for green manuring:

The use of green manures in dry farming areas in arid and semiarid regions receiving less than 25 inches of annual rainfall is, as a rule, impracticable. In such areas, only one crop is raised, as soil moisture is limited. Such dry farming areas are located in Punjab, Maharashtra, Rajasthan, M.P. and Gujarat (Kutch and Saurashtra).

On very fertile soils in good physical condition, it is not advisable to use green manures as a part of the regular rotation.

In areas where *Rabi* crops are raised on conserved soil moisture, due to lack of irrigation facilities, it is not practicable to adopt green manuring. If green manuring is followed in this areas, there is danger of incomplete decomposition of the green matter and as such less moisture for the succeeding crop.

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CHAPTER- II: TRANSFORMATION REACTIONS OF ORGANIC MANURES IN SOIL AND IMPORTANCE OF C: N RATIO IN RATE OF DECOMPOSITION.

Organic matter in the soil comes from the remains of plants and animals. As new organic matter is formed in the soil, a part of the old becomes mineralized. The original source of the soil organic matter is plant tissue. Under natural conditions, the tops and roots of trees, grasses and other plants annually supply large quantities of organic residues. Thus, higher plant tissue is the primary source of organic matter. Animals are usually considered secondary sources of organic matter. Various organic manures, that are added to the soil time to time, further add to the store of soil organic matter.

Composition of plant residues

Composition of organic residues have un-decomposed soil organic matter (mainly plant residues together with animal remains, i.e. animal excreta etc.) The moisture content of plant residues varies from 60 to 90% (average 78%) and 25% dry matter (solid). Plant tissues (organic residues) may be divided into 91) organic and (2) inorganic (elemental) composition. The compounds constituting the plant residues or un-decomposed soil organic matter is shown in the following diagram

Organic Residues
(Un-decomposed organic matter)

Organic

Inorganic
(Mineral matter/ elemental composition or ash)

S, P, Cl, CO_3 , Ca, Mg, Na, K, Fe, Zn, Cu, Mn, etc.

Nitrogenous

Insoluble: protein, peptides, Peptones *etc.*

Water-soluble: Nitrates, ammonical compounds etc

Non-nitrogenous

Carbohydrates: Cellulose (insoluble); starch, hemicelluloses, pectin, mucilage etc. (Hydrolysable); sugars (soluble)

Ether-soluble: Fats, oils, waxes, resins steroids etc.

Miscellaneous: Lignin, tanin, essential oils, organic acids

Transformation Reactions of Organic Manures in Soils:

It is found that both bulky and concentrated organic manures contain some amount of plant nutrients including macro-and micro-nutrients, of which organic nitrogen content is likely to be dominant. The organic forms of soil nitrogen occur as consolidated amino acids, proteins, amino sugars etc. When Organic manures like FYM, composts, oil cakes, green manures etc. are added to the soil, the microbial attack to these materials takes place and results complete disappearance of the organic protein with the remainder of the nitrogen being changed into inorganic form of nitrogen through the process of mineralization.

The organic materials incorporated in the soil do not remain as such very long. They are at once attacked by a great variety of microorganisms, worms and insects present in the soil especially if the soil is moist. The microorganism for obtaining their food, break up the various constituents of which the organic residues are composed, and convert them into new substances, some of which are very simple in composition and others highly complex. The whole of the organic residues is not decomposed all at once or as a whole. Some of the constituents are decomposed very rapidly, some less readily, and others very slowly.

It is evident that different constituents of organic residues decompose at different rates. Simple sugars, amino acids, most proteins and certain polysaccharides decompose very quickly and can be completely utilized within a very short period. Large macro-molecules which make up the bulk of plant residues must first be broken down into simpler forms before they can be utilized further for energy and cell synthesis. This process is carried out by certain specific enzymes excreted by microorganisms.

$$\text{Proteins} \longrightarrow R\text{-}NH_2 + CO_2 + \text{energy} + \text{other products}$$

(Present in organic manures)

$$R - NH_2 + HOH \longrightarrow NH_3 + R - OH + \text{energy} + H_2O$$

$$\downarrow$$

$$NH_4^+ + OH^-$$

(release of ammonium in the soil)

The released ammonium (NH_4^+) is subject to following changes:

1) It may be converted to nitrites and nitrates through the process of nitrification carried out by microorganisms,

$$2\,NH_4^+ + 3O_2 \xrightarrow[\text{Oxidation}]{\text{enzymic}} 2\,NO_2^- + 2H_2O + 4H^+ + \text{energy}$$

$$2\,NO_2^- + O_2 \xrightarrow[\text{oxidation}]{\text{enzymic}} 2\,NO_3^- + \text{energy}$$

2) It may be absorbed directly by the plants.

3) It may be utilized by hetero-trophic organisms in further decomposing organic carbon residues.

4) It may be fixed in the lattice of certain expanding type of clay minerals.

5) It could be slowly released back to the atmosphere as elemental nitrogen.

Mineralization and immobilization of nitrogen or any other nutrient elements occur continuously in microbial metabolism and the magnitude and direction of the net effect are greatly influenced by the nature and amount of organic manures added. Normally organic manures are applied to the soil as a source of fertilizer nitrogen should contain about 1.5 to 2.0 per cent of the dry weight of the manures in order to meet the needs of the soil microorganisms, otherwise little or no nitrogen will be released for the use of plants. The carbon nitrogen ratio (C : N ratio) in the organic manures remaining in the soil after consuming by the soil microorganisms is approximately 10:1. Therefore, different organic manures containing variety of organically bound nutrients like P, S, and other micro nutrients etc. are subject to transformation in soils similar to that of mineralization and immobilization processes of nitrogen and releases inorganic forms of nutrients ion soils which become available to plants.

Role of Organic Manure:

1. Organic manure binds soil particles into structural units called aggregates. These aggregates help to maintain a loose, open, granular condition. Water infiltrates and percolates more readily. The granular condition of soil maintains favorable condition of aeration and permeability.
2. Water-holding capacity is increased by organic matter. Organic matter definitely increases the amount of available water in sandy and loamy soils.
3. Surface run off and erosion are reduced by organic matter as there is good infiltration.
4. Organic matter or organic manure on the soil surface reduces losses of soil by wind erosion.

5. Surface mulching with coarse organic matter lowers soil temperatures in the summer and keeps soil warmer in winter.
6. The organic matter serves as a source of energy for the growth of soil microorganisms.
7. Organic matter serves as a reservoir of chemical elements that are essential for plant growth as well as many hormones and antibiotics.
8. Fresh organic matter has a special function in making soil phosphorus more readily available in acid soils. Organic acids released from decomposing organic matter help to reduce alkalinity in soils.
9. Fresh organic matter supplies food for such soil life as earthworms, ants and rodents. These microorganisms improve drainage and aeration. Earthworms can flourish only in soils that are well provided with organic matter.
10. Organic matter on decomposition produces organic acids and carbon dioxide which help to dissolve minerals such as potassium and make them more available to growing plants.
11. Humus (highly decomposed organic matter) provides a storehouse for the exchangeable and available cations – potassium, calcium and magnesium. Ammonium fertilizers are also prevented from leaching because humus holds ammonium in an exchangeable and available form. It acts as a buffering agent. Buffering checks rapid chemical changes in pH and in soil reaction.

Importance of C:N ratio in rate of decomposition

The ratio of the weight of organic carbon (C) to the weight of total nitrogen (N) in a soil (or organic material), is known as C: N ratio. When fresh plant residues are added to the soil, they are rich in carbon and poor in nitrogen. The content of carbohydrates is high. This results in wide carbon-nitrogen ratio which may be 40 to 1. Upon decomposition the organic matter of soils changes to humus and have an approximate C: N ratio of 10:1.

The ratio of carbon to nitrogen in the arable (cultivated) soils commonly ranges from 8:1 to 15:1. The carbon-nitrogen ratio in plant material is variable, ranging from 20:1 to 30:1. Low ratios of carbon to nitrogen (10:1) in soil organic matter generally indicate an average stage of decomposition and resistance to further microbiological decomposition. A wide ratio of C: N (35:1) indicates little or no decomposition, susceptibility to further and rapid decomposition and slow nitrification.

► **Significance of C:N Ratio**

(1) Keen competition for available nitrogen when organic residues (with high C: N ratio) are added to soils. When organic residues with a wide C/N ratio (50:1) are incorporated in the soil, decomposition quickly occurs. Carbon dioxide is produced in large quantities. Under these conditions, nitrate-nitrogen disappears from the soil because of the instant microbial demand for this element to build up their tissues. And for the time being, little (or no) nitrogen is an available to plants. As decomposition occurs, the C/N ratio of the plant material decrease since carbon is being lost and nitrogen conserved. Nitrates-N again appear in quantity in the soil, thus, increases plant growth.

(2) *Consistency of C: N Ratio*. As the decomposition processes continue, both carbon and nitrogen are now subject to loss the carbon as carbon dioxide and the nitrogen as nitrates which are leached or absorbed by plants. At a point carbon-nitrogen ratio, becomes more or less constant, generally stabilizes at 10:1 or 12:1.

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CHAPTER- III: INTEGRATED NUTRIENT MANAGEMENT

Modern agricultural production practices have emphasized the wide spread use of fertilizer and this approach has certainly increased grain yield in many countries in the last two decades. However, long-term use of chemical fertilizers also led to a decline in crop yields and soil fertility in the intensive cropping system. There is evidence that over fertilization has increased the concentration of many plant nutrients in both surface and ground water, which has created a potential health hazards.

In order to safeguard the environmental from further degradation and to maintain the purity of air, water and food. We should opt for less use of chemicals and shift from chemical to ecological agriculture to fertilize our fields. Hence, in recent years integrated use of inorganic fertilizers and organic manures has become important for higher agricultural production. No single source of plant nutrients, be it chemical fertilizer, organic manure, crop residue, green manure or even biofertilizers can meet the entire nutrient needs of crops in present day agriculture.

Farmyard manure and compost are limited in supply and have low nutrient content. However, green manure is a potential source of organic manure. The use of plant residues and biofertilizers is also being advocated in nutrient management. Organic manure, however, can not be used as a substitute for chemical fertilizer but only as a component in the whole nutrient management system as the nutrient needs essential for higher yield goal can not be met exclusively through them particularly for reasons of insufficiency.

Therefore, to maintain production at high levels, resource has to be made to the application of fertilizers and organic manure not only provide essential plant nutrients but also build up the organic carbon and improve soil physical as well as biological conditions. As “sustainable plant nutrition to increase food production” has been identified as one of the priorities directly linked to land and water management resources in relation to environment. Therefore, for the sustained growth, the soil health is very important to achieve national food security targets. In addition to this, for maximizing fertilizer use efficiency and ensure a balanced and optimum supply of essential plant nutrients, INMs has got special emphasizes in present day of agriculture.

The concept of integrated nutrient management (INM) is the maintenance of soil fertility and health, sustaining agricultural productivity and improving farmers’ profitability through the judicious and efficient use of mineral fertilizers together with organic manures industrial/farm wastes and bio fertilizers. Thus, the **objectives of INM** are to ensure efficient and judicious use of all the major sources of plant nutrients in an integrated manner so as to get maximum economic yield from a specific cropping system.

Thus, integrated nutrient management (INM) involving soil resources, chemical fertilizers, biofertilizers and organic manures is key to the sustained productivity as it reduces dependence on chemical fertilizers and improve fertilizer use efficiency by improving physical and biological properties of soil.

Integrated nutrient management has a great potential to offset the growing heavy nutrient demands, to achieve maximum yields and to sustain the crop productivity on long-term basis. However, the adoption of green manure technology in India is limited. Despite the existing constraints in availability and usage of different organic and biological sources, efforts should be made to synthesise the available data for developing a agro-ecological specific and practically feasible INM packages for different crops and cropping system. Therefore, a challenging task ahead for the researchers is to convert the concept of sustainable productivity into an operational reality through INMS. It should always be kept in mind that the development of INMS system is just the beginning and not the end till we make this system itself self-sustainable.

The various sources of plant nutrients are

1. **Soil sources**

The nutrient supplying capacity of many soils declined steadily as a result of continuous and intensive cultivation practices. The low and declining soil fertility are the main causes of low productivity of most of the cultivated lands. Intensive cultivation also resulted in the deficiency of certain secondary and micronutrients in the soils. A scenario of nutrients deficiency shows that N deficiency is universal and nearly 49, 20 and 47 per cent soils of India are deficient in P, K and Zn, respectively. Sulphur deficiency is recorded in 125 districts. The Fe, Mn and B have also become most serious constraints in some agricultural production systems. The long-term fertilizer experiments in different agro-ecological regions have demonstrated very clearly that in future K deficiency will become most limiting factor for crop production under intense cropping. It will also reduce the efficiency of other fertilizer nutrients. Further, it is estimated that through every year up to 8 m.t. of nutrients are being depleted through soil erosion.

It becomes, therefore, necessary to reduce the nutrient losses through suitable soil management practices, to ameliorate problems of soils and to use appropriate crop varieties, cultural practices and cropping system to maximize utilization of available nutrients.

1. Mineral fertilizers

Mineral fertilizers play an important role in sustaining agricultural production. However, it is costly input and needs to improve its use efficiency through optimization of all other crop production factors such as:

a) Making fertilizer recommendations for a cropping system instead of single crop in the system.
b) Eliminating limiting factors including secondary and micronutrients.
c) Minimizing losses in the field through appropriate time and method of application and
d) Using appropriate products including super granules and coated urea, direct use of locally available phosphate rocks in acidic soils, etc.

Thus, to get benefit from fertilizers, they must be applied in the right quantity, at the right time and placed from the right source and in the right combination.

2. Organic sources

Organic manure acts many ways in augmenting crop growth and soil productivity. The direct effect of organics relates to uptake of humic substances or its decomposition products affecting favourably the growth and metabolism of plants. Indirectly, it augments the beneficial soil micro- organisms and their activities and thus increases the availability of major and minor plant nutrients.

Organic sources are valuable by-products of farming and allied industries derived from plant and animal matter. Organic sources include farm yard manure, animal droppings, crop waste residues, sewage, sludge, compost, biofertilizers human wastes and other various industrial wastes.

The potential annual plant nutrients (N, P and K) generated through organic sources is about 9.9, 2.7 and 4.4 million tonnes of N, P_2O_5 and K_2O, respectively. Cattle and buffalo dung contribute to the extent of 3.7, 1.1 and 1.8 million tonnes of N, P2O5 and K_2O, respectively. Most of it is used as fuel. Adoption of biogas technology can go a long way in saving the much needed nutrients on the one hand

and the fuel for which the dung is burnt, on the other. Biogas slurry is richer in plant nutrients especially in nitrogen than the animal dung. Night soil if properly exploited can provide about 5 m. t. of N P K nutrients. Estimated current potential availability of crop residues is 400 million metric tonnes (mmt). In regions where mechanical harvesting is done, a sizeable quantity of residues is left in the field. These residues are being burnt in situ causing loss of plant nutrients and organic matter. Rice and wheat straw account for 70 % of crop residues generated. About one-third of the crop residues generated get recycled directly on the land and a substantial proportion get recycled after serving as animal feed where animal dung is used as FYM.

A few more million tones of NPK nutrients might become available from crop residues, green manuring, rural and urban wastes, agro- industrial wastes, fisheries, bone meal, *etc.* Careful collection, conservation and recycling of those manures would enable India to meet its nutrient requirement and develop its agriculture on a sustainable basis. The organic manures also contain sufficient quantity of micronutrients. Hence, the combined use of organic, biological and inorganic fertilizers assumes special significance as complementary and supplementary to each other in agricultural production and soil productivity.

Thus, all the major sources of plant nutrients such as soil mineral, organic and biological should be utilized in an efficient and judicious manner in sustainable crop production. Also, integrated nutrient supply is important as a soil ameliorant in alleviating the adverse soil ecological conditions and improving soil productivity.

3. Organic cycling

(A) Green manuring

Green manuring has a long history with the farmers. However, in the intensive farming, a farmer may not be able to practice green manuring in a traditional manner by devoting an entire season to a green manure crop. But, green manuring is one of the most effective and environmentally sound method of organic manuring that offers an opportunity to cut down the use of chemical fertilizers. Green manuring of soils for the benefit of crop is an old practice but it has gone into background in late 1960. In the present context of integrated nutrient supply system, it needs adequate attention being the cheapest source of input for building up the soil fertility and supplementing plant nutrients especially nitrogen.

The green manuring helps to increase crop yield through following processes

a) The nodulated legumes fix atmospheric N to enrich soil N.
b) The decomposing organic matter has a solubilizing effect on N, P, K and micronutrients present in the soil.
c) It reduces leaching and gaseous losses of N to increase the use efficiency of plant nutrients, and
d) It improves physical, chemical and biological environs of the soil.

Where farmers are not willing to spare their merge land resources and inputs for growing a green manure crop, fresh lopping of some perennial leguminous trees like *Glyricidia* grown in hedge rows and field bunds may be used for incorporation into soil as a source of N. This practice is common in southern parts of the country.

4. **Biological sources**

With the discovery of Hellrigel and Wilfarth a century ago (1886) that the nodules of legume roots contain colonies of symbiotic bacteria able to capture atmospheric nitrogen molecules to the benefit of the host plants heralded a growing realization of the importance of soil biota in fertility studies. **Biofertilizers are the fertilizers of biological origin.** Recent use of the term encompasses all the organic manure including green manure. However, in restricted scope, biofertilizers are the preparations of living microorganisms used to improve plant nourishment and soil fertility and thereby achieving more sustainable crop production. Biofertilizers are considered to be cost effective ecofriendly and renewable sources of non-bulky, low cost plant nutrients supplemental to chemical fertilizers in sustainable agricultural systems in India.

1. Rhizobium Inoculants: Rhizobium fixes nitrogen symbiotically with legumes. Rhizobium cultures are recommended for inoculation of seeds of various pulses and legume crops for meeting about 80% of the nitrogen requirement of such crops. In case of legumes, about 10-20 kg inorganic N\ha is recommended for application to soils for initial growth and establishment of the seedlings. Introduction of leguminous crops in crop rotation has shown to maintain soil fertility. Normally inoculation with Rhizobium in traditional pulses results in increase of grain yield by 2-3 q\ha. Rhizobium inoculations now become a practice for introduced legume crops.

2. Azotobacter inoculants: Azotobacter fixes nitrogen non-symbiotically and benefits the plants by growing in the rhizosphere of plants. Several workers have tested azotobacter chrococcum inoculants in field trials. It is estimated that Azotobacter inoculation could save about 15-20kg N\ha and increase grain yield by about 10 per cent. They also produce growth hormones, which improve the germination of seeds, development of better root system and better stand of plants.

3. Azospirillum inoculants: The group of gram-negative nitrogen fixing spirilla, which was originally named as spirillum lipoferum, has been reclassified into at least two species in the genus Azosperillum, *A. brasilense* and *A. lipoferum*. Field trials showed that sorghum and pearl millet usually responded to inoculation with *A. brasilense* cultures and could save about 20-40 kg N\ha. Similarly, wheat showed significant response to *A. lipoferum.*

4. Blue green algae inoculants: Wetland rice field is an ideal ecosystem for algal nitrogen fixation values ranging from 40-80 kg N/ha/year. Algal inoculation can increase grain yield by about 10-20 %. BGA is also reported to produce growth promoting substances.

5. Azolla: The water fern Azolla fixes atmospheric N due to the presence of heterocystons blue green algal Anabeana azolla in its dorsal leaves. A. pinnata is found in India. The chemical composition of Azolla (dry basis) is 4-6% N, 0.5-0.6% P, 2-6% K, 9-10% ash, 5 % crude fat, 9 % crude fiber and 20-30 % crude protein. It is thus a good source of organic N and can also be used as a green manure.

6. Phosphatic biofertilizer: Several soil bacteria (*Pseudomonas striata, Bacillus polymixa*) and fungi (*Aspergillus awamori*) posses the ability to bring insoluble phosphate in to soluble forms through secretion of organic acids. These acids lower the pH and bring about dissolution of immobilized forms of phosphates. Besides, some of the hydroxy acids may chelate with calcium and iron resulting in effective solubilization and thereby higher utilization of soil phosphate by plants. Application of organic manure along with PSM can enhance the availability of P from rock phosphate. VAM can play an important role in enhancing P availability to plants on P deficient soils. They can also increase the transport of other mineral elements such as zinc and copper.

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CHAPTER- IV: CHEMICAL FERTILIZERS

Fertilizer is any material dry or liquid added to the soil in order to supply one or more plant nutrients. The term fertilizer is generally applied to commercially manufactured materials other than lime and gypsum.

NITROGEN FERTILIZERS

Nitrogen is present in soil as (i) Organic form and (ii) inorganic form. Inorganic form includes ammonical (NH_4^+), Nitrite (NO_2^-) and Nitrate (NO_3^-). Plant absorbs N in the form of NO^-_3 and NH^+_4 forms by paddy in early stages. Nitrogen in NH^+_4 form goes on exchange complex on clay and organic colloids and hence, this part is not lost due to leaching, while NO^-_3 is lost due to leaching as it does not go on exchange complex under neutral to higher pH values of soil. But it goes on exchange under highly acidic conditions. The nitrate fertilizers are hygroscopic in nature, it is for this reason, nitrate fertilizers are not commonly used even though plant absorbs N as NO^-_3. Therefore, organic form (urea) and fertilizers of NH_4 form like ammonium sulphate are widely used.

Most of Indian soils are low in N and the requirement of N by crop is throughout its growing period, therefore N should be applied in such a way that plant gets it throughout its life period. It becomes absolutely necessary to apply nitrogenous fertilizers to every soil and crop. For this, the total quantity of nitrogenous fertilizers requirement is more compared to fertilizers of other nutrients.

COMMERCIAL NITROGENOUS FERTILIZERS

Commercial nitrogenous fertilizers are those fertilizers that are sold for their nitrogen content and are manufactured on a commercial scale.

Nitrogenous Fertilizers:

Nitrogenous fertilizers may be classified into four groups on the basis of the chemical form in which nitrogen is combined with other elements with a fertilizer.

Nitrogenous Fertilizers

- Nitrate Fertilizers
- Ammonical Fertilizers
- Nitrate and Ammonical Fertilizers
- Amide Fertilizers

1) **Nitrate Fertilizers**:

Nitrogen is combined as NO_3^- with other elements. Such fertilizers are

i) Sodium nitrate or Chilean nitrate ($NaNO_3$) – 16% N

ii) Calcium nitrate [Ca $(NO_3)_2$] – 15.5% N.

Out of these, sodium nitrate is an imported commercial fertilizer.

2) **Ammonical Fertilizers :-**

In these fertilizers, nitrogen is combined in ammonical (NH_4) form with other elements. Such fertilizers are

i) Ammonium sulphate [$(NH_4)_2 SO_4$] – 20% N

ii) Ammonium Chloride (NH_4Cl) $\longrightarrow$ 24 to 26% N

iii) Anhydrous ammonia - 82% N

3) Nitrate and ammonical Fertilizers:

These fertilizers contain nitrogen in the form of both nitrate and ammonical. Such fertilizers are

i) Ammonium nitrate ($NH_4 NO_3$) - 33 to 34% N

ii) Calcium ammonium nitrate -- 26% N

iii) Ammonium sulphate nitrate – 26% N

4) Amide fertilizers:

These fertilizers contain nitrogen in amide or cynamide form. Such fertilizers are

i) Urea [$CO (NH_2)_2$]– 46% N

ii) Calcium cynamide ($Ca CN_2$) – 21% N

General characteristics of four groups:

1) Nitrate fertilizers:

Most of the field crops except paddy in early stages of their growth, take up nitrogen in nitrate form as such,

i) Nitrate fertilizers are readily absorbed and utilized by these crops. Nitrate fertilizers are very often used as top and side dressings.

ii) The great mobility of the nitrate ion in the soil has the advantage that, even by broadcasting the fertilizer on the surface of the soil, the nitrogen reaches the root zone quickly.

iii) On the other hand, there is also the increased danger of leaching of these fertilizers. On dry soils, nitrate fertilizers are superior to the other forms of nitrogenous fertilizers.

iv) All nitrate fertilizers are basic in their residual effect on the soils and their continued use may play a significant role in reducing soil acidity. Sodium nitrate, for example, has a potential basicity of 29 pounds of calcium carbonate per 100 pounds of fertilizer material.

2) Ammonical Fertilizers:

i) Ammonical fertilizers are water soluble.

ii) It is less rapidly used by plant than NO^-_3, as it is to be changed to NO^-_3 before use by crop.

iii) It is resistant to lost due to leaching as being cation goes on exchange complex.

iv) Any fertilizers which contain N as NH^+_4 or which is changed as NH^+_4 produced acidity in soil due to production of HNO_3.

v) Ammonium (NH^+_4) of fertilizer goes on exchange complex, used by crop like paddy.

vi) Used by microorganisms nitrified to NO_3 and lost due to volatilization from soil.

3) Nitrate and Ammonical Fertilizers:

i) Fertilizers of this group are soluble in water.

ii) Nitrate part can readily be used by crop.

iii) NH^+_4 can go on exchange and hence, this is best type but did not over take ammonium sulphate and urea, as they are hygroscopic in nature.

iv) They are acidic in their residual effect on soil

4) Amide Fertilizes:

i) Fertilizers of this group are readily soluble in water. They are easily decomposed by microorganisms due to presence of oxidisable carbon.

ii) They are quickly changed to NH^+_4 then in to NO^-_3.

Manufacturing process of ammonium sulphate and urea:

Most of the nitrogenous fertilizes like ammonium sulphate, urea, ammonium nitrate, ammonium sulphate nitrate and even DAP are manufactured by using NH^-_3 as one of the important compound. Most of the commercial NH^-_3 is prepared by Haber's process by the fixation of atmospheric N by means of H_2.

The reaction is:

$$N_2 + 3H_2 \xrightarrow[\text{at } 550^oC \text{ temp, Fe and Mo as catalysts}]{\text{200 atm. Pressure}} 2NH_3 + 24.4 \text{ KCal}$$

Ammonia can also be obtained from natural gas, coal gas and naphtha. Therefore, cost of fertilizer production in fertilizer factory installed near a petrochemical will be low.

The NH_3 gives ammonium sulphate with sulphuric acid, NH_4Cl with HCl; NH_4NO_3 with HNO_3; urea with CO_2; MAP and DAP with H_3PO_4. Thus, NH_3 is chief compound for most of the nitrogenous fertilizers.

i) **Preparation of Ammonium sulphate (A/S)** :-

It is prepared by

(a) reacting NH_3 with H_2SO_4

(b) gypsum process

(c) by-product of coal and steel industries.

a) **NH_3 with H_2SO_4** :- NH_3 is reacted with H_2SO_4 giving A/S. The liquid is crystallized and crystals of A/S are obtained.

$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$

Since the sulphur used in sulphuric acid is to be imported, the source of H_2SO_4 becomes costlier and hence, gypsum a cheaper source of sulphur is used in gypsum process.

b) **Gypsum process**: The main raw materials required in gypsum process is NH_3, pulverized gypsum, CO_2 and water. NH_3 is obtained by Haber's process. This NH_3 when reacts with CO_2, gives $(NH_4)_2CO_3$. The ground gypsum when reacts with $(NH_4)_2CO_3$ solution gives $(NH_4)_2SO_4$ and $CaCO_3$. The reactions are :

$N_2 + 3H_2$ ----- $2NH_3$

$2NH_3 + H_2O + CO_2 = (NH_4)_2CO_3$

$(NH_4)_2CO_3 + CaSO_4 = (NH_4)_2SO_4 + CaCO_3$

ii) Preparation of Urea :-

Urea is manufactured by reacting anhydrous ammonia with CO_2 under higher pressure in presence of suitable catalyst. The intermediate unstable product ammonium carbamate is decomposed to urea :

$N_2+3H_2 = 2NH_3$

$2NH_3+CO_2 \xrightarrow{\text{30 atm}} NH_2COONH_4$ (Amm. Carbomate)

$NH_2COONH_4 \longrightarrow NH_2CONH_2 + H_2O$

Urea

During the preparation of urea, biuret is formed which is harmful. This biuret is formed when two molecules of urea are reacted eliminating NH_3.

$NH_2.CO.N\ (H_2 + H.N)\ HCO.NH_2 = NH_2\ CO.\ NH.CO\ NH_2 + NH_3$

Urea　　Urea　　Biuret

In urea biuret should not be more than 1.5%.

Now a days urea is used as fertilizer more compared to other nitrogenous fertilizers due to the following reasons:

a) Higher N content (44 to 46 per cent).
b) Good physical conditions.
c) Less acidic in residual effect compared to A/S.
d) Less cost per unit of N in production, storage and transport.
e) Lack of corrosiveness.
f) Suitable for foliar application, and
g) It is having of equal agronomical value compared to other nitrogenous fertilizers.

Ease of storage, handling and residual effect of nitrogenous fertilizers in soil:

The nitrogenous fertilizers differ in their ability to become moist or hygroscopic and as such they have to handle carefully in rainy season. The main features of nitrogenous fertilizers from storage view point are as follows:

(A) Ease of storage and handling:

Sr.No.	Fertilizer	Ease of storage and handling
i.	A/S	Storage property good, no difficulty in handling and storage.
ii.	Ammonium chloride	Storage property excellent, no difficulty in handling and storage.
iii	Ammonium Nitrate	Storage property satisfactory but it is hygroscopic, so the bag should be firmly tied. As it is fire hazardous, handle carefully.
iv.	Sodium nitrate	Storage property good, no difficulty in handling and storage.
v.	Ammonium sulphate nitrate	Storage property satisfactory, slightly hygroscopic, store in dry condition.
Sr. No.	**Fertilizer**	**Ease of storage and handling**
vi.	Calcium ammonium nitrate	Storage property satisfactory but it is hygroscopic. Use entire bag in one lot. Store bags in dry place. Tie half way used bag firmly when it is to be used.
vii	Urea	Storage property satisfactory. It is hygroscopic. Use entire bag in one lot and store in a dry place.

(B) Residual effect of nitrogenous fertilizers in soil:

(On lime basis) – Nitrogenous fertilizers differ in their residual effect. Fertilizers which contain NH^{+}_4 ions or which produce NH^{+}_4 ion in soil, produce acidity in soil or cause loss of lime. While other fertilizers being basic in reaction save lime. Among several nitrogenous fertilizes, except $NaNO_3$ and calcium ammonium nitrate are acid producing. Sodium Nitrate is basic in residual effect as it save lime, while CAN is neutral.

The amount of lime lost or saved when nitrogenous fertilizers are added to soil is as under:

S.No.	**Fertilizer**	**Pounds of $CaCO_3$/100 lbs of fertilizers when added to soil for**	
		Equivalent acidity (lime lost)	**Equivalent basicity (lime saved)**
1.	Ammonium Sulphate	110	--
2.	Ammonium chloride	128	--
3.	Ammonium Nitrate	60	--
4.	Ammonium Sulphate Nitrate	93	--
5.	Urea	80	--
6.	Sodium nitrate	-	29
7.	Potassium Nitrate	--	26
8.	Calcium Nitrate	--	21
9.	Calcium Cynamide	--	63
10.	CAN	(Neutral)	(Neutral)

SLOWLY AVAILABLE NITROGENOUS COMPOUNDS AND NITRIFICATION INHIBITORS

Firstly, the N requirement of growing plant is less in early stages of growth, maximum during its grand growth period and very low at the subsequent stages up to harvest. It is thus, seen that N is required through out the growth period.

Secondly, the nitrogenous fertilizers in general, and high analysis nitrogenous fertilizer in particular, give out the entire amount of added N through fertilizer in available form in very short period. The crop is unable to use the entire available amount in such a short period.

Thirdly, the N not used by a crop is either lost due to leaching and volatilization or fixed as NH_3 by clay particles and immobilization by micro-organisms.

In general, the crop recoveries of N seldom exceeds 60 to 70% of that added as fertilizers. Under the circumstances, one should be careful for the use of nitrogenous fertilizers. Therefore, the nitrogenous fertilizers should be used or manufactured or made to act in soil in such a way that there should be minimum loss, maximum recovery and availability should be through out the growth period as per requirement of crop.

Attempts have been made in this direction to overcome the problem by four ways:

I. Proper agronomic practices
II. Preparing large size granules
III. Preparing slow release nitrogenous compounds
IV. Use of nitrification inhibitors

i) Proper Agronomic Practices:

There are two established agronomic practices (a) application of fertilizers N to a crop in two or more splits to coincide with the important growth stages (b) Placement of N 3 to 5 cms below soil surface at the time of sowing/planting, which permits better contact with soil particles to retain NH_4-N and also prevent losses due to volatilization.

ii) Preparing large size granules and briquettes:

By preparing large size granules like urea super granules and briquettes of varying in weight from 1 to 3 gram, increase efficiency of fertilizers, by slower rate of hydrolysis, increase in the rate of downward diffusion and low volatilization loss as NH_3.

iii) Preparing slow release nitrogenous compounds:

By the formation of slow release compounds which are ranging from quite soluble to completely insoluble but slowly available form Nitrogenous fertilizers which have few dissolving rates and release their nitrogen slowly are known as slow release nitrogenous fertilizers. These fertilizers are classified into two groups: a) Chemical compounds with inherently slow rate of dissolution. Eg. Urea formaldehyde compound, Isobutylidene Diured (IBDU), Crotonylidene Diurea (CDU), Oxamide $(CONH_2)_2$, and

(b) Material formed by coating to conventional N fertilizers, Eg. sulphur coated urea, lac coated urea, neem cake coated urea, plastic coated urea.

iv) Nitrification Inhibitors:

These materials decrease the activity of nitrifying bacteria (organisms) and slow rate of nitrification. These compounds are :

a) AM (2 amino chloro-6-methyl pyrimidins)
b) N-serve or Nitrapyrin (2-chloro-6trichloromethyl pyridine)
c) Thiourea

PHOSPHATIC FERTILIZERS

The phosphorus (P) nutrient of all phosphatic fertilizers is expressed as P_2O_5. In soil, P is present as (i) Organic P (ii) Inorganic P. The forms of inorganic P are $H_2PO^{-}_4$; HPO^{-2}_4; and PO^{-3}_4; Out of which, H_2PO_4 and HPO_4 ions are available to plant. In soil, water in is changed to HPO^{-2}_4 and PO^{-3}_4 ions with increase in pH.

$$H_2PO^{-}_4 \xrightarrow{-H^+} HPO^{-2}_4 \xrightarrow{-H^+} PO^{-3}_4$$

Firstly, the P in soil is immobile or slightly mobile around one cm diameter and therefore, they should be applied in root zone.

Secondly, the requirement of P is maximum in the initial stages. The crop takes up 2/3 of total P when the crop gains 1/3 of total dry matter and hence, the entire quantity should be applied at one time that is at the time of sowing as a basal dose.

Thirdly, water soluble-P is changed to insoluble form as Fe and Al –PO_4 (Phosphate) under acidic and calcium phosphate in calcareous or high Ca content or in higher pH soils and hence, there is no danger for the loss due to leaching and volatilization.

Classification of phosphatic fertilizers:

The phosphatic fertilizers are classified into three classes depending on the form in which H_3PO_4 combined with Ca.

Phosphatic fertilizers

I	II	III
Water soluble P containing	**Citric acid soluble P containing**	**Citrate and water insoluble-P containing**
Super phosphate (SSP) (16 to18% P_2O_5)	Basic slags (14 to 18% P_2O_5)	Rock phosphate (20 to 40% P_2O_5)
Double Super phosphate (DSP) (32 to 36% P_2O_5)	Dicalcium phosphate (34 to 39% P_2O_5)	Raw bone meal (20 to 25% P_2O_5 and 3 to 4% N)
Triple Super phosphate (TSP) (46 to 48% P_2O_5)	Rhenania phosphate (23 to 26% P_2O_5)	
Mono ammonium phosphate (20% N and 20% P_2O_5)	Steamed bone meal (22% P_2O_5) (Part of P_2O_5 soluble in citric acid)	
Diammonium phosphate (18% N and 46% P_2O_5)		

i) Characteristics and conditions for the use of water soluble P containing fertilizer:

a) They contain water soluble-P as H_2PO_4 ion which can be absorbed quickly and available to plants when root system is not fully developed.
b) Water soluble-P is rapidly transformed into water insoluble form in soil and hence there is no danger of loss due to leaching.
c) These fertilizers should be used on slightly acidic, neutral to alkaline soils but not on acidic soils as the water soluble-P is changed to unavailable Fe and A1-PO_4.
d) These fertilizers are applied when a crop requires quick start and for short duration crops.

ii) Characteristics and conditions for the use of citric acid (1%) soluble P containing fertilizers:

a) They contain citrate soluble-P and hence this P is less available than water soluble-P.
b) They are suitable for moderately acid soils because it gets converted into water soluble form. They are basic in reaction and Ca content.
c) There are less chances of getting fixed by Fe and Al.
d) They are suitable for long term crops and where immediate and quick start to crops is not important.

iii) Characteristics and conditions for the use of citrate and water insoluble P fertilizers :

a) They are suitable for strongly acidic soils
b) They contain insoluble P and hence not available to crops
c) The P is available when ploughed with green manuring crop or organic residues.
d) They are used for long duration crops and in large quantity 500 to 1000 kg/ha
e) They are used where immediate effects are not important

POTASSIC FERTILIZERS

Potassium (K) is present in soil as:

i) Readily available forms as in soil solution and as exchangeable. These forms are available and plant absorbs these K forms as K^+ ion.

ii) Slowly available form as non-exchangeable i.e. fixed

iii) Relatively unavailable in the form of minerals (feldspars and micas etc.)

Firstly, the potash behaves partly like N and partly like P. From view point of the rate of absorption, it is required (absorbed) up to harvesting stage like N and like P, it becomes slowly available. Therefore, the entire quantity is applied at sowing time.

Secondly, potash being cation adsorbed on clay complex and hence leaching loss reduces. Leaching is greater in light soils than heavy textured soils. Therefore, like N, some time split application of K is desirable in sandy soil.

Thirdly, even though the soil contains enough potash or does not give response to crops, it becomes necessary to apply for the following reasons:

a) Maintaining K status of soil
b) For improving burning quality of tobacco
c) For neutralizing harmful effects of chloride in plant
d) For sugars or starch producing crops like potato, sweet potato, sugar cane, sugar beet, banana etc. for formation of sugar and starch.
e) For fibrous crops like sann, flex etc. to give strength to fibre and
f) For the formation of pigments in crops like tomato, brinjal *etc.* for quality purpose and it improves the luster and gives more colouration to the fruits of these crops by which more price can be have of the said products.

Classification of potassic fertilizers :

Potassic fertilizer

Fertilizer containing Chlorine .	**Fertilizer containing other than chlorine.**
Eg. KCl (Muriate of potash 58% K_2O). This is cheaper fertilizer and used extensively by cultivators for all crops except where chlorine is not desired in fertilizer	Eg. Sulphate of potash (K_2SO_4 48% K_2O) Potassium Nitrate (KNO_3 44% K_2O, 13% N) Sulphate of potash and magnesium (double salt of K and Mg, (Schoenite)

K_2SO_4, $MgSO_4$

(25 to 30% K_2O)

Chemistry of K compounds:

Potassium is not found in free state in soil. As metal, it reacts with CO_2 forming K_2O and K_2O with H_2O gives KOH. For this reason, K in elemental form is not used as fertilizer. It must be combined with other element like chlorine or group of elements.

Properties of Potasic fertilizers:

Muriate of Potash (KCl):

It is commonly marketed as a commercial fertilizer in granular form. However, it is also available in powder form. It is easily soluble in water. On application to the soil, it ionizes to dissociate into K^+ and Cl ions. K^+ like NH_4^+ gets attached or absorbed on the soil complex. As such, though muriate of potash is readily soluble in water, it is not leached.

Potassium sulphate (K_2SO_4) :

It is water soluble. On application to the soil, it separates into K^+ and SO_4^{-2} ions. K^+ is absorbed by growing plants or is absorbed on the soil complex. As such, though potassium sulphate is readily soluble in water, it is not lost by leaching.

SECONDARY AND MICRONUTRIENT FERTILIZERS

The secondary nutrients fertilizers: The secondary plant nutrients are Ca, Mg and S. Out of these, three nutrients, Ca and Mg are added indirectly in soil through fertilizes and soil amendments. Soil contains Ca and Mg as exchangeable and as $CaCO_3$ and dolomite. Normally, it is not necessary apply Ca and Mg fertilizers in soils of India.

Formerly, the use of FYM, A/S and superphosphate sources of S were used and now their use is either restricted or their replacement by other fertilizers which are devoid of S. Therefore, sulphur now becomes necessary to apply in soil because of the following reasons:

i) A/S a source of S is replaced by urea

ii) Another source of S, superphosphate is replaced by DAP

iii) Use of KCl instead of K_2SO_4

iv) Decrease in the use of FYM and

v) Use of high yielding varieties which absorb more quantity of nutrients.

The soils deficient in sulphur are supplied with the sources of S like elemental S. Elemental S when applied to soil, it is changed to $SO_2 \rightarrow SO_3$ and H_2SO_4. This H_2SO_4 with basic material of soil gives its sulphate salt. Plant absorbs S as SO^{-2}_4.

Micronutrients or Trace Elements:

The micro-nutrients are zinc (Zn), iron (Fe), copper (Cu), Manganese (Mn), Boron (B), Molybdenum (Mo) and Chlorine (Cl). These nutrients are present in available forms in soil in very small quantity and the requirement by crops is also less. Application of micronutrient fertilizers now become necessary as their deficiencies are observed in soil. The deficiency of micronutrients was observed in soil because of the following reasons.

I. Due to increase in irrigation facility, the number of crops taken in an year are increased.

II. Use of hybrid varieties which absorb more nutrients

III. Intensive cultivation

IV. Reduction in the use of organic manures like FYM, which supply these nutrients,

V. Use of high analysis fertilizers which are devoid of these nutrients.

Out of these micronutrients, chlorine is not applied as its fertilizer because it is indirectly applied through irrigation water. Mo is required in very small quantity and is also present in sufficient in some of seeds and soils and hence generally its fertilizers are not used. Boron is found to be deficient in calcareous soil as it is changed to calcium borate which is insoluble and hence boron is applied as its fertilizers. All these nutrients are present as anions. These four micronutrients are generally applied both soil and foliar as their sulphates at the time of deficiency. The micronutrient limits of the deficiency in soil, quantity and type of fertilizers added by soil and foliar application is given below:

SN	Element	Rating (ppm)			Soil application	Foliar application (200 to 300 lit/ha)
		Low	Medium	High		
1.	Iron	<2	2 to 5	> 5	10 ppm Fe as $FeSO_4$ i.e. 100 Kg $FeSO_4$/ha	Mix.0.4% $FesO_4$ solution with 0.2% lime solution
2.	Managanese Exchange Reducible	<3 <100	3 to 5 100 to 200	>5 >200	10ppm Mn as $MnSO_4$ *i.e.* 80Kg $MnSO_4$/ha	Mix.0.6% $MnSO_4$ Solution with 0.3% lime solution
3.	Zinc	<0.5	0.5 to 1.0	>1.0	5 ppm Zn as $ZnSO_4$ i.e. 45 kg $ZnSO_4$/ha	Mix 0.6% $ZnSO_4$ with 0.3% lime solution
4.	Copper	<0.2	0.2to 0.5	>0.5	5 ppm Cu as $CuSO_4$ i.e. 40 Kg $CuSO_4$/ha	Mix 0.4% $CuSO_4$ solution with 0.2% lime solution
5.	Boron	<0.1	0.1 to 0.5	>0.5	0.2 ppm B as Borax i.e.15 Kg Borax/ha	0.2% Borax solution
6.	Molybdenum	<0.05	0.05 to 0.1	>0.1	0.05 ppm Mo as ammonium molybdate *i.e*. 1.8 kg/ha	0.05% ammonium molybdate solution.

The micronutrients are soon changed to insoluble forms when they are added to soil and hence chelates are used as one of the sources. Chelates (meaning “Claw") is a compound in which metallic cation is bounded to an organic molecule.

The common chelating agents are:

EDTA : Ethylene Diamine Tetra Acetic Acid
DTPA : Diethylene Triamine Penta Acetic Acid
HEDTA : Hydroxy Ethylenthylene diamine Triacetic Acid
NTA : Nitricotriacetic acid

FERTILIZER MIXTURES (MIXED FERTILIZERS)

For application of individual nutrient, fertilizers of the nutrients were also applied separately which increased labour cost, transport and storage cost. In order to avoid the said difficulty, the fertilizer mixtures were used.

Fertilizers Mixtures: A mixture of two or more straight fertilizer materials is referred to as fertilizer mixture. The term complete fertilizer refers to these fertilizers that contains three major (N, P and K) nutrients.

Advantages of fertilizer mixtures :

1) Less labour is required to apply a mixture than to apply its components separately.
2) Use of fertilizer mixture leads to balanced manuring.
3) The residual acidity of fertilizers can be effectively controlled by the use of proper quantity of lime in fertilizer mixture.
4) Micronutrients can be incorporated in fertilizer mixture.
5) Mixture have better physical condition.

Disadvantages of fertilizer mixtures:

1) Use does not permit individual nutrient application which oat specific growth stage of crop.
2) Unit cost of plant nutrients in mixtures is usually higher than those of straight fertilizers.
3) Farmers use mixtures without careful study of their needs.

Materials and methods of preparing fertilizer mixtures:

The type of grade of fertilizer mixture to be prepared should be decided. The straight fertilizers are chosen according to compatibility in mixture. The quantity of each fertilizer is calculated for the preparation of desired quantity of preparing fertilizer mixture. It happens that there is a gap in weight of fertilizers taken on the basis of nutrient content and the total weight of fertilizer mixture. The gap is filled by using **filler**. A filler is the make weight material added to a fertilizer mixture. The common fillers used are: sand, soil, ground coal, ash and other waste products. It is also necessary to add the **conditioners** to avoid caking. For this low grade organic materials like tobacco stem, peat, groundnut and paddy hulls are added at the rate of 100 lbs/ton of mixture. If the fertilizers used leave acidic residual effect when it is added in soil then liming materials like lime stone, dolomite *etc.* are added.

Incompatibility in fertilizer mixtures:

1. Fertilizers containing NH_3 should not be mixed with basically reactive fertilizers, otherwise there will be loss of N as NH_3.

2. All water soluble phosphatic fertilizers should not be mixed with those fertilizers that contain free lime, otherwise a portion of soluble phosphate is converted into an insoluble form.
3. Easily soluble and hygroscopic fertilizers tend to cake or form slums after mixing. Such fertilizers should be mixed shortly before use.

Considering the incompatibility, the chart is given below which can be used while preparing fertilizer mixture.

1	2	3	4	5	6	7	8	9	10	11	
√	√	X	X	*	√	√	√	X	√	√	1. Muriate of Potash
√	√	X	X	*	√	√	X	X	√	√	2.Sulphate of potash
X	X	√	√	*	X	*	*	√	√	√	3.Sulphate of ammonia
X	X	√	√	*	X	*	*	√	√	√	4.Calcium amm.nitrate
*	*	*	*	*	*	*	*	*	*	*	5.Sodium nitrate
√	√	X	X	*	√	*	X	X	X	*	6.Calcium cynamide
√	√	*	*	*	*	√	√	√	*	*	7.Urea
√	X	*	*	*	X	*	√	√	*	*	8.Superphosphate single or triple
X	X	√	√	*	X	*	√	√	√	√	9.Ammon.Phosphate
√	√	√	√	*	√	*	*	√	√	√	10.Basic slag
√	√	√	√	*	*	*	*	√	√	√	11.Calcium carbonate

Guide for mixing fertilizers

√	Fertilizer which can be mixed
*	Fertilizer which may be mixed shortly before use
X	Fertilizer which can not be mixed

Calculation of quantity of fertilizers to be used in mixture :

Example :- Prepare 600 kg of a 4-8-10 fertilizers mixture in which half the nitrogen is in ammonium sulphate (20 per cent N) and the other half divided between nitrate of soda (16 per cent N) and tankage (6 per cent N and 6 per cent P_2O_5). P_2O_5 and K_2O are to be added in the form of superphosphate (16 per cent P_2O_5) and muriate of potash (60 per cent K_2O) respectively.

In the present example, 4 Kg of nitrogen in every 100 Kg of mixture is supplied with 2 Kg N as ammonium sulphate

1 Kg N as nitrate of soda

1 Kg N as tankage

For N $= \frac{2x100}{20}$ ***= 10 Kg of ammonium sulphate***

N $= \frac{1 \times 100}{16}$ = 6.25 kg of nitrate of soda

N $= \frac{1 \times 100}{6}$ = 16.66 kg of tankage

Since, tankage contains nitrogen and phsophoric acid, 16.66 kg of tankage, mixed in every 100 Kg of fertilizer.

Mixture wil also add $\frac{16.66 \times 6}{100}$ = 1 Kg of P_2O_5.

This means that out of 8 Kg of P_2O_5, 1 Kg is supplied through tankage and the remaining 7 Kg comes from superphosphate.

For P_2O_5 $= \frac{7x100}{16}$ = 43.75 Kg of superphosphate

K_2O $= \frac{10x100}{60}$ = 16.66 Kg of muriate of potash

Thus, the total quantity of various fertilizers required to prepare 100 kg of a 4-8-10 fertilizer mixture will be

Ammonium sulphate…….	10.00 Kg
Nitrate of soda	6.25 Kg
Tankage	16.66 Kg
Superphosphate	**43.75 Kg**
Muriate of potash	16.66 Kg
Total quantity of straight fertilizer	***93.32 Kg***
Filler	6.68 Kg

Mixed fertilizer 100.00 Kg

For preparing 600 kg of the fertilizer mixture of the 4-8-10 grade, the following quantities of fertilizers and filler will be required:

Ammonium sulphate	**:**	**10x6**	**= 60.0 kg**
Nitrate of soda	**:**	**6.25x6**	**= 37.5 Kg**
Tankage	**:**	**16.66x6**	**= 100.00 Kg**
Superpohosphate	**:**	**47.75x6**	**= 262.5 Kg**
Muriate of potash	**:**	**6.68x6**	**= 40.0Kg**
Total	**:**		**600.00 Kg**

Fertiliser mixtures available in the market:

1. ***Sufla (15:15:15)***
2. ***Sufla (20:20:0)***
3. ***Lakshmi (12:12:12)***
4. ***Lakshmi (8:8:8)***
5. ***IFFCO-1 (10:26:26)***
6. ***IFFCO-2 (12:32:16)***

COMPLEX FERTILIZERS

Due to uneconomical and labour cost of using individual fertilizer, the fertilizer mixtures were prepared and they were used. These fertilizer mixtures were not homogenous, containing less quantity of N, P, K and many times inferior quality of material were used. For these difficulties, complex fertilizers have been prepared. These complex fertilizers contain the nutrients of grade mentioned, homogenous, granular and good physical conditions.

Complex Fertilizers:

Commercial complex fertilizers are those fertilizers which contain at least two or three or more of the primary essential nutrients. When it contains only two of the primary nutrients, it is designated as incomplete complex fertilizer. While those contain three nutrients are designated as complete complex fertilizers. At present, the complex fertilizers obtained by chemical reaction are more important than fertilizer mixtures. Complex fertilizers being manufactured in India are Nitrophosphate DAP and Ammonium phosphate sulphate **Characteristics of complex fertilizers:**

1. They usually have high content of plant nutrients more than 30 kg/100 kg of fertilizer. As such they are called **high analysis fertilizers.**
2. They usually have uniform grain size and good physical condition.
3. They supply N and P in available form in one operation. Nitrogen is present as NO^{-}_{3} and NH^{+}_{4} forms and P as water soluble form upto 50 to 90% of total P_2O_5.
4. They are cheaper compared to individual fertilizer on the basis of per Kg of nutrient.
5. Transport and distribution cost is reduced on the basis of per kg of nutrients.

Fertilizers grades: The grades of complex fertilizers are given below:

Sr. No.	N	P	K
1	10	26	26
2	12	32	16
3	14	36	12
4	22	22	11
5	14	35	14
6	17	17	17
7	14	28	14
8	11	22	22
9	19	19	19
10	14	14	14
11	11	11	11
12	17	17	16
13	20	10	10
14	13	13	20

TIME AND METHOD OF FERTILIZER APPLICATION AND BLANCED FERTILIZETION

To obtain the maximum benefit from fertilizers, it is most essential that fertilizes to be applied at the proper time and at the proper place. The fertilizers to be applied, possess different qualities with regard to solubility in water and movement in to the soil solution. Similarly, soils are of different nature, sandy to clayey. The nature of the soil governs the movement of applied fertilizers. Again, the requirement of plants for different plant nutrients varies to their stage of growth. For example, nitrogen is absorbed by the plants throughout the growth period. While phosphorus is absorbed at a faster rate during the early growth period. Thus, the time and method of fertilizers application will vary in relation to :

1) The nature of fertilizer
2) The soil type and
3) The difference in nutrient requirement and nature of field crops.

Principles governing selection of proper time for application of fertilizers :

1) Nitrogen is required throughout the crop growth. As such, it is absorbed by the plant at the same rate as that of its growth. All plants grow at a slow rate in the beginning. Then follows a rapid increase in the growth rate. Near the harvest time, the rate of growth again slows down. Accordingly, nitrogen is taken up by the plant slowly in the beginning, rapidly during the grand growth period, and again slowly as it nears maturity. In other words, the nitrogen requirement of a growing plant is less in the early stages of growth, maximum during its grand growth period, and very low at the subsequent stages upto harvest. It is thus seen that nitrogen is required throughout the growth period.
2) Nitrogenous fertilizers are soluble in water. They are mobile and move rapidly in all directions within the soil. As such nitrogen is easily lost through leaching. Since nitrogen is required throughout the growth period and nitrogenous fertilizers are lost through leaching, it is better not to apply too much nitrogenous fertilizers at one time, but to apply in split doses throughout the growth period. This will supply nitrogen to growing plants during the entire growth period and the plants will not suffer from nitrogen deficiency.
3) Phosphorus is required during the early root development and early plant growth. As such, crop plants utilize 2/3 of the total requirement of phosphorus when the plants accumulate 1/3 of their dry weight. In other words, plants require more of phosphorus during the early growth period.
4) All phosphatic fertilizers release phosphorus for plant growth slowly. This is true even for super phosphate which contains monocalcium phosphate or water soluble P_2O_5. On application of super phosphate to the soil watersoluble P_2O_5 becomes immediately slightly insoluble or is converted into dicalcium phosphate or citrate soluble P_2O_5.In this form, phosphorus becomes available to plants slowly.
5) On the one hand, phosphorus is required in greater quantities during the early growth period; while on the other, all phosphatic fertilizers become available to the growing plants slowly. As such, it is always recommended that the entire quantity of phosphatic fertilizers should be applied before sowing or planting.
6) Potash behaves partly like nitrogen and partly like phosphorus. From the point of view of the rate of absorption, it is like nitrogen, being absorbed up to the harvesting stage. But potassic fertilizers, like phosphatic fertilizers, become

available slowly. As such, it is always advisable to apply the entire quantity of the potash at sowing time.

7) Leaching is greater from sandy soils than from heavy textured soils. This means that more frequent applications or split application of nitrogenous fertilizers, and sometimes of potassic fertilizers, is desirable on sandy soils.

Practical recommendations based on the principles guiding the time of application of fertilizers can be summed up as follows :

1. Nitrogenous fertilizers should be applied in two split doses to crops of four to five months duration, in three splits to crops of 9 to 12 months duration, and in four to five splits when crops are of still longer duration, like **adsali** crop of sugarcane.
2. On sandy soils or light textured soils more frequent or split application of nitrogenous fertilizers is desirable, compared to heavy textured soils, like clayey soils. This is important for reducing losses due to leaching.
3. The entire quantity of water soluble phosphatic fertilizers should be applied in one dose at sowing time. In acid soils, it is advisable to apply bone meal or rock phosphate a week or fortnight prior to sowing.
4. Potassic fertilizers also should be applied in one dose at planting time.

Principles involved in selecting the correct methods of fertilizer application:

1. Nitrogenous fertilizers are easily soluble in water and move rapidly in all directions from the place of application. In other words, nitrogenous fertilizers applied on the soil surface reach the plant roots easily and rapidly. As such, these fertilizers are broadcasted on the soil surface just before sowing.
2. Since nitrogen is liable to be lost by leaching, it is applied at different stages of plant growth. Since nitrogenous fertilizers move rapidly in moist soil, application of nitrogenous fertilizers on the soil surface followed by irrigation is good enough to meet the nitrogen requirement at the critical stage of plant growth. In other words, nitrogenous fertilizers are suitable for topdressing and side dressing.
3. Since phosphorus moves slowly from the point of placement it should be placed where it will be readily accessible to the plant roots.
4. Progressive fixation of phosphates by soil clays continues to diminish their efficiency for a considerable period following application. Fixation refers to any chemical or physical interaction between the applied plant nutrients and the soil whereby the nutrients become less available to crops. To reduce the fixation of

phosphate, phosphatic fertilizers should be so placed that they come into minimum contact with the soil particles and are closer to the plant roots. In other words, localized placement of phosphatic fertilizers near the seeds or seedling roots should be practiced.

5. Since potassic fertilizers move slowly in the soil, they should also be placed near the root zone.

Balanced Fertilization:

Plants contain 90 or more elements, only 16 of which are currently known to be essential. The elements essential for plant growth are carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulphur, calcium, iron, magnesium, boron, manganese, copper, zinc, molybdenum and chlorine. On practical point of view, generally application of nitrogenous, phosphatic and potassic fertilizers are considered as balanced fertilization.

Unbalanced fertilization has led to decrease in the yield of crops and also deteriorate the physical condition of the soil. the growing of crops by using only nitrogen fertilizer have depleted the reserve of available phosphoric acid, potash, and other nutrients in the soil. The result is that subsequent additions of nitrogen fertilizer do not result in increased yields because some other essential elements such as phosphorus and potash are now a limiting factor.

Balanced application of fertilizers enhances the efficiency of nutrients. For example, the efficiency of a nutrient like nitrogen is greatly enhanced when it is used in conjunction with phosphorus. For instance, when a dose of 30 Kg of nitrogen was applied in the field, only 14 to 30% of nitrogen is utilized by the crops. On the other hand, when 30 Kg of nitrogen was applied along with 30 Kg of phosphoric acid, the recovery of added nitrogen varied from 23 to 50%. This clearly shows that phosphoric acid contributed to the better utilization of the nitrogen. Just as phosphoric acid helps in the better utilization of nitrogen, potash also helps in the better assimilation of nitrogen and phosphoric acid. Balanced fertilizer application, particularly, phosphorus and potash makes plants more drought resistant and winter hardy.

Soil amendments

Soil amendments are substances which when added to the soil help plant growth indirectly by augmenting physical, chemical or biological changes in the soil. Soil amendment usually contains plant nutrient. But they cannot be classified along with fertilizers as their main aim is not to supply the nutrient directly, but they are very helpful for plant growth (Rai, 1965).

***The organic amendments*:** The organic amendments as such do not help in replacing the exchangeable Na as against the gypsum or other amendments. Primarily, they improves the physical condition of the soil by improving the aggregation in the soil. The most common organic amendment is the FYM which is added in the first year of reclamation @ 50 tones/ha and is reduced to half in succeeding years. The efficiency of gypsum has been found to increase when it is applied along with FYM. Molasses and pressmud, which are sugar factory waste, have also been used. Pressmud, a byproduct from sugar factories, contains $CaCO_3$. Since Ca is present as $CaCO_3$, it is slow acting amendment requiring acid or acid formers. As against carbonation process, pressmud from sugar factories employing sulphitation process has superior reclamation value, as it contains sulphate of lime instead of its carbonate.

Green manuring with Dhaincha (*Sesbania aculeata*) has been found most successful. The juice of green plants can neutralize high alkalinity, its initial pH being 4.01, with only slight rise even within a month. In black cotton soil, it thrives well under moderately saline conditions and can with stand high alkalinity, water logging or drought so that it is remarkably suited in that region to alkali soils, characterized by such adverse conditions. Sulphurated hydrogen is generated by the decomposition of Dhaincha.

Paddy straw or rice husk have also been used at a rate varying between 15 to 30 tones/ha. Weeds like *Argemone mexicana* has been found very suitable for alkali soils. The other weeds found suitable for the purpose of green manuring are *Ipomea grandiflora* and *Pongamia glabra*. The Russian workers have suggested the addition of cellulose with sufficient addition of nitrogen for easy decomposition.

A. *Different types of chemical amendments:*

1. Soluble calcium salts e.g.

(i)	Calcium chloride	($CaCl_2.2H_2O$)
(ii)	Gypsum	($CaSO_4.2H_2O$)
(iii)	Calcium sulphate	($CaSO_4$)

2. Acid or acid formers e.g.

(i)	Sulphur	(S)
(ii)	Sulphuric acid	(H_2SO_4)
(iii)	Iron sulphate	($FeSO_4.7H_2O$)
(iv)	Aluminium sulphate	($Al_2(SO_4)_3.18H_2O$)
(v)	Lime sulphur (calcium poly sulphide)	(CaS_5)

(vi) Pyrites (FeS_2)

The kind and amount of chemical amendment to be used for the replacement of exchangeable Na in soils depend upon the soil characteristics, the desired rate of replacement and economic considerations. Soluble calcium salts are preferred when soil does not contain alkaline earth carbonates or calcium carbonate. Acid or acid formers are preferred when soil contains alkaline earth carbonates or $CaCO_3$. Acid or acid formers are also used along with calcium salt of low solubility but the rate of reaction is very low.

B. ***Advantages and disadvantages of amendments:***

The $CaCl_2$ is highly soluble and Ca is readily available but its cost is a prohibitive factor. Iron and aluminum sulphates also hydrolyze readily in the soil to form H_2SO_4 but here also the cost is acting. Amendment, which can be used in calcareous soils but it requires special equipments and is hazardous in handling. Sulphur is a slow acting amendment and large applications are needed. It requires more time for complete oxidation. In cool winter season, the oxidation rate is too slow to give satisfactory results. Since the oxidation process is fully microbial, an optimum amount of moisture has to be maintained continuously in the soil. The soil should not be leached until sufficient time has been allowed for most of the sulphur to oxidize. Limestone is a low cost amendment but the solubility is affected by pH of the soil and particle size of the amendment. Like S, pyrite has to be oxidized first which is a slow process and the rate of reaction depends on particle size. Again the application of pyrites at higher rate markedly decreases its oxidation rate. It is a cheap amendment.

Gypsum is the most common amendment used for reclaiming saline-sodic as well as non-saline sodic soils. It is a low cost amendment and the rate of reaction in replacing Na is limited on its solubility in water, which is about 0.25 % at ordinary temperature. While applying gypsum, mixing it in shallow depth (upper 10 cm depth) is more effective. It is applied by broadcast method or incorporated by disc plough. Gypsum is applied at the time of ponding or leaching. Gypsum directly prevents crust formation, swelling, dispersion and acts as mulch in case of surface application and indirectly increases porosity, structural stability, infiltration and hydraulic properties, soil tilth, drainage and leaching and reduces dry soil strength.

C. Chemical reactions of amendments in soil: The following chemical reactions illustrate the manner in which various amendments react in the different classes of alkali soils. In these equations the letter **X** represents the soil exchange complex.

Reclamation of saline-alkali soils

Class 1. Soils Containing Alkaline-Earth Carbonates

GYPSUM: $2NaX + CaSO_4 \leftrightarrow CaX_2 + Na_2SO_4$

SULPHUR: (1) $2S + 3O_2 \leftrightarrow 2SO_3$ (microbiological oxidation)

(2) $SO_3 + H_2O \leftrightarrow H_2SO_4$

(3) $H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + CO_2 + H_2O$*

(4) $2NaX + CaSO_4 \leftrightarrow CaX_2 + Na_2SO_4$

LIME-SULPHUR (CALCIUM POLYPHOSPHATE):

(1) $CaS_5 + 8O_2 + 4H_2O \leftrightarrow CaSO_4 + 4H_2SO_4$

(2) $H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + CO_2 + H_2O$*

(3) $2NaX + CaSO_4 \leftrightarrow CaX_2 + Na_2SO_4$

IRON SULPHATE:

(1) $FeSO_4 + H_2O \leftrightarrow H_2SO_4 + FeO$

(2) $H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + CO_2 + H_2O$*

(3) $2NaX + CaSO_4 \leftrightarrow CaX_2 + Na_2SO_4$

D. *Quantity of amendments to be added:* These are evidences to show that even 50 % of the theoretical gypsum requirement for replacement of exchangeable Na in alkali soils has improved their physical properties and assisted response to management practices. Generally, 50 to 75 % of GR (as determined by Schoonover's method) has been found most satisfactory in many types of soils.

The equivalent proportion of different amendments in relation to 1 ton of gypsum is as follows:

Amendments	Weight in tones equivalent to 1 tone gypsum
Gypsum	1.000
Sulphuric acid	0.570
Sulphur	0.186
$FeSO_4.7H_2O$	1.620
Aluminium sulphate	1.290
Limestone ($CaCO_3$)	0.580
Lime sulphur (Calcium polysulfide containing 24 % S)	0.756

Among all the amendments, gypsum is the most common amendment that is used for the purpose of reclamation. The rate of addition of gypsum can be determined by estimating the gypsum requirement (GR) of a soil. Alternatively, the GR can also be determined by knowing the exchangeable Na in soil and working out the extent of reduction of Na on equivalent basis. The gypsum requirement for replacing 1 me of Na upto a soil depth of 15 cm comes to about 1.92 tones/ha. Since an ESP of 10 and below is considering safe for tolerable physical condition of the soil, replacement by calcium to this level is all that is attempted in practice.

E. ***The organic amendments*****:** The organic amendments as such do not help in replacing the exchangeable Na as against the gypsum or other amendments. Primarily, they improve the physical condition of the soil by improving the aggregation in the soil. The most common organic amendment is the FYM which is added in the first year of reclamation @ 50 tones/ha and is reduced to half in succeeding years. The efficiency of gypsum has been found to increase when it is applied along with FYM. Molasses and pressmud, which are sugar factory waste, have also been used. Pressmud, a byproduct from sugar factories, contains $CaCO_3$. Since Ca is present as $CaCO_3$, it is slow acting amendment requiring acid or acid formers. As against carbonation process, pressmud from sugar factories employing sulphitation process has superior reclamation value, as it contains sulphate of lime instead of its carbonate.

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Reclamation of Acidic Soils

Principles of Liming Reactions: The reclamation of acidic soils is done by addition of liming material which may be calcitic limestone ($CaCO_3$) or dolomitic limestone [$CaMg(CO_3)_2$]. The rate of lime requirement is determined in the laboratory by method of Shoemaker (1961). The particle size of liming material affects the rate of neutralization reaction. Both these limestones are sparingly soluble in pure water but do become soluble in water containing CO_2. The greater the partial pressure of CO_2 in the system, the more soluble the limestone becomes. Dolomite is somewhat less soluble than calcite. The reaction of limestone ($CaCO_3$) can be written as:

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

$$Ca(HCO_3)_2 \rightarrow Ca^{2+} \downarrow + 2HCO_3^-$$

(Takes part in cation exchange reactions)

$$H^+ + CO_3^{2-} \rightarrow H_2CO_3^- \leftrightarrow H_2O + CO_2$$

(From soil solution) (from lime)

In this way hydrogen ions (H^+) in the soil solution react to form weakly dissociated water, and the calcium (Ca^{2+}) ion from limestones is left to undergo cation exchange reactions. The acidity of the soil is, therefore, neutralized and the per cent base saturation of the colloidal material is increased.

Why Gypsum is not considered as a Liming Material?

Gypsum is not considered as liming materials because on its application to an acid it dissociates into (Ca^{2+}) and sulphate (SO_4^{2-}) ions:

$$CaSO_4 \leftrightarrow Ca^{2+} + SO_4^{2-}$$

The accompanying anion is sulphate and it reacts with soil moisture produces mineral acid (H_2SO_4) which also increases soil acidity instead of reducing soil acidity.

Beneficial effect of lime

1. Lime makes P_2O_5 more available.
2. Lime increase availability of N, increase nitrification and nitrogen fixation.
3. Increase soil pH favours the microbial activity and increase organic matter decomposition and nutrient transformation for root growth.
4. Mo an essential element to *rhizobium* in N fixation process increases with increase in soil pH following lime.
5. Reduce toxicity of Al, Fe and Mn.

6. Lime is essential source of essential Ca as well as Mg if dolomitic lime stone has been applied as liming material.
7. It causes an increase in CEC, which reduces the leaching of base cations, particularly K.

(**Source:** Soil Fertility and Nutrient Management. S. S. Singh)

SOLVED EXAMPLES:

Example 1: *A soil contains 12 me Na/100 g soil. The CEC of the soil is 20. Exchangeable Na percentage is to be reduced to 10. Workout the gypsum requirement.*

ESP = Exch. Na/CEC x 100 = 12/20 x 100 = 60 %

Initial ESP – Final ESP = 60 – 10 = 50 % ESP to be reduced

Exch. Na = 12 x 50/60 = 10 me exch. Na/100 g to be replaced

GR = 1 me exch. Na/100 g = 86 mg gypsum/100 g
= 860 mg/1000 g
= 860 ppm
= 860 x 2.24 = 1926.4 kg/ha

10 me exch. Na = 10 x 1926.4 = 19264 kg/ha = 19.2 t/ha

If purity is 80 then,

GR = 19.2 x 100/80 = 24 t/ha

The GR in this example is 19.2 tones/ha. To get the net value of weight of gypsum, the value has to be multiplied by purity percentage i.e. if the purity of the commercial gypsum is 80 %, then the exact weight in the above example would be 24 tones/ha.

Example 2: *Calculate GR of alkali soils containing CEC 20 me/100 g [cmol(p^+)kg^{-1}] and 10 me exch. Na/100 g soil, ESP reduced to 10.*

CEC = 20 me/100 g

Exch. Na = 10 me/100 g

ESP reduced to = 10 %

ESP = [Exch. Na/CEC] x 100
= [10/20] x 100
= 50

Initial ESP – Final ESP = 50 – 10 = 40 ESP to be reduced

ESP 50 = Exch. Na 10

So ESP 40 =10 x 40/50 = 8 Exch. Na me/100 g to be reduced

1 me Exch. Na/100 g = 86 mg Gypsum/100 g
= 860 mg Gypsum/1000 g
= 860 ppm Gypsum
= 860 x 2.24 = 1926 kg/ha Gypsum
= 1.926 t/ha Gypsum

So 8 me Exch. Na/100 g = 8 x 1.926 = 15.41 t/ha

Example 3: *Soil having CEC 40 me/100 g. It has Na 20 me/100 g in exch. form. Bring down exch. Na to 10 %. Calculate % Na. How much Na to be replaced as to bring its saturation to 10 % and calculate GR in kg/ha. Gypsum purity is 80 %.*

(1) ESP = (Exch. Na/CEC) x 100 = (20/40) x 100 = 50 ESP
Initial ESP – Final ESP = 50 – 10 = 40 ESP to be reduced
(2) Exch. Na = (ESP x CEC)/100 = (40 x 40)/100 = 16 me Na/100 g to be replaced

(3) GR =	1 me Na/100 g	= 86 mg gypsum/100 g
		= 860 ppm
		= 860 x 2.24 kg/ha
	16 me Na/100 g	= 16 x 860 x 2.24 = 30822 kg/ha
(4)	80 % purity	= 30822 x 100/80 = 38528 kg/ha

Example 4: *A soil have CEC = 25 me/100 g soil which possesses 5, 8 and 3 me/100 g of Ca, Mg and K, respectively. Calculate quantity of Na in me/100g and kg/ha and K_2O kg/ha.*

(1)	Na me/100 g	= CEC – (Ca + Mg + K)
		= 25 – (5 + 8 + 3) = 9 me/100 g
		= 9 x 23 mg/100 g = 207 mg/100 g
		= 2070 mg/1000 g = 2070 ppm
(2)	Na (kg/ha)	= 2070 x 2.24 = 4636.8 kg/ha
	K	= 3 me/100 g
		= 3 x 39 mg/100 g = 117 mg/100 g
		= 1170 mg/1000 g = 1170 ppm
		= 1170 x 2.24 = 2620.8 kg/ha
(3)	K_2O (kg/ha)	= 2620.8 x 1.20 = 3144.96 kg/ha

Example 5: *Workout the GR from following observations*

(1) Weight of alkali soil = 5 g
(2) Sat. gypsum soln. = 100 ml
(3) Aliquate taken = 5 ml
(4) Difference of 0.02 N EDTA reading between blank and sample = 0.4

GR t/ha = Z x (1.72/1000) x (100/5) x (100/5) x 10,000 x 2.24/1000
= 0.4 x 15.411 = 6.16 t/ha

Soil Conditioner

These are material, which are used to bring about required physical properties of soil or it is used to improve and maintain the physical conditions of the soils. Crop residues, organic manures and other organic materials are the organic soil conditioners. Other synthetic organic materials which are used as soil conditioners are Polyvinyl alcohol (PVA), Carboxymethyl cellulose (CMC) and Krillium conditioners. These materials use to form soil aggregates or they use to stabilize soil aggregate formed by mechanical manipulations. However, its application is found restricted to green house, glass house or in growing high value crops like vegetables, ornamental plants or spices and condiments etc.

(**Source**: Soil Fertility and Nutrient Management. S. S. Singh)

Nano-Fertilizers:

Nanotechnology has progressively moved away from the experimental into the practical areas, like the development of slow/controlled release fertilizers, conditional release of pesticides and herbicides, on the basis of nanotechnology has become critically important for promoting the development of environment friendly and sustainable agriculture.

Indeed, nanotechnology has provided the feasibility of exploiting nanoscale or nanostructured materials as fertilizer carriers or controlled release vectors for building of so-called **"smart fertilizer"** as new facilities to enhance nutrient use efficiency and reduce costs of environmental protection. Encapsulation of fertilizers within a nanoparticle is one of these new facilities which are done in three ways

a) the nutrient can be encapsulated inside nanoporous materials,

b) coated with thin polymer film and

c) delivered as particle or emulsions of nanoscales dimensions.

In addition, nanofertilizers will combine nanodevices in order to synchronize the release of fertilizer-N and -P with their uptake by crops, so preventing undesirable nutrient losses to soil, water and air via direct internalization by crops, and avoiding the interaction of nutrients with soil, microorganisms, water, and air. Among the latest line of technological innovations, nanotechnology occupies a prominent position in transforming agriculture and food production.

Some of the major evident benefits of nano fertilizer are as under:

- The quantity required for nano fertilizer application is considerably reduced as compared to conventional fertilizers.
- Nano fertilizer will help to boost the crop production efficiently besides reducing nutrient losses into the surrounding water bodies (Eutrophication).
- Nano-structured formulation might increase fertilizer efficiency and uptake ratio of the soil nutrients in crop production, and save fertilizer resource.
- Nano-structured formulation can reduce loss rate of fertilizer nutrients into soil by leaching and/or leaking.

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CHAPTER- V: FERTILIZER STORAGE AND FERTILIZER CONTROL ORDER

Warehousing and storage of fertilizers is a very important and massive activity. Ideally a marketer would like the fertilizer to spend minimum time in a godown because storage costs money, blocks money, occupies space, needs supervision and inspite of precautions, some fertilizer can be stolen or damaged. **Storage can be called a necessary evil.** People who pay for storage, often think whether it is better to spend on this item or to give off- season rebate to the farmer and let him do the storage.

The principles of good storage at the field level are:

(i) The fertilizers should be stored in a cool, dry and damp proof godown. The rain water must not get entered in the godwon and there is no need to have windows in the godown. But they should have proper ventilation for regulating for exit of gases from the store. The ventilators should be sealed in rainy season.

(ii) The bags should not be piled up directly on the floor as moisture of the floor causes the damage to the fertilizer. The wooden racks should be used for pilling the fertilizer bags.

(iii) The bags should not be piled together in a row of 8-10 bags.

(iv) The bags should not touch the wall of the godwon.

(v) Proper space should be allowed between two of piled fertilizers for convenience of lifting the fertilizers.

(vi) The fertilizer that are hygroscopic in nature such as Urea, Ammonium Nitrate, Ammonium Sulphate Nitrate, Calcium Ammonium Nitrate must be stored in water proof bag and the entire bag should be used in one lot. Otherwise, the bag should be tied tightly and stored in a dry and damp proof godwon after taking required fertilizers.

(vii) The fertilizers that are fire hazardous such as Ammonium Sulphate must be handled very carefully.

(viii) All types of fertilizers such as Nitrogenous, Phosphatic and Potassic fertilizers should not be piled together. But they should be piled separately so that their handling is easy and gas fumes release from one group may not affect the quality of others.

(ix) The bag should not be kept open at any time to avoid the formation of cakes or lumps.

(x) The home mixed fertilizer should not be stored. Rather it should be used immediately after mixing of different fertilizers.

(xi) Prolonged storage of fertilizer should be avoided.

Fertilizer Control Order:

The history of the Indian fertilizer industry dates back to 1906, when the first fertilizer factory opened at Ranipet (Tamil Nadu). Since then, there have been major developments in terms of both the quantity and the types of fertilizers produced, the technologies used and the feedstocks employed. The fertilizer industry in India is in the core sector and second to steel in terms of investment.

Prior to 1960/61, India produced only straight nitrogenous fertilizers [ammonium sulphate (AS), urea, calcium ammonium nitrate (CAN), ammonium chloride and single superphosphate (SSP)]. The production of NP complex fertilizers commenced in 1960/61. Currently, India produces a large number of grades of NP / NPK complex fertilizer. These include 16–20–20, 20–20–0, 28–28–0, 15–15–15, 17–17–17, 19–19–19, 10–26–26, 12–32–16, 14–28–14, 14–35–14 and 19–19–19. In addition, India produces various grades of simple and granulated mixtures.

The fertilizer was declared as an Essential Commodity in 1957 in India. To control the trade, price, quality of fertilizers and their distribution, “The fertilizers (Control) Order” came in to force in 1957. Since then the The Fertilizer (Control) order (FCO) has been amended periodically. It is useful for the personnels engaged in: Fertilizer manufacture, fertilizer business, fertilizer analysis and fertilizer inspection.

FERTILIZER CONTROL ACT

The Union Government of India promulgated the fertilizer Control Act (F.C.O) in 1957 under the Essential Commodities Act, 1955 (section 3) with a view to regulate fertilizer business in India.

The F.C.O. keeps a strict watch on quality control of fertilizers, provides for the registration of dealers and statutory control of fertilizer prices by Government. Therefore, everybody involved in fertilizer business as a manufacturer, dealer or a salesperson, must have proper understanding of the F.C.O. in order to avoid infringement of Government regulations.

The provisions given in the Order will also help the consumers/ farmers to know their rights and privileges in respect of fertilizer quality and Authorities to be approached for their grievances regarding supply of substandard materials, overcharging or containers of underweight supplies.

The F.C.O. is published by the Fertilizer Association of India (F.A.I.), updated when ever felt necessary. The Order has provisions on quality for each consumed fertilizer product and F.C.O. should be consulted under infringement of any of them.

Control of Quality of Fertilizers

The F.C.O. has provisions to penalize manufactures, distributors, and dealers for supply of spurious or adulterated fertilizers to consumers or farmers. The F.C.O. has fixed specifications for various fertilizers, which must be present in them failing which the legislation comes in force, and guilty is punished.

Specifications of fertilizers

To control the quality of fertilizers “The Fertilizer Control Order, 1985” has laid down specifications for the fertilizers. The parameters of the specifications are as follows:

i. Moisture, per cent by weight maximum
ii. Total nutrient content, percent by weight
iii. Forms of nutrient, per cent by weight
iv. Impurities, per cent by weight
v. Particle size.

1. Ammonium Sulphate

(i) Moisture per cent by weight, maximum	1.0
(ii) Ammoniacal nitrogen per cent by weight, minimum	20.6
(iii) Free acidity (as H2SO4.) per cent by weight, maximum (0.04 for material obtained from by product ammonia and by-product gypsum)	0.025
(iv) Arsenic as (As2O3) per cent by weight, maximum	0.01
(v) Sulphur (as S) ,per cent by weight, minimum	23.0

2. Urea (46% N) (While free flowing)

(i) Moisture per cent by weight, maximum	1.0
(ii) Total nitrogen, per cent by weight, (on dry basis) minimum	46.00
(iii) Biuret per cent by weight, maximum	1.5
(iv) Particle size—Not less than 90 per cent of the material shall pass through 2.8 mm IS sieve and not less than 80 per cent by weight shall be retained on 1 mm IS sieve	

3. Potassium Chloride (Muriate of Potash)

(i) Moisture per cent by weight, maximum	0.5
(ii) Water soluble potash content (as K_2O) per cent by weight, minimum	60.0
(iii) Sodium as NaCI per cent by weight (on dry basis) maximum	3.5
(iv) Particle size -—minimum 65 cent of the material shall pass through 1.7 mm IS sieve and be retained on 0.25 mm IS sieve.	

4. Diammonium Phosphate (18-46-0)

(i) Moisture per cent by weight, maximum	1.5
(ii) Total nitrogen per cent by weight, minimum	18.0
(iii) Ammonical nitrogen form per cent by weight, minimum	15.5
(iv) Total nitrogen in the form of urea per cent by weight, maximum	2.5
(v) Neutral ammonium citrate soluble phosphates (as P_2O_5) per cent by weight, minimum	46.0
(vi) Water soluble phosphates (as P_2O_5) per cent by weight, minimum	41.0
(vii) Particle size -– not less than 90 per cent of the material shall pass through 4 mm IS sieve and be retained on 1 mm IS sieve. Not more than 5 per cent shall be below than 1 mm size.	

5. Zinc Sulphate Heptahydrate ($ZnSO_4.7H_2O$)

(ii) Matter insoluble in water per cent. by weight, maximum	1.0
(iii) Zinc (as Zn) per cent. by weight, minimum	21.0
(iv) Lead (as Pb) per cent by weight, maximum	0.003
(v) Copper (as Cu) per cent by weight, maximum	0.1
(vi) Magnesium (as Mg) per cent by weight, maximum	0.5
(vii) pH not less than	4.0
(viii) Sulphur (as S),percent by weight, minimum	10.0
(ix) Cadmium (as Cd), percent by weight, maximum	0.0025
(x) Arsenic (as As),percent by weight, maximum	0.01

SPECIFICATIONS OF MANURE

***Example:* Vermicompost :**

(i) Moisture, per cent by weight	15.0-25.0
(ii) Colour	Dark brown to black
(iii) Odour	Absence of foul odour
(iv) Particle size Minimum material should pass through 4.0 mm IS sieve	90%
(v) Bulk density (g/cm^3)	0.7-0.9
(vi) Total organic carbon, per cent by weight, minimum	18.0
(vii) Total Nitrogen (as N), per cent by weight,minimum	1.0
(viii) Total Phosphates (as P_2O_5), per cent by weight, minimum	0.8
(ix) Total Potash (as K_2O), per cent by weight, minimum	0.8
(x) C:N ratio	<20
(xi) pH	6.5-7.5

(xii) Pathogens	Nil
(xiii) Conductivity (as dsm^{-1}),not more than	4.0
(xiv) Heavy metal content, (as mg/kg), maximum	
Cadmium (as Cd) Chromium (as Cr) Nickel (as Ni) Lead (as Pb)	5.0 50.00 50.00 100.00

Fertilizer Movement Control Order

The Fertilizer Movement Order (F.M.O.) was promulgated by Government of India in April 1973 to ensure an equitable distribution of fertilizers in various States. According to the fertilizer movement order, no person or agency can export chemical fertilizers from any State. However, Food Corporation of India, Warehousing Corporation of India and Indian Potash Limited; materials like Rock phosphate, bone meal (both raw and steamed) and zinc sulphate are exempted from the movement restriction.

Agency responsible for Enforcement of F.C.O

The Controller of Fertilizers for India, usually a Joint Secretary to the Government of India (Ministry of Agriculture) is responsible for the enforcement of F.C.O. throughout the country.

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CHAPTER- VI: SOIL FERTILITY AND PLANT NUTRITION

The word 'fertile' means bearing abundantly and a fertile soil is considered to be one that produces abundant crops under suitable environmental condition. Soil fertility is vital to a productive soil. But a fertile soil is not necessarily a productive soil. All fertile soils may or may not be productive. Poor drainage, insects, drought and other factors can limit production, even when fertility is adequate. To fully understand soil fertility, one must know other factors which support or limit productivity.

SOIL FERTILITY:

It refers to the inherent capacity of soil to supply all the essential nutrients to plant in suitable quantity and in the right proportion.

SOIL PRODUCTIVITY:

Soil productivity is the ability of a soil for producing a specified plant or sequence of plants under a specified system of management. It is usually expressed in terms of crop yield.

The soil is said to be productive when good yields are obtained. Productive soils are those, which contain adequate amounts of all essential nutrients in readily forms to plants are in good physical condition to support plants and contain just the right amount of water and air for desirable root growth. Thus, soil fertility, good management practices, availability of water supply and a suitable climate contribute towards soil productivity. Soil fertility denotes the status of plant nutrients in the soil while soil productivity denotes the resultant of various factors influencing crop production both within and beyond the soil. Thus, soil productivity is a function of environmental factors combined with soil fertility or more correctly, in combination with environmental factors and management practices constituents soil productivity.

“All the productive soils are fertile but all the fertile soils may not be productive”

History of development of soil fertility

Francis Bacon (1591- 1624) suggested that the principle nourishment of plants was water and the main purpose of the soil was to keep plants erect and to protect from heat and cold.

Jan Baptiste Van Helmont (1577 – 1644) was reported that water was sole nutrient of plants.

Robert Boyle (1627 – 1691) an England scientist confirmed the findings of Van Helmont and proved that plant synthesis salts, spirits and oil etc from H_2O.

Anthur Young (1741 – 1820) an English agriculturist conducted pot experiment using Barley as a test crop under sand culture condition. He added charcoal, train oil, poultry dung, spirits of wine, oster shells and numerous other materials and he conduced that some of the materials were produced higher plant growth.

Priestly (1800) established the essentiality of O_2 for the plant growth.

J. B. Boussingault (1802-1882) French chemist conducted field experiment and maintained balance sheet. He was first scientist to conduct field experiment. He is considered as **father of field experiments.**

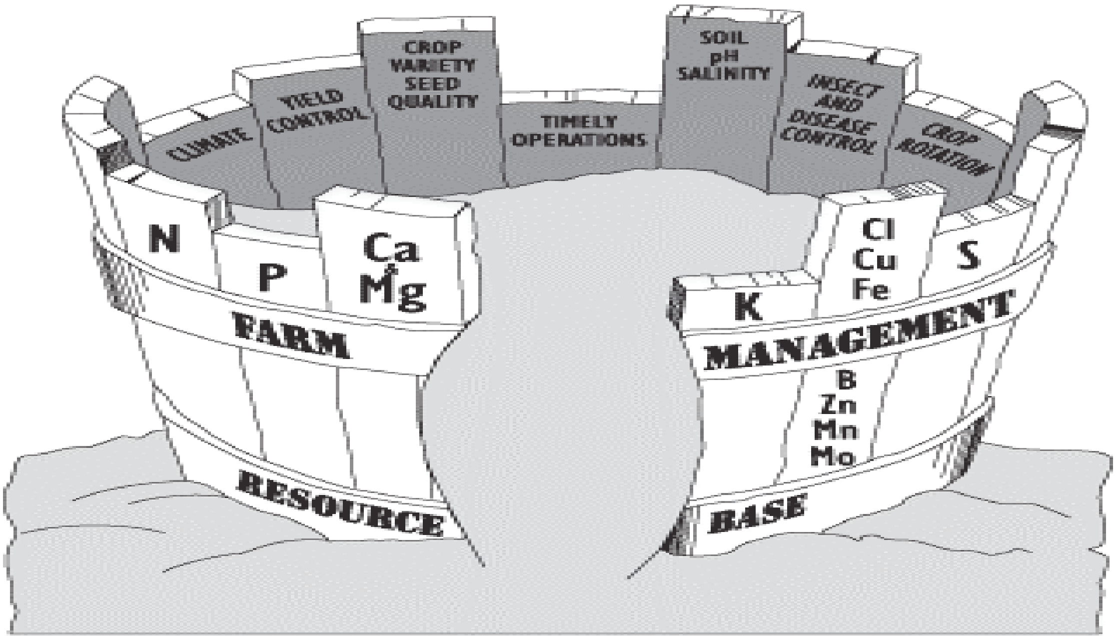
Justus Von Liebig (1835) suggested that

a) Most of the carbon in plants comes from the CO_2 of the atmosphere.
b) Hydrogen and O_2 comes from H_2O.
c) Alkaline metals are needed for neutralization of acids formed by plants as a result of their metabolic activities.
d) Phosphorus is necessary for seed formation.
e) Plant absorb everything from the soil but excrete from their roots those materials that are not essential.

The field may contain some nutrient in excess, some in optimum and some in least, but the limiting factor for growth is the least available nutrient. **The Law of Minimum**, stated by **Liebig in 1862**, is a simple but logical guide for predicting crop response to fertilization. This law states that, "the level of plant production cannot be greater than that allowed by the most limiting of the essential plant growth factors". The contributions made by Liebig to the advancement of agriculture were monumental and he is recognized as the **father of agricultural chemistry.**

Crops depend on extrinsic and intrinsic factors for their growth and environment to provide them with basic necessities for photosynthesis. These essential plant growth factors include: • light, heat, air, water, nutrients & physical support

If any one factor, or combination of factors, is in limited supply, plant growth will be adversely affected. The importance of each of the plant growth factors and the proper combination of these factors for normal plant growth is best described by the principle of limiting factors. This principle states: "The level of crop production can be no greater than that allowed by the most limiting of the essential plant growth factors." The principle of limiting factors can be compared to that of a barrel having staves of different lengths with each stave representing a plant growth factor.



J.B. Lawes and J. H. Gilbert (1843) established permanent manurial experiment at Rothemsted Agricultural experiment station at England. They conducted field experiments for twelve years and their findings were

S. N. Winogradsky discovered the autotrophic mode of life among bacteria and established the microbiological transformation of nitrogen and sulphur. Isolated for the first time nitrifying bacteria and demonstrated role of these bacteria in nitrification (l890), further he demonstrated that free-living *Clostridium pasteuriamum* could fix atmospheric nitrogen (1893). Therefore, he is considered as **"Father of soil microbiology".**

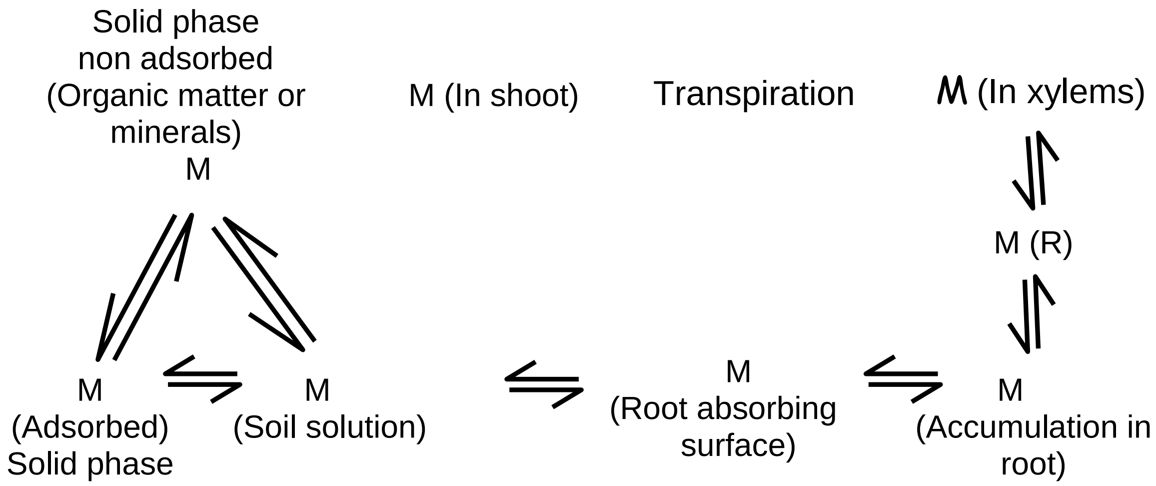
Robert Warrington England showed that the nitrification could be supported by carbon disulphide and chloroform and that it would be stopped by adding a small amount of unsterilized soil. He demonstrated that the reaction was two step phenomenon. First NH_3 being converted to nitrites and the nitrites to nitrites.

6.1 The soil as a Nutrient Source for Plants

Mineral Nutrients in the Soil: Mineral nutrients occur in the soil in both dissolved and bound form. Only a small fraction (less than 0.2%) of the mineral nutrient supply is dissolved in soil water. Most of the remainder, i.e., almost 98% is either bound in organic detritus, humus and relatively insoluble inorganic compounds or incorporated in minerals. These constitute a nutrient reserve, which becomes available very slowly as a result of weathering and mineralization of humus. The remaining 2% is adsorbed on soil colloids. The soil solution, the soil colloids and the reserves of mineral substances in the soil are in a state of dynamic equilibrium, which ensures continued replenishment of supplies of nutrient elements.

Adsorption and Exchange of ions in the soil: Both clay minerals and humic colloids have a negative net charge so that they attract and adsorb primarily cations. There are also some positively charged sites where anions can accumulate. How tightly a cation is held depends on its charge and degree of hydration. In general, ions with high valences are attracted more strongly for example, Ca^{2+} is more strongly attracted than K^{+}. Among ions with the same valence those with little hydration are retained more firmly than those that are strongly hydrated. The tendency for cations adsorption decreases in the order Al^{3+}, Ca^{2+}, Mg^{2+}, NH_4^{+}, K^{+} and Na^{+}

The swarm of ions around particles of clay and humus as an intermediary between the solid soil phase and the soil solution. If ions are added to or withdrawn from the soil solution, exchange takes place between solid and liquid phases. Adsorptive binding of nutrient ions offers a number of advantages nutrients liberated by weathering and the decomposition of humus are captured and protected from leaching the concentration of the soil solution is kept low and relatively constant; so that the plant roots and soil organisms are not exposed to extreme osmotic conditions; when required by the plant, however, the adsorbed nutrients are readily available.



Nutrient release and path for absorption

ESSENTIAL AND BENEFICIAL ELEMENTS

► ***The criteria of essentiality***: In order to distinguish elements, which are essential from those which may be taken up by the plant but are not essential, Arnon (1954) has laid down the following criteria:

(1) The plant must be unable to grow normally or complete its life-cycle in the absence of the element;

(2) The element is specific and can not be replaced by another; and

(3) The element plays a direct role in metabolism.

Table 1: Essentiality of nutrients discovered by scientists. Source: Tisdale *et al.* (1997)

Nutrient	**Essentiality discovered authors (Discoverer)**	**Year of discovery**
H & O	Since time immemorial	
C	Priestley *et al.*	1800
N	Theodore de Saussure	1804
K, Ca, Mg & P	C. Sprengel	1839
S	Sachs and Knop	1860
Cl	T.C. Broyer, A.B. Carlton, CM. Johnson and P.R. Stout	1954
Fe	E Gris	1843
B	K. Warington	1923
Mn	J.S. McHargue	1922
Zn	A.L. Sommer and CP. Lipman	1926
Cu	A.L. Sommer, CP. Lipman and G. McKinney	1931
Mo	D.I. Arnon and P.R. Stout	1939
Ni	P.H. Brown, R.M. Welch and E.E. Cary	1987

► ***Essential nutrients so far recognized***: Carbon, hydrogen and oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, boron, molybdenum and chlorine are recognized as universally essential. There is convincing evidence that these mineral elements are essential requirements for diverse groups of plants algae, bacteria, fungi and the green plants.

CLASSIFICATION OF ESSENTIAL PLANT NUTRIENTS:

(i) On the basis of amount of nutrients present in plants, they can be classified in to three groups:

Nutrients	Average concentration in plant tissue	Function in plant	Nutrient category
N	1.5%	Proteins, amino acids	**Primary Macronutrients**
P	0.2%	Nucleic acids, ATP	
K	1.0%	Catalyst, ion transport	
Ca	0.5%	Cell wall component	**Secondary**
Mg	0.2%	Part of chlorophyll	
S	0.1%	Amino acids	
Fe	100 mg/kg	Chlorophyll synthesis	**Micronutrients**
Cu	6 mg/kg	Component of enzymes	
Mn	20 mg/kg	Activates enzymes	
Zn	20 mg/kg	Activates enzymes	
B	20 mg/kg	Cell wall component	
Mo	0.1 mg/kg	Involve in N fixation	
Cl	100 mg/kg	Photosynthesis reactions	

(ii) According to mobility:

(a) In soil:

1. Mobile: NO_3^-, SO_4^{2-}, BO_3^{3-}, Cl^- and Mn^{2-}

2. Less mobile: NH_4^{2-}, K^+, Ca^{2+}, Mg^{2+} and Cu^{2+}

3. Immobile: $H_2PO_4^-$, HPO_4^{2-} and Zn^{2+}

(b) In plant:

1. Highly mobile: N, P and K

2. Moderately mobile: Zn

3. Less mobile: S, Fe, Mn, Cu, Mo and Cl

4. Immobile: Ca and B

(iii) According to metal and non metal

1. Metal: K, Ca, Mg, Fe, Mn, Zn and Cu

2. Non metal: N, P, S, B, Mo and Cl

(iv) According to cation and anion

1. **Cation:** K, Ca, Mg, Fe, Mn, Zn and Cu

2. **Anion:** NO_3, H_3PO_4 and SO_4

6.3 Beneficial elements: Apart from vanadium, silicon, aluminum, iodine, selenium and gallium, which have been shown to be essential for particular species of plants, there are several other elements, like rubidium, strontium, nickel, chromium and arsenic, which at very low concentrations and often under specific conditions have been shown to stimulate the growth of certain plants or to have other beneficial effects. These elements, the essentiality of which for growth and metabolism has not been unequivocally established but which are shown to exert beneficial effects at very low concentrations are often referred to as 'beneficial elements',

6.4 Forms of nutrients in soil

In soil, Nutrient present in different forms are as under

Sr. No.	Nutrient	Forms
1.	Nitrogen	Organic N (97%) and Mineral N NH_4^+, NO_3^-
2.	Phosphorus	Solution P, Calcium, Iron, Aluminium and Occluded P, Organic P (25%-90%) and Mineral P
3.	Potassium	Water soluble K, Exchangeable K, Fixed K and Mineral K (90-98%),
4.	Sulphur	Sulphate S, Non sulphate S, Adsorbed S, Organic S(95%) and Total S,
5.	Micronutrients	Water soluble ion, Exchangeable, Adsorbed, chelated or complexed ion, Cation held in secondary clay mineral and insoluble metal oxides and cation held in primary mineral

6.5 Mechanisms of nutrient transport to plants

Two important theories, namely, soil solution theory and contact exchange theory explain nutrient availability to plants.

(i) Soil solution theory:

(a) ***Mass flow:*** Movement of nutrient ions and salts along with moving water.

(b) ***Diffusion:*** Occurs when there is concentration gradient of nutrients between root surface and surrounding soil solution. Ions move from the region of high concentration to the region of low concentration.

(ii) Contact exchange theory: The important of contact exchange in nutrient transport is less than with soil solution movement. A close contact between root surface and soil colloids allows a direct exchange of ions.

6.6 Factors Influencing Nutrient Availability

Several factors influence nutrient availability:

(1) Natural supply of nutrients in the soil which is closely tied up to parent material of that soil and vegetation under which it is developed.

(2) Soil pH as it affects nutrient release,

(3) Relative activity of microorganisms which play a vital role in nutrient release and may as in the case of mycorrhizae directly function in nutrient uptake

(4) Fertility addition in the form of commercial fertilizer, animal manure and green manure, and Soil temperature, moisture and aeration.

6.7 Nutrient deficiency

Generalized symptoms of plant nutrient deficiency

Nutrients		Visual deficiency symptoms
N	:	Light green to yellow appearance of leaves, especially older leaves, stunted growth, poor fruit development
P	:	Leaves may develop purple colouration, stunted plant growth and delay in plant development
K	:	Marginal burning of leaves, irregular fruit development
Ca	:	Reduced growth or death of growing tips, poor fruit development and appearance
Mg	:	Initial yellowing of older leaves between leaf veins spreading to younger leaves, poor fruit development and production
S	:	Initial yellowing of young leaves spreading to whole plant, similar symptoms to N deficiency but occurs on new growth
Fe	:	Initial distinct yellow or white areas between veins of young leaves leading to spots of dead leaf tissue
Mn	:	Interveinal yellowing or mottling of young leaves
Zn	:	Interveinal yellowing on young leaves, reduce leaf size, brown leaf spot on paddy
Cu	:	Stunted growth, terminal leaf buds die, leaf tips become white and leaves are narrowed and twisted.
B	:	Terminal buds die, breakdown of internal tissues in root crops, internal cork of apple, impairment of flowering and fruit development
Mo	:	Resemble N deficiency symptoms, whiptail diseases of qualiflower, leaves show scorching and whithering
Cl	:	Chlorotic leaves, some leaf necrosis

Nutrient deficiency may not be apparent as striking symptoms such as chlorosis on the plant, especially when mild deficiency is occurring. However, significant reduction in crop yields can occur with such deficiencies. This situation is termed **hidden hunger** and can only be detected with plant tissue analysis or yield decline

6.8 Management:

1. Addition of nutrient through fertilizer in soil as well as foliar application
2. Addition of organic manure
3. Correction of soil problems *i.e.* salinity, sodicity, acidity *etc.*

6.9 Nutrient toxicity and management

Nutrient toxicities in crops are more frequent for manganese (Mn) and boron (B) than for other nutrients. Manganese toxicity is found on acid soils in many parts of the world. 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, that bind the some of the toxic elements.

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

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CHAPTER VII: CHEMISTRY OF SOIL NITROGEN, PHOSPHORUS, POTASSIUM, CALCIUM, MAGNESIUM, SULPHUR AND MICRONUTRIENTS

The changes undergone by common fertilizers after these are taken out of the bag and added to soils are discussed. By understanding the fate of fertilizers, measures for increasing their efficiency can be suggested and adopted. When fertilizers react with soils, the compounds produced are by and large similar to the ones which are present in soils and which are produced by the breakdown of minerals and organic matter. That is why soils accept fertilizers without any fuss.

7.1 Nitrogen:

Nitrogen occurs in soil in both cationic (NH_4^+) and anionic (NO_3^-, NO_2^-) forms, the greater parts occurs in organic forms. NH_4^+ fixed on the cation exchange sites, are tightly bound by clay and is slowly available to plants. The available nitrates and ammonium form is only 1-2% of the total soil nitrogen. Nitrate is highly mobile. Nitrogen availability depends upon the rate at which organic nitrogen is converted to inorganic nitrogen (mineralization). Most soil nitrogen is unavailable to plants. The amount in available forms is small and crops withdraw a large amount of nitrogen. Two forms of nitrogen available to plants are nitrate (NO_3^-) and ammonium (NH_4^+).

Nitrogen transformation in Soils

The cycling of N in the soil-plant-atmosphere system involves many transformations of N between inorganic and organic forms. Nitrogen is subjected to amino compounds ($R\text{-}NH_2$, R represents the part of the organic molecules with which amino group (NH_2) is associated), then to ammonium (NH_4^+) ion and nitrate (NO_3^-). Ammonium nitrogen is often converted to nitrate-nitrogen by micro-organisms before absorption through a process called **nitrification**.

Nitrogen Mineralization

The conversion of organic N to NH_4^+ and NO_3^- is known as **nitrogen mineralization**. Mineralization of organic N involves two reactions, aminisation and ammonification, which occur through the activity of heterotrophic micro-organisms. The enzymatic process may be indicated as follows:

$$RNH_2 \underset{-H_2O}{\overset{+H_2O}{\rightleftharpoons}} ROH + NH_4 \underset{-O_2}{\overset{+O_2}{\rightleftharpoons}} NO_2^- + 4H \underset{O}{\overset{+O}{\rightleftharpoons}} NO_3^-$$

Mineralization (forward) / Immobilization (reverse)

Aminisation:

The decomposition of protein into amines, amino acids and urea is known as **aminisation**.

$$\text{Proteins} \xrightarrow[\text{Bacteria, Fungi}]{H_2O} \underset{\text{Amino acids}}{R-\overset{\overset{NH_2}{|}}{\underset{\underset{H}{|}}{C}}-COOH} + \underset{\text{Amines}}{R-NH_2} + \underset{\text{Urea}}{H_2N-\overset{\overset{O}{||}}{C}-NH_2} + \overset{\overset{O}{||}}{CO_2} + \text{Energy}$$

Ammonification

The step, in which, the amines and amino acids produced by aminisation of organic N are decomposed by other heterotrophs, with the release of NH_4^+, is termed as **ammonification**.

$$R-NH_2 + H_2O \rightarrow NH_3^+ \quad R-OH + \text{Energy}$$

$$NH_3^+ \xrightarrow{H_2O} NH_4^+ + OH^-$$

Nitrogen immobilization

Immobilisation is the process in which available forms of inorganic nitrogen (NO_3^- NH_4^+) are converted to unavailable organic nitrogen. Immobilisation includes assimilation and protein production so those inorganic ions are made into building block of large organic molecules.

Nitrification

Nitrification is a process in which NH_4^+ released during mineralization of organic N is converted to NO_3^-. it is a two step process in which NH_4^+ is converted first to NO_2^- and then to NO_3^-. Biological oxidation of $NH_4^+$to NO_2^- is represented by:

$$2NH_4+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 2H_2O + 4H+$$

NO_2^- is further oxidized to NO_3- be bacteria

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobactor}} 2\ NO_3^-$$

7.2 Phosphorus

Organic and inorganic forms of phosphorus occur in soils and both the forms are important to plants as source of phosphorus. The relative amounts of phosphorus in organic and inorganic forms vary greatly from soil to soil.

Organic phosphorus compounds

Organic phosphorus represents about 50% of the total P in soils (Varies between 15 and 80% in most soil. Most organic P compounds are esters of orthophosphoric acid and have been identifies primarily as (a) inositol phosphates, (b) phospholipids and (c) nucleic acids.

Inorganic phosphorus compounds

Most inorganic phosphorus compounds in soil fall into one of the two group: (a) those in which calcium is the dominant controlling cation (calcium phosphate) and (b) those in which iron and aluminum are the controlling cations (iron and aluminum phosphates).

Phosphate Retention and Fixation

Phosphate anions can be attracted to soil constituents with such a bond that they become insoluble and not easily available to plants. This process is called phosphate fixation or retention.

Phosphate retention

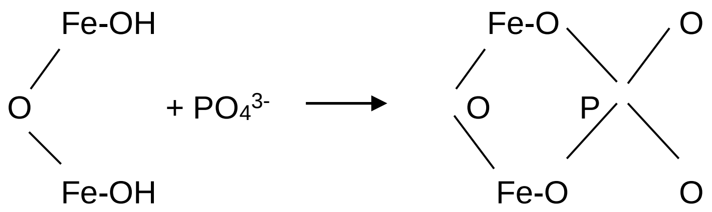
Acid soils usually contain significant amounts of soluble and exchangeable Al_3^+, Fe_3^+ and Mn_2^+ ions. Phosphate, when present, may be adsorbed to the colloid surface with these ions serving as a bridge. This phenomenon is called co-adsorption. The phosphate retained in this way is still available to plants. Such a reaction can also take place with Ca-saturated clays.

Ca clay adsorbs large amounts of phosphate. The $Ca2^+$ ions forms the linkage between he clay and phosphate ions as : Clay-Ca-H_2PO_4.

The phosphate ions can also enter into a chemical reaction with the foregoing free metal ions as: $Al3^+ + 3H_2PO_4^- \rightarrow \downarrow Al(H_2PO_4)_3$. The product formed is not soluble in water and precipitates from solution. With the passage of time the Al phosphate precipitates, become less soluble and less available to plants. The lower the soil pH, the greater the concentration of soluble Fe, Al, and Mn: consequently, larger the amount of phosphorus retention in this way.

Phosphate fixation in acidic soils:

Many acidic soils contain high amounts of free Fe and Al and Fe and Al hydrous oxide clays. The free Fe, Al and the sesquioxide clays react rapidly with phosphate, forming a series of not easily soluble hydroxyl phosphates.



The amount of phosphate fixed by this reaction usually exceeds that fixed by phosphate retention. Generally, clays with low sesquioxide ratios (SiO_2/R_2O_3) have a higher P-fixing capacity.

Phosphate fixation in alkaline soils:

Many alkaline soils contain high amounts of soluble and exchangeable Ca2+ and, frequently, CaCO3. Phosphate react with both the ionic and carbonate form of Ca.

$$3Ca^{2+} + 2PO_4^{3-} \longrightarrow Ca_3(PO_4)_2 \quad \text{(Insoluble)}$$

$$3CaCO_3 + 2PO_4^{3-} \longrightarrow Ca_3(PO_4)_2 + 3CO_2 \quad \text{(Insoluble)}$$

Phosphate fixation cannot be avoided entirely, but it may be reduced by addition of competing ions for fixing sites. Organic anions from stable manure and silicates are reported to be very useful in reducing P fixation.

7.3 Potassium

Forms and availability of potassium in soils

Potassium in soil occurs in four phases namely soil solution phase, exchangeable phase, non-exchangeable phase and mineral phase. The different forms are in dynamic equilibrium with one another.

The forms of potassium in soils were positively and significantly correlated with K content in silt and clay.(Venkatesh and Satyanarayan, 1994).

Water soluble K:

The water soluble K is the fraction of soil potassium that can be readily adsorbed by the growing plants. However this is a very small fraction of total K. The dilution of the soil incrases the concentration of water-soluble K and drying decreases it further. It is about 1 to 10 mg kg^{-1} of total K.

Exchangeable K:

Exchangeable K is held around negatively charged soil colloids by electrostatic attraction. Thus, exchangeable potassium represents that fraction of K, which is adsorbed on external and accessible internal surfaces. It is about 40 to 60 mg kg^{-1} of total K.

Non-exchangeable (fixed) K:

Potassium held at inter lattice position is generally non-exchangeable. Non-exchangeable K is distinct from mineral K in that it is not bonded covalently within the crystal structures of soils mineral particles. Instead, it is held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculites and intergrade clay minerals. It is about 50 to 750 mg kg-1 of total K.

Mineral (lattice) K:

Lattice K is a part of the mineral structure and is available to the plants very slowly. (As compared to the non-exchangeable K). Both the rate and amount of lattice K released to plants depend on the quantity of clay, especially the smaller clay particles, and its mineralogy. It is about 5,000 to 25,000mg kg^{-1}.

For convenience, the various forms of potassium in soils can be classified on the basis of availability in three general groups: (a) unavailable (b) readily available and (c) slowly available.

A dynamic equilibrium of various forms of K in the soil may be shown as :

K(lattice) ↔ K(exchangeable) ↔ K (solution)

Relatively Unavailable Forms

The greatest part (90-98%) of all soil potassium in a mineral soil is in relatively unavailable forms. The compounds containing most of this form of potassium are the feldspars and micas. These minerals are quite resistant to weathering and probably supply relatively insignificant quantities of potassium during a given growing season.

Readily Available Forms

The readily available potassium constitutes only about 1-2% of the total amount of this element in an average mineral soil. It exists in soils in two forms; (i) potassium in soil solution and (ii) exchangeable potassium adsorbed on soil colloidal surfaces. Most of this available potassium is in the exchangeable form (approximately 90%). Soil solution potassium is most readily adsorbed by higher plant and is, of course, subject to considerable leaching loss.

Slowly Available Forms

In the presence of vermiculite, smectite, and other 2:1- type minerals the potassium of such fertilizers as muriate of potash not only becomes adsorbed but may become definitely 'fixed' by the soil colloids. The potassium as well as ammonium ions fit in between layers in the crystals of these normally expanding clays and become an integral part of the crystal. Potassium in this form cannot be replaced by ordinary exchange methods and consequently is referred to as non-exchangeable potassium. As such this element is not readily available to higher plants. This form is in equilibrium, however, with the available forms and consequently acts as an extremely important reservoir of slowly available potassium.

7.4 Sulphur Transformation in Soil

Sergei Nikolaievich Winogradsky (1856 – 1953) was microbiologist, ecologist and soil scientist who pioneer for his notable work on bacterial sulfate reduction. The transformation of sulphur are important indicators of its availability to plants. Availability of sulphur from organic sulphur reserves in soils depends on its mineralization through microbial activity.

Sulphur Oxidation:

Sulphur oxidation ocuuring in soils is mostly biochemical in nature. Sulphur oxidation is accomplished by number of autotrophic bacteria including those of genus *Thiobacillus*, five species of which have been characterized:

(a) *Thiobacillus thioxidans* (b) *T. thiparus* (c) *T. nonellus* (d) *T. denitrificans* (e) *T. ferooxidans*

In soils, sulfides, elemental sulphur, thiosulphates and polythionates are oxidized.

Oxidation reactions:

$$H_2S + 2O_2 \rightarrow H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$$

$$2S + 3O_2 + 2H_2O \rightarrow 2H_2SO_4 \quad 4H^+ + 2SO_4^{2-}$$

Thus S-oxidation is an acidifying process.

Sulphur reduction:

Sulphate tend to be unstable in anaerobic environments so they are reduced sulfides by a number of bacteria of two genera, *Desulfovibro* (five species) and *Desulfotomaculum* (three species).

The organisms use the combined oxygen in sulfate to oxidize organic materials.

Reduction reactions:

$$2R\text{-}CH_2OH + SO_4^{2-} \rightarrow 2R\text{-}COOH + 2H_2O + S^{2-}$$

(Organic alcohol) (Sulfate) (Organic acid) (Sulfide)

Also, sulfites (SO_3^{2-}), thiosulfates ($S_2O_3^{2-}$) and elemental sulphur (S) are rather easily reduced to the sulfides form by bacteria and other organisms.

The oxidation and reduction of inorganic sulphur compounds are of great importance to growing plants. These reactions determine the quantity of sulfate present in soils at any one time. Also, the state of sulphur oxidation determines to a marked degree the soil acidity as S-oxidation is an acidifying process.

7.5 Calcium and Magnesium Transformations in Soil

Calcium is an important amendment element in saline and alkali soils. Calcium application helps in correcting the toxicity and deficiency of several other nutrients. The main transformations of Ca and Mg in soils are (i) solubilization and leaching and (ii) conversion into less soluble fractions by adsorption.

Solubilization and leaching of calcium and magnesium: It is affected by following:

Soil texture: Losses are more in light textured soils because of high permeability and percolation of rain and irrigation water.

Rainfall: As the rainfall increases the loss of Mg and Ca also increases.

Organic matter: Application of organic matter leads to net loss of Ca and Mg from the soil.

Ferrolysis: High amounts of bases such as Ca2+ and Mg2+ may be lost from the exchange complex and laeached by high amounts of cations such as Fe2+ and Mn2+ which are released following reduction of soil. This is called **ferrolysis**.

Conversion of calcium and magnesium into less soluble form by adsorption: Clacium and magnesium in soil solution and in exchange complex are in a state of dynamic equilibrium. When their concentration in solution decreases, Ca and Mg coming from the exchange complex replenish this. On the other hand if their concentration in soil solution is high, there is tendency towards their being adsorbed on the exchange complex.

7.6 Fe and Zn Transformations in Soil:

Iron

The most important chemical change that takes place when a soil is submerged is the reduction of iron and the accompanying increase in its solubility. The intensity of reduction depends upon time of submergence, amount of organic matter, active iron, active manganese, nitrate etc.

Due to reduction of Fe^{3+} to Fe^{2+} on submergence, the colour of soil changes from brown to grey and large amounts of Fe^{2-} enter into the soil solution. It is evident that the concentration of ferrous iron (Fe^{2+}) increases initially to some peak value the thereafter decreases slowly with the period of soil submergence. Organic matter also enhances the rate of reduction of iron in submerged soils. The initial increase in the concentration of ferrous iron (Fe2+) on soil submergence is caused by the reduction that are shown below:

$$\underset{\text{(Insoluble)}}{Fe(OH)_3} + e^- \xrightleftharpoons{\text{Reduction}} \underset{\text{(Soluble)}}{Fe^{2+}} + 3OH^-$$

The decrease in the concentration of Fe^{2+} following the peak rise is caused by the precipitation of Fe^{2+} as $FeC0_3$ in the early stages where high partial pressure of $C0_2$ prevails and *as* $Fe_3(OH)_8$ due to decrease in the partial pressure of $C0_2$($pC0_2$)

$$\underset{\text{(Soluble)}}{2Fe^{2+}} + 3CO_2 \longrightarrow \underset{\text{(Insoluble)}}{2FeCO_3}$$

Rice benefits from the increase in availability of iron but may suffer in acid soils, from an excess. The reduction of iron has some important consequences: (i) the concentration of water soluble iron increases, (ii) pH increases, (iii) cations are displaced from exchange sites, *(iv)* the solubility of P and Si increases and *(v)* new minerals are formed.

A schematic representation for the transformation of iron in submerged soils is shown below:

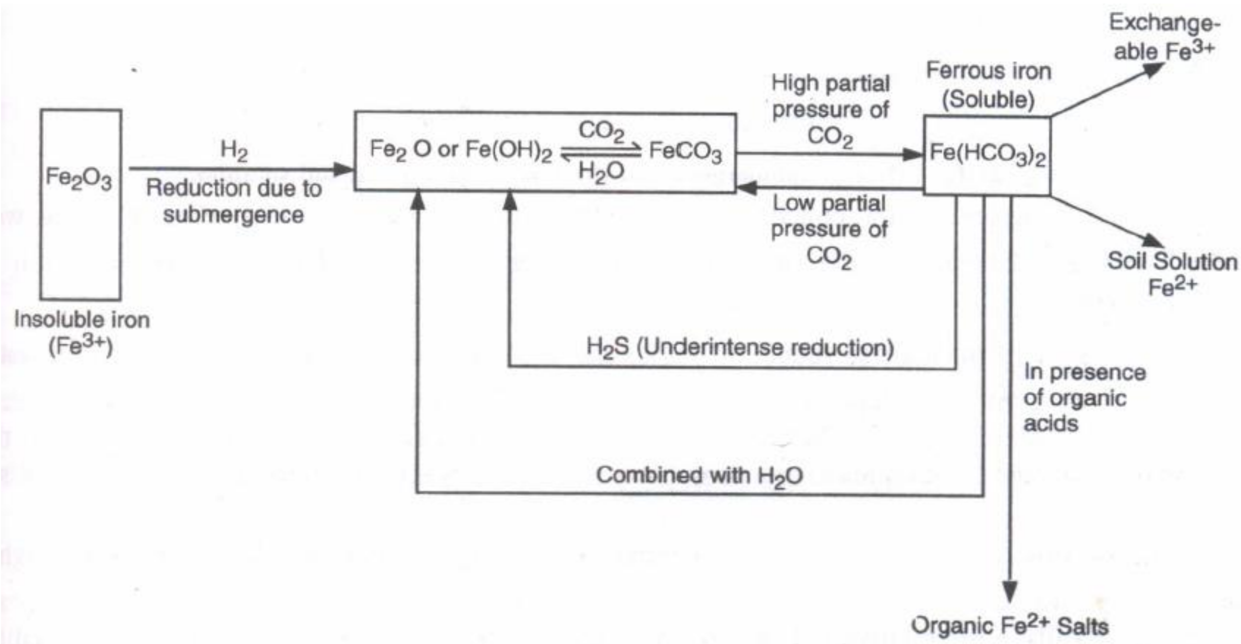


Fig. 21.12. Transformation of iron in submerged soils.

Zinc

The transformation of zinc in submerged soils is not involved in the oxidation-reduction process like that of iron and manganese. However, the reduction of hydrous oxides of iron and manganese, changes in soil pH, partial pressure of C02, formation insoluble sulphide compound etc. In soil on submergence is likely to influence the solubility of Zn in soil either favourably or adversely and consequently the Zn nutrition of low and rice. The reduction of hydrous oxides of iron and manganese, formation of organic complexing agents, and the decrease in pH of alkaline and calcareous soils on submergence are found to favour the solubility of Zn, whereas the formation of hydroxides, carbonates, sulphides may lower the solubility ofZn in submerged soils. Zinc deficiency in submerged rice soils is very common owing to the combined effect of increased pH, $HC0_3^-$ and S^{2-} formation.

The solubility of native forms of Zn in soils is highly pH dependent and decreases by a factor of 10^2 for each unit increase in soil pH. The activity of Zn-pH relationship has been defined as follow:

$$Soil + Zn^{2+} \rightleftharpoons Soil - Zn + 2H^+$$

The pK value for the above reaction with the solid phase of soils is 6.0. This equation holds good for submerged soils. Some equations relating to solubility of Zn in submerged soils governed by various metastable compounds are given below :

$$3Zn^{2+} + 2PO_4^{3-} \rightleftharpoons Zn_3(PO_4)_2 \qquad pK_2 = 32.0$$

$$Zn^{2+} + NH_4^+ + PO_4^{3-} \rightleftharpoons ZnNH_4PO_4 \qquad pK_s = 16.0$$

$$Si(OH)_4 + Zn^{2+} \rightleftharpoons Zn(OH)_2 + SiO_2 + 2H^+ \qquad pK_2 \geq 17.5$$

$$Zn^{2+} + S^{2-} \rightleftharpoons Zn\,S \qquad pK_2 = 22.8$$

$$Zn^{2+} + 2OH^- \rightleftharpoons Zn(OH)_2 \qquad pK_s = 17.5$$

$$Zn^{2+} + CO_3^{2-} \rightleftharpoons ZnCO_3 \qquad pK_s = 16.5$$

Many of these compounds are metastable intermediate reaction products and varying mean residence time in submerged soils. Applied Zn tends to approach the solubility of the native forms instead of having residual effect in the former Zn forms.

When an aerobic soil is submerged, the availability of native as well as applied Zn decreases and the magnitude of such decrease vary with the soil properties. The transformation of Zn in soils was found to be greatly influenced by the depth of submerged and application of organic matter. If an acid soil is submerged, the pH of the soil will increase and thereby the availability of Zn will decrease. On the other hand, if an alkali soil is submerged, the pH of the soil will decrease and as a result the solubility of Zn will generally increase.

The availability of Zn decreases due to submergence may be attributed to the following reasons:

(i) formation of insoluble franklinite ($ZnFe20_4$) compound in submerged soils.

$$Zn^{2+} + 2Fe^{2+} + 4H_2O \underset{\text{reduction}}{\rightleftharpoons} ZnFe_2O_4 \text{ (Franklinite)}$$

(ii) Formation of very insoluble compounds of Zn as ZnS under intense reducing conditions.

$$Zn^{2+} + S^{2-} \rightleftharpoons \underset{\text{(Very insoluble in water}}{ZnS \text{ (Sphalerite)}}$$

(iii) Formation of insoluble compounds of Zn as $ZnC0_3$ at the later period of soil submergence owing to high partial pressure of $C0_2(PC0_2)$ arising from the decomposition of organic matter.

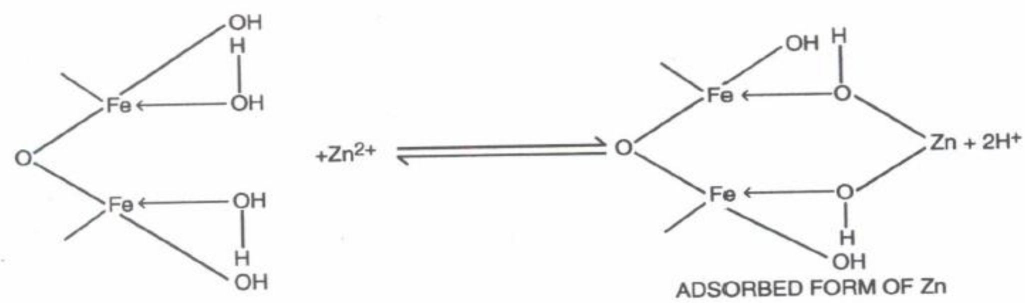
$$Zn^{2+} + CO_2 \rightleftharpoons \underset{\text{(Insoluble)}}{ZnCO_3} \text{ (Smithsonite)}$$

(iv) Formation of Zn(OH)2 at a relatively higher pH which decreases the availability of Zn.

$$Zn^{2+} + 2HO^{-} \rightleftharpoons \underset{\text{(Insoluble)}}{Zn(OH)_2}$$

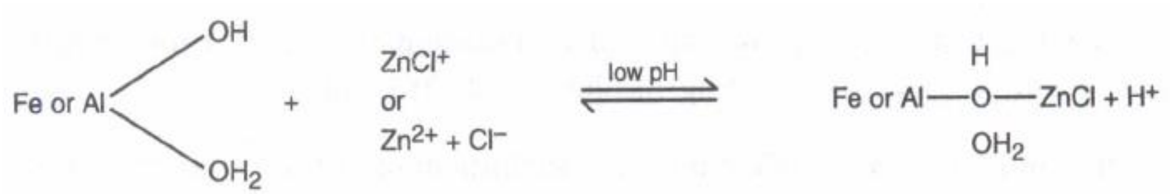
(v) Adsorption of soluble Zn^{2+} by oxide minerals *e.g.* sesquioxides, carbonates, soil organic matter and clay minerals etc. decreases the availability of Zn, the possible mechanism of Zn adsorption by oxide minerals is shown below :

Mechanism I:



In mechanism I, Zn^{2+} adsorption occurs as bridging between two neutral sites, but in addition to this mechanism, Zn^{2+} could also be adsorbed to two positive sites or to a positive and neutral site.

Mechanism II:



This mechanism occurs at low pH and results non-specific adsorption of Zn^{2+}. In this way Zn^{2+} is retained and rendered unavailable to plants.

(vi) Formation of various other insoluble zinc compounds which decreases the availability of Zn in submerged soils, *e.g.* high phosphatic fertilizer induces the decreased availability of Zn^{2+}.

$$Zn^{2+} + PO_4^{3-} \longrightarrow \underset{\text{(Insoluble)}}{Zn_3(PO_4)_2}$$

A simplified diagram illustrating dynamic equilibria of Zn in submerged soils is shown in figure.

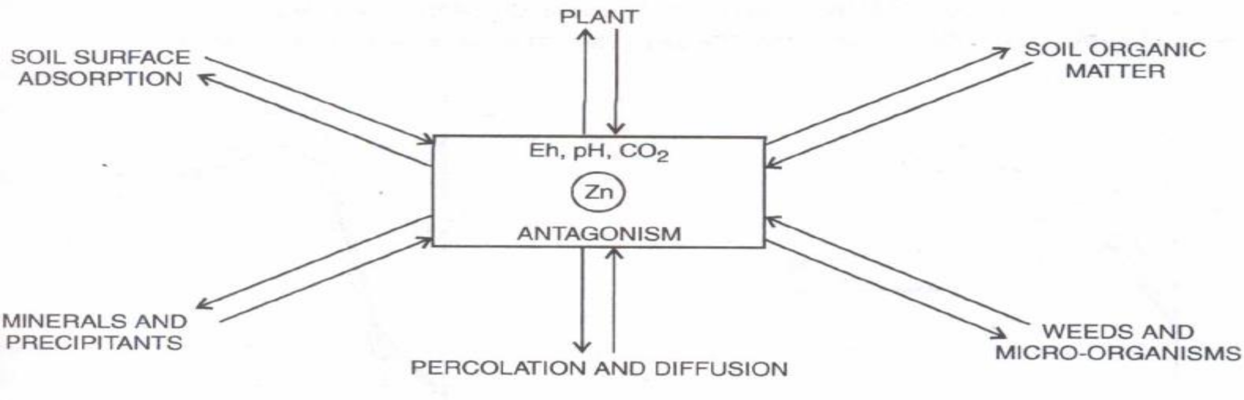


Fig. 21.14. Dynamic equilibria of Zn in submerged soils.

It shows that rice receives Zn from the soil solution and the exchangeable and adsorbed solid phase including the soil organic fractions.

Zinc sulphide (ZnS, Sphalerite) in the presence of traces of hydrogen sulphide (H_2S) in submerged soils may control the solubility of Zn. Zinc is stable in submerged soils. So it can be concluded that higher the pH and poorer the aeration, the greater is the likelihood of Zn deficiency if the soil solution Zn activity is controlled by sphalerite (ZnS).

Q/I relationship

In addition to these, the availability of Zn in submerged soils is governed by the mutual interaction of quantity *(q)* intensity *(c),* and kinetic parameters as regulated by the adsorption, desorption, chelation and diffusion of Zn from soils to the plant roots. The quantity-intensity relationship of Zn in submerged soils may be described by the linear form of the Langmuir type equation. The supply parameter assumes the form,

$$\text{Supply parameter} = qc^{1/2} . K_1K_2^{-1/4} \text{ or } \sqrt{cq/\sqrt{K_1K_2}}$$

where *q* is the quantity c is the intensity, K_1 and K_2 are constants.

The optimum Zn supply to rice is ensured when the value of the supply parameter is unity (1.0).

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CHAPTER- VIII: SOIL FERTILITY EVALUATION AND SOIL TESTING

The proper rate of plant nutrient is determined by knowing the nutrient requirement of the crop and the nutrient supplying power of soil. Hence, the evaluation of soil fertility becomes important. Soil fertility evaluation is essential for balanced nutrition of the crops. Balance nutrients use refers to the application of essential plant nutrients in right amounts and proportions using correct methods and time of application suited for specific soil-crop-climatic situations. It helps in maintenance and improving soil productivity. Thus soil fertility evaluation is the key for adequate and balanced fertilization in crop production. Several techniques are commonly employed to asses the fertility status of the soils. The diagnostic techniques are

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

8.1 Soil testing:

Soil testing is the chemical analysis that provides a guideline for amendments and fertilizer needs of soils. The primary advantage of soil testing when it is compared to the plant analysis is its ability to determine the nutrients status of the soil before the crop is planted

The soil testing is done with following objectives:

1. Soil fertility evaluation for making fertilizer recommendation
2. Prediction of likely crop response to applied nutrient
3. Classification of soil into different fertility groups for preparing soil fertility maps of a given area
4. Assessment of the type and degree of soil related problems like salinity, sodicity, acidity etc., and suggesting appropriate reclamation / amelioration measure. The following steps are involved in soil analysis

1. Sampling
2. preparation of samples
3. Analytical procedure
4. Calibration and interpretation of the results

5. Fertilizer recommendation

1. Sampling: Soil sampling is perhaps the most vital step for any analysis. Since, a very small fraction of the huge soil mass of a field is used for analysis; it becomes extremely important to get a truly representative soil sample from it.

2. Preparation of sample: Drying, grinding and sieving according to the need of analytical procedure

3. Analytical procedure: A suitable method is one which satisfies the following three criteria.

i. It should be fairly rapid so that the test results can be obtained in a reasonably short period.

ii. It should give accurate and reproducible results of a given samples with least interferences during estimation.

iii. It should have high predictability *i.e.,* a significant relationship of test values with the crop performance.

Following chemical methods are widely used for determination of different nutrients

Nutrients	Methods	Merits and demerits
Total N	Kjeldahl method	• This method is time consuming, lengthy and costly • Rate of mineralization of N varies with the soil
Organic C	Walkley and Black method	• This method is simple and rapid • Based on C:N ratio which is varied (7.7 to 11.7)
Available N	Alkaline-$KMnO_4$	• Extract part of organic and mineral N
Available P_2O_5	Olsen's method for alkaline soils	• High efficiency of HCO_3 ion to remove P from Ca, Al and Fe • Reduce the activity of Ca • Used in slightly acidic, neutral and alkaline soil
	Bray's method for acid soils	• High efficiency of F ion in dissolving P • Useful in acidic or slightly calcareous soils
Available K_2O	NH_4OAc	• Higher efficiency of extraction as compared

	extratable	to salt solution • Inefficiency to remove part of non exchangeable K, which isconsidered to be available to some extent
Available S	0.15% $CaCl_2$ extractable	• Extract water soluble S and adsorbed S
	Heat soluble S	• Heat soluble- extract WS + organic S • Time consuming and lengthy procedure
Available Micronutrients	DTPA extractable	• Extract complexed, chelated and adsorbed form of Fe, Mn, Zn, Cu

4. Calibration and interpretation of the results: For the calibration of the soil test data, a group of soils ranging in soil fertility from low to high in respect of the particular nutrient are selected and the test crop is grown on these soils with varying doses of particular nutrient with basal dose of other nutrients.

The most common method is to plot soil test values against the percentage yield and to calculate the relationship between soil test values and per cent yield response

$$\text{Percent yield} = \frac{\text{Crop yield with adequate nutrient} - \text{Yield of control without addition of particular nutrient under study}}{\text{Crop yield with adequate nutrient}} \times 100$$

► **Critical level of nutrients in soil:**

SN	Nutrients	**Category**		
		Low	**Medium**	**High**
1.	Alkaline $KMnO_4$-N (kg/ha)	<250	250-500	>500
2.	Olsens-P_2O_5 (kg/ha),	<28	28-56	>56
3.	Neutral N NH_4OAc-K_2O	<140	140-280	>280
4.	0.15% $CaCl_2$ –S (mg/kg)	<10	10-20	>20
5.	DTPA extractable Fe (mg/kg)	<5	5-10	>10
6.	DTPA extractable Mn (mg/kg)	<5	5-10	>10
7.	DTPA extractable Zn (mg/kg)	<0.5	0.5-1.0	>1.0
8.	DTPA extractable Cu (mg/kg)	<0.2	0.2-0.4	>0.4
9.	Hot water soluble B (mg/kg)	<0.1	0.1-0.5	>0.5
10.	Hot water soluble Mo (mg/kg)			

This classification indicated that low class of soil would respond to added fertilizer means add 25% more fertilizer than recommended dose. Medium class soil may or may not respond to added fertilizer, add recommended dose of fertilizer. High status soils do not respond to added fertilizer, add 25% less recommended dose.

8.2 Plant Testing:

1. Analysis of tissues from plant growing on the soil

Plant analysis in a narrow sense is the determination of the concentration of an element or extractable fraction of an element in a sample taken from a particular part or portion of a crop at a certain time or stage of morphological development

Plant analysis is complementary to soil testing. In many situations, the total or even the available content of an element in soil fails to correlate with the plant tissue concentration or the growth and yield of crop. This can be ascribed to many reasons including the physico chemical properties of the soils and the root growth patterns. On the other hand, the concentration of an element in the plant tissue is, generally, positively correlated with the plant health. Therefore, the plant analysis has been used as a diagnostic tool to determine the nutritional cause of plant disorders/diseases. The plant analysis constitutes (1) the collection of the representative plant parts at the specific growth stage, (2) washing, drying and grinding of plant tissue, (3) oxidation of the powdered plant samples to solubilize the elements, (4) estimation of different elements, and (5) interpretation of the status of nutrients with respect to deficiency / sufficiency /toxicity on the basis of known critical concentrations.

► Plant analysis has many applications such as:

1. Diagnosis of nutrient deficiencies, toxicities or imbalances
2. Measurement of the quantity of nutrients removed by a crops to replace them in order to maintain soil fertility
3. Estimating overall nutritional status of the region or soil types
4. Monitoring the effectiveness of the fertilizer practices adopted
5. Estimation of nutrient levels in the diets available to the live stock

2. *Collection and Preparation of plant samples*

Plant scientists have been able to standardize the procedures for collection of samples of plant tissue with respect to the plant part and growth stage, which reflect the nutrient concentrations corresponding to the health of the growth because the concentrations of different nutrients vary significantly over the life cycle of a plant.

Generally, the recently matured fully expanded leaves just before the onset of the reproductive stage are collected and put in perforated paper bags. The plant samples are often contaminated with dust, dirt and residues of the sprays, *etc.* and need to be washed first under a running tap water followed by rinsing with dilute HCl (0.001N), distilled water and finally in deionized water. The washed samples are dried in a hot air oven at 60 ± 5°C for a period of 48 hours and ground in a stainless steel mill to pass through a sieve of 40/60 mesh.

3. Oxidation of plant material

The main objective of oxidation is to destroy the organic components in the plant material to release the elements from their combinations. The plant materials can be oxidized by either dry ashing at a controlled high temperature in a muffle furnace or wet digestion in an acid or a mixture of two or more acids.

(a) Dry-ashing : The powdered plant materials in tall form silica crucibles are ashed at 500ºC in a muffles furnace for 3-4 hours. High temperatures are likely to result in the loss of some volatile elements but with adjusting the time of muffling between 2-72 hours, any significant effect on the analytical results can be avoided. Nitrogen and sulphur, being highly volatile, are lost more or less completely during dry ashing even at 500ºC but at higher temperatures, elements like K are also reported to be lost. Thus, temperature is an important consideration in dry ashing. The ash is dissolved in 2ml of 6N HCl, heated on a hot plate to near dryness and taken in 10 ml dilute HCl (0.01N) or 20% aqua regia before making up the final volume with distilled water. These extracts contain different amounts of insoluble materials, mainly silica, depending upon the plant species. These insoluble materials settle down on keeping for some time or can be separated by filtration before estimation of different elements. All elements, except N and S, can be estimated in these extracts by any technique. In general, the results obtained by this method, are quite satisfactory and comparable to those obtained by this method, are quite satisfactory and comparable to those obtained by wet digestion procedures. Moreover, B can only be determined by dry ashing since it is volatilized during wet digestion with di-or triacid mixtures.

(b) Wet Digestion :

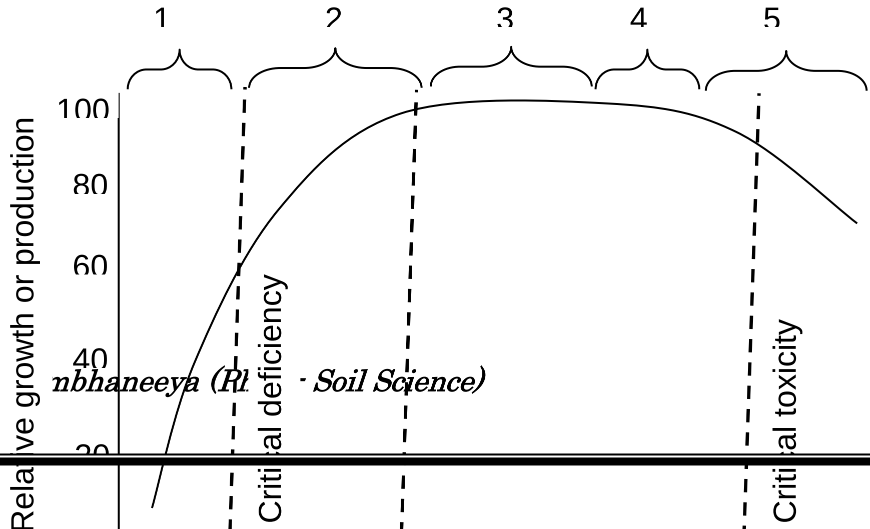
The powdered plant samples can also be dissolved by digesting in acids, usually HNO_3, $HClO_4$ and H_2SO_4. These acids are used either singly or in combinations of two or three acids, e.g. a di-acid combination is HNO_3 and $HClO_4$ (in 4:1 ration) or a triple acid is a mixture of HNO_3, $HClO_4$ and H_2SO_4 (in 10:4:1 ration).

A triple acid combination destroys the organic matter in a shorter time without any hazard. But the method is unsatisfactory for plant materials with high Ca and in cases where S is one of the test elements. The insoluble sulphate renders the method unsuitable because of adsorption of different element ions on the precipitate and exclusion of Ca from the analysis. The use of perchloric acid in the di- or triple acid digestion mixtures results in the formation of sparingly soluble potassium perchlorate, resulting in lower estimates of K, especially when the plant material contains K, more than 1%. As such for multi element analysis, the plant materials should be digested in nitric acid alone.

Wet oxidation digestion reagents and their applicability

Sr. No.	Reagents	Applicability to organic manure	Remarks
1	H_2SO_4/HNO_3	Vegetable origin	Most commonly used
2	H_2SO_4/H_2O_2	Vegetable origin	Not very common
3	HNO_3	Biological origin	Easily purified reagent, short digestion time, temperature 350 ^{0}C
4	$H_2SO_4/HClO_4$	Biological origin	Suitable only for small samples, danger of explosion
5	$HNO_3/HClO_4$	Protein, carbohydrate (no fat)	Less explosive
6	HNO_3/ $HClO_4/H_2SO_4$	Universal (also fat and carbon black	No danger with exact temperature control

4. Interpretation of results: The basis for plant analysis as a diagnostic technique is the relationship between nutrient concentration in the plant and growth and production response. This relation should be significant to have complete interpretation in teem of deficient, adequate and excess nutrient concentration in the plant. Curves representing the relationship between nutrient concentration and growth response vary in shape and character depending on both the nutrient concentration in the growth medium and the plant species.



1. Deficient	2. Marginal	3. Adequate	4. Excess	5. Toxic

When nutrients are in deficiency range, plant growth and yield are significantly reduced and foliar deficiency symptoms appear. In this range, application of nutrient results in sharp increase in growth. In marginal range, growth or yield is reduced, but plant does not show deficiency symptoms. Sometimes the marginal range is also called transition zone. Within the marginal or transition zone lies the critical level or concentration. The critical level can be defined as that concentration at which the growth or yield begins to decline significantly.

Rapid tissue tests:

These tests are rapid and are essentially qualitative. The nutrients are absorbed by roots and transported to those parts of plants where they are needed. The concentration of cell sap is usually good indication of how well the plant is supplied at the time of testing.The plant parts, usually leaves are removed and plant sap is extracted. The plant sap is usually tested for nitrate, phosphorus and potassium. The use of specific reagent for each nutrient to be tested develops the colour. The intensity of colour is a qualitative measure of the content of the nutrient.

DRIS approach

Recently Diagnosis Recommendation Integration System (DRIS) is suggested for fertilizer recommendation. In this approach, plant samples are analyzed for nutrient content and they are expressed as rations 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.*

8.3 Biological tests

The biological methods consist of raising a crop or a microbial culture in a field or in a sample of the soil and estimating its fertility from the volume of crop or microbial count. Although these methods are direct estimates of soil fertility, they are time consuming and therefore, not well adapted to the practice of soil testing.

(i) Field tests: The field plot technique essentially measures the crop response to nutrients. In this, specific treatments are selected, randomly assigned to an area of land, which is representative of the conditions. Several replications are used to obtain more reliable results and to account for variation in soil. Field experiments are essential in establishing the equation used to provide fertilizer recommendation that will optimize crop yield. Maximum profitability, and minimize environment impact of nutrient use

(ii) Pot culture tests: The pot culture test utilize small quantities of soil to quantify the nutrient supplying power of a soil. Selected treatments are applied to the soils and a crop is planted and evaluated. Crop response to the treatments can be than determined by measuring total plant yield and nutrient content

(iii) Laboratory tests

(a) Neubauer seedling Method: the neubaur technique is based on the uptake of nutrient by growing a large number of plants on a small amount of soil. The seedlings (plants) exhaust the available nutrient supply within short time. The total nutrients removed are quantified and tables are established to give the minimum values of nutrients available for satisfactory yield of various crops.

(b) Microbial methods: In the absence of nutrients, certain microorganisms exhibits behaviour similar to that of higher plants. For example, growth of Azotobacter or Aspergillus niger reflacts nutrient deficiency in the soil. The soil is rated from very deficient to not deficient in the respective elements, depending on the amount of colony growth. In comparison with methods that utilize higher plants, microbiological methods are rapid, simple and require little space. These laboratory tests are not in common use in India.

8.4 Nutrient deficiency symptoms of plant

As already mentioned, the plant requires sixteen essential nutrients for their optimum growth and development. When a plant badly needs a certain nutrient element, it shows deficiency symptoms. These symptoms are nutrient specific and show different patterns in crops for different essential nutrients. It is good tool to detect deficiencies of nutrient in the field but these techniques have several limitations and are:

1. The visual symptoms may be caused by more than one nutrient.
2. Deficiency of one nutrient may be related to an excess quantity of another.
3. It is difficult to distinguish among the deficiency symptoms in the field, as disease or insect damage can be resemble certain micronutrient deficiencies.
4. Nutrient deficiency symptoms are observed only after the crop has already suffered an irreversible loss.There are some indicator plants which shoes the nutrient deficiencies or excesses. Some of them are given as follows:

Plant		**Nutrient deficiency/toxicity**
Oat	:	Mg, Mn and Cu deficiencies
Wheat and barley	:	Mg, Cu and some times Mn deficiencies
Sugar beets	:	B and Mn deficiencies
Maize	:	N, P, K, Mg, Fe, Mn and Zn deficiencies
Potatoes	:	K, Mg and Mn deficiencies
Brassica species	:	K and Mg deficiencies
Celery and sunflower	:	B deficiency
Cauliflower	:	B and Mo deficiencies
Barley	:	B, Mn and Al toxicities
Cucumber	:	N and P excess

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CHAPTER- IX: FERTILIZER RECOMMENDATIONS AND APPLICATION

9.1 Blanket Recommendation

Based on the fertilizer experiments conducted in different regions with improved varieties, fertilizer dose is recommended for each environment.

This approach does not consider soil contribution. However, it is suitable for recommendation of nitrogen since residual effect of fertilizer N applied to previous crop is negligible and soils are generally low in nitrogen content.

Problem: Let the recommended fertilizer dose for low land rice be, 120, 60, 40kg N-P_2O_5 and K_2O per hectare, respectively. The amount of fertilizer required in the form of urea, single super phosphate (SSP) and muriate of potash (MOP) is calculated as shown below:

Urea contain 46%N

To supply 46kg N, 100kg urea is necessary

To supply 120kg N/ha, $\frac{100}{46} \times 120$ =260.9 kg or 261 kg urea is required

Similarly,

SSP contain 16% P_2O_5

To supply 60kg P_2O_5/ha, $\frac{100}{16} \times 60$ =375kg SSP is required

MOP contain 58% K_2O

To supply 40kg K_2O/ha, $\frac{100}{58} \times 40$ =68.9 or 69kg MOP is required

Problem: In above example, fertilizer dose of paddy is 120, 60, 40kg N-P_2O_5 and K_2O per hectare, respectively. The recommendation of fertilizer is given below

► Nutrient application

Category	N	P_2O_5	K_2O
Low	150	75	50
Medium	120	60	40
High	90	45	30

Fertilizer application

Category	Urea	SSP	MOP
Low	326	469	86
Medium	261	375	69
High	196	281	52

9.2 Soil Test Crop Response (STCR) Approach

In this approach, soil contribution and yield level are considered for recommending fertilizer dose. This approach is also called as rationalized fertilizer prescription. From the soil test crop response experiments, following parameters are available.

$$\text{Nutrient requirement (kg nutrient/q of grain)} : \frac{\text{Total uptake of nutrient (kg/ha)}}{\text{Grain yield (q/ha)}}$$

$$\text{\% contribution from soil (CS)} : \frac{\text{Total uptake of nutrient in control plot(kg/ha)}}{\text{Soil test value of nutrient In control plot (kg/ha)}} \times 100$$

$$\text{Contribution from fertilizer (CF)} : \text{Total uptake of nutrient inTreated plot} - \text{Soil test value of nutrient In treated plot (kg/ha)} \times \frac{\text{CS}}{100}$$

$$\text{\% Contribution from fertilizer} : \frac{\text{CF (kg/ha)}}{\text{Fertilizer dose}} \times 100$$

$$\text{Fertilizer dose(kg/ha)} : \frac{\text{Nutrient requirement in kg/q of grain} \times 100}{\text{\% Contribution from fertilizer}} \times T - \frac{\text{\% contribution from soil}}{\text{\% contribution from fertilizer}} \times \text{STV (kg/ha)}$$

Fertilizer dose (kg/ha): Constant(kg/ha)x T(q/ha)- Constant x STV(kg/ha)

Based on this, fertilizer recommendations are developed for different regions. One such equation developed to recommend P and K, fertilizers for sugarcane in south Gujarat is given below:

Dose of P_2O_5 (kg/ha) = 2.24T - 3.97 x STV for available P_2O_5

Dose of K_2O (kg/ha) = 2.67T - 0.383 x STV for available K_2O

Nutrient use efficiency (NUE):

"Nutrient use efficiency defined as yield (biomass) per unit input (Fertilizer, nutrient content)". The nutrient most limiting plant growth are N, P,K and S. NUE depends on the ability to efficiently take up the nutrient from the soil, but also on transport, storage, mobilization, usage within the plant and even on the environment. Two major approaches may be taken to understand NUE. Firstly, the response of plants to nutrient deficiency stress can be explored to identify processes affected by such stress and those that may serve to sustain growth at low nutrients input. A second approach makes use of natural or induced genetic variation.

Increasing nutrient efficiency is the key to the management of soil fertility. The proportion of the added fertilizer actually used by plants is a measure of fertilizer efficiency. Soil characteristics, crop characteristics and fertilizer management techniques are the major factors that determine fertilizer efficiency.

9.3 Factors influencing nutrient use efficiency (NUE)

9.3.1 Soil characteristics

(1) Nutrient Status of Soil: The response of any crop or a cropping system to added nutrient depends largely upon the inherent capacity of soil to supply that nutrient as per the requirement of crop. In a low nutrient soil, the crop responds remarkably to its application. On the other hand, in a high nutrient soil, the crops may show little or no response. In medium test soil, the response is intermediate. Soil testing helps in adjusting the amount of fertilizer and thus improves the efficiency of fertilizers use. By demarcating the areas responding differently to different plant nutrients, right type and proper amount of fertilizers can be applied to them.

(2) ***Nutrient Losses and Transformations****:* The amounts of nutrients estimated by soil tests may not be entirely available to plants because of their leaching, volatilization, denitrification and transformations to unavailable forms. Leaching losses are important for nitrate nitrogen because it is not held by exchange sites in the soil, it is lost. Such losses are of particular significance in sandy soils and in situations if heavy rain or irrigation follows its application. In acid soils, leaching losses of calcium, sulphate, potassium and magnesium are more common. Volatilization of ammonia in high pH surface soils is considerable when urea is applied at the surface. Denitrification loss of nitrogen mainly occus under waterlogged conditions prevailing during rice cultivation, particularly under higher temperatures and in the presence of easily decomposable organic materials.

The conversion of a portion of available nutrients into insoluble mineral forms is also important. Thus, the efficiency of added phosphorus is 20 to 30 per cent. Microbial immobilization also converts temporarily the soluble forms of nutrients into unavailable forms. Similarly, the efficiency of zinc applied to soil is less than 3%.

Soil characteristics play a dominant role in the transformation of nutrients. Soil reaction (pH) is one of the important soil properties that affects plant growth. The harmful effects of soil acidity are more due to secondary effects except in extreme case. The important secondary effects of high acidity or low pH in a soil are the inadequate supply of available calcium, phosphorus and molybdenum on one hand

and the excess of soluble aluminum, manganese and iron on the other. Likewise, in saline-alkali soil, the deficiency of Ca, Mg, P, Zn, Fe and Mn is very common. The fertilizers practices are, therefore, to be modified accordingly for soils with different soil reactions. The main aim of liming of acid soils and addition of gypsum to alkali soils is to change the soil pH suitable for the availability of most plant nutrients.

(3) ***Soil Organic Matter****:* Soil organic matter content is generally considered as the index of soil fertility and sustainability of agricultural systems. It improves the physical and biological properties of soil, protects soil surface from erosion and provides a reservoir of plant nutrients. In tropics, the maintenance of soil organic matter is very difficult because of its rapid decomposition under high temperatures. The cultivation of soils generally decreases its organic carbon content because of increased rate of decomposition by the current agricultural practices. In cultivated soils, prevalent cropping system and associated cultural practices influence the level at which organic matter would stabilize in a particular agro-eco-system. Long-term fertilizer experiments have shown that the integrated use of organic manures and chemical fertilizers can maintain high productivity and sustainable crop production. Recent studies have indicated that a periodic addition of large quantity of crop residue to the soil maintains the nitrogen and organic matter at adequate levels even without using legumes in the rotation. The application of FYM, compost and cereal residues effectively maintains the soil organic matter. There is a significant increase in soil organic matter due to incorporation of rice or wheat straw into the soil instead of removing or burning it. Yields are, however, low in residue incorporated treatments due to wide C:N ratio of the residues. This ill effect, however, can be avoided if the rice straw is incorporated at least 20 days before seeding wheat.

(4) ***Soil moisture***: Fertilizer application facilitates root extension into deeper layers and leads to grater root proliferation in the root zone. Irrigated wheat fertilized with nitrogen used 20-38 mm more water than the unfertilized crop on loamy sand and sandy loam soils and increased dry matter production Soil moisture also affects root growth and plant nutrient absorption. The nutrient absorption is affected directly by soil moisture and indirectly by the effect of water on metabolic activities of plant, soil aeration and concentration of soil solution. If soil moisture becomes a limiting factor during critical stage of crop growth, fertilizer application may adversely affect the yield.

***(5) Physical Conditions of Soil*:** Despite adequate nutrient supply, unfavorable physical conditions resulting form a combination of the size, shape, arrangement and mineral composition of the soil particles, may lead to poor crop growth and activity of microorganisms. Soil nitrogen generally increases as the texture becomes finer. The basic requirements for crop comes finer, The basic requirements for crop growth in terms of physical conditions of soil are adequate soil moisture and aeration, optimum soil temperature and freedom from mechanical stress. Tillage, mulching, irrigation, incorporation of organic matter and other amendments like liming of acid soils and addition of gypsum to sodic soils are the major field management techniques that aim at creating soil physical environment suitable for crop growth. Tillage affects water use by crops not only through its effect on root growth but also affects the hydrological properties of soils. Mulching with residues, plastic film *etc.,* influences evaporation losses from soil by modifying the hydro-thermal regime of the soil and affects root growth and rooting pattern. Use of organic mulch also decreases maximum soil temperature in summer and increases minimum soil temperature in winter and help in the conservation of soil moisture.

9.3.2 Crop Characteristics

(i) Nutrient Uptake: The total amount of nutrients removed by a crop may not serve as an accurate guide for fertilizers recommendations; it does indicate the differences in their requirement among crops and the rate at which the nutrients reserves in the soil are being depleted. The nutrient uptake may vary depending upon the crops and its cultivars, nutrient level in the soil, soil type soil and climatic conditions, plant population and management practices. It is estimated that 8t of rice grain remove 160 kg N, 38 kg P, 224 kg K, 24 kg S and 320 g Zn as compared to a removal of 125 kg N, 20 kg P, 125 kg K, 23 kg S and 280 g Zn by 5t of wheat from one hectare field.

(ii) Root Characteristics: Roots are the principal organs of nutrient absorption. A proper understanding of their characteristics helps in developing efficient fertilizer practices. The absorption of nutrients depends upon the distribution of roots in soil. The shallower the root system, the more dependent the plant is on fertilizers. Hence, any soil manipulation, which encourages deep rooting, will encourage better utilization of fertilizers. It is well known that some plants are better scavengers of certain nutrients than others. This is mainly because of the preferential absorption of these nutrients by the roots of those plants. For example, legumes have a marked preference for divalent cations like Ca^{2+} whereas grasses feed better on monovalent cations like K^{+}.

The efficiency of the applied fertilizer can be improved considerably if the rooting habits of various plants during early growth stages are known. This is particularly true for relatively immobile nutrients and for situations where the fixation of applied nutrients is very high. If a plant produces tap root system early, fertilizer can best be placed directly below the seed. On the other hand, if lateral roots are formed early, side placement of fertilizer would be helpful.

Mycorrhizal fungi often associated with plant roots, increase the ability of plants to absorb nutrients particularly under low soil fertility. However, fertilizer additions generally reduce their presence and activity.

9.3.3 Crop Rotation: The nature of cropping sequence has a profound effect on the fertilizer requirement and its efficiency. Crops are known to differ in their feeding capacities on applied as well as native nutrients. The crops requiring high levels of fertilizers such as maize, potato may not use the applied fertilizers fully and some amount of the nutrient may be left in the soil which can be utilized by the succeeding crop. Phosphorus, among the major nutrients, is worthy of consideration because only less than 20 per cent of the applied phosphatic fertilizer is utilized by the first crop. Similarly, less than 3% of the applied zinc is used by the first crop. The magnitude of the residual effect is, however, dependent on the rate and kind of fertilizer used, the cropping and management system followed and to a great extent on the type of soil. Crops have a tendency of luxury consumption of N and K and may not leave any residual effect unless doses in excess of the crop requirement are applied. On the other hand, if sub-optimal doses of fertilizers are applied to a crop, they may leave the soil in a much exhausted condition and the fertilizer requirement of the succeeding crop may increase. The legumes leave nitrogen rich root residues in the soil for the succeeding crop and thus reduce its nitrogen requirement.

9.4 Methods of fertilizer application

An important item in efficient use of fertilizer is that of placement in relation to plant.

(1) Solid fertilizers

Broadcasting is the method of application of fertilizer uniformly over the entire field. It may be at planting or in standing crop as top dressing.

(i) Broadcasting at planting is adopted under certain conditions.

1. Soils highly deficient, especially in nitrogen,
2. Where fertilizers like basic slag, dicalcium phosphate, bone meal and rock phosphate are to be applied to acid soils, and
3. When potassic fertilizers are to be applied to potash deficient soils.

(ii) Top dressing is application of fertilizer to the standing crop. Usually, nitrate nitrogen fertilizers are top dressed. Depending on the duration of the crop and soil type, top dressing may be more than one to meet the crop needs at times of greatest need of the crop.

(iii) Placement: Fertilizers are placed in the soil either before sowing or after sowing the crop.

(a) Plough-sole placement consists of placing the fertilizer in a continuous band at the bottom of the furrow during the process of ploughing, which is usually covered by the next furrow adjacent to it.

(b) Deep placement is application of fertilizers, especially nitrogen, in the reduced zone to avoid nitrogen losses in low land rice.

(c) Localized placement: In this method fertilizer are applied close to the seed or plant. It is usually adopted when relatively small quantizes of fertilizers are be applied.

(d) Contact placement or drill placement refers to drilling seeds and fertilizer simultaneously at sowing. Care must be taken to place the seed and fertilizer at different depths to avoid salt injury to the germinating seed.

(e) Band placement consists of applying the fertilizer in continuous bands, close to the seed or plant. This method is ideal for crops grown in wide space *i.e.,* cotton, castor, sugarcane, tobacco, maize *etc.*

(f) Pellet placement is application of fertilizer, especially nitrogen in pellet from in the low land rice avoid nitrogen loss from applied fertilizer.

(2) Liquid Fertilizers

(i) Starter solution: These are solutions of fertilizers prepared in low concentrations used for soaking seed, dipping roots or spraying on seedlings for early establishment and growth.

(ii) Foliar application: This method, nutrients are applied are to the standing crops in the from of spray for quick recovery from the deficiency. It avoids fixation of nutrients in the soil.

In the case of calcium, transport from roots to fruit is limited, so foliar applications are the best method we know of go get more calcium into fruit tissue to reduce post harvest disorders. The expense of the calcium sprays is more than justified by the potential post-harvest losses.

If soil pH limits nutrient availability, and ground applied fertilizes are not taken up, foliar fertilizers may be a valid option. In this case, a soil sample should be taken to determine pH, and a leaf tissue sample taken to determine the need for addition foliar fertilization. In some cases poor root health from compaction, replant disease, crown rot, mouse damage, water logging or other problem may warrant foliar feeding of trees. However, the fertilizer in the required amount cannot be phototoxic as a foliar spray, and uptake must have been demonstrated with the product under consideration.

Zinc uptake deserves special attention. In our soils zine is largely immobile and it is difficult to supply roots with adequate amounts of available Zn. As a result of limited soil availability, zine is applied as a foliar spray. Research has shown that only a small amount of Zn can be taken up by leaves, however foliar application are still more successful than soil applied Zn.

(iii) Soil application: Liquid fertilizer such as anhydrous ammonia are applied directly to the soil with special injecting equipment. Liquid manures such as urine, sewage water and shed washing are directly let into the field.

(iv) Fertigation: This is the application of fertilizer in irrigation water in either open or closed system. The open system includes lined and unlined open ditches and gated pipes that are used for furrow and flood irrigation. Sprinkler and trickle systems are main closed systems. Nitrogen and sulphur are the principal nutrients applied by fertigation.

The fertigation allows to apply the nutrients exactly and uniformly only to the wetted root volume, where the active roots are concentrated. This remarkably increases the efficiency in the application of the fertilizer, which allows reducing the amount of applied fertilizer. This not only reduces the production costs but also lessens the potential of groundwater pollution caused by the fertilizer leaching.

Other advantage of the fertigation are: (1) the saving of energy and labor, (2) the flexibility of the moment of the application (nutrients can be applied to the soil when crop of soil conditions would otherwise prohibit entry into the field with conventional equipment), (3) convenient use of compound and ready-mix nutrient solutions containing also small concentrations of micronutrients which are otherwise very difficult to apply accurately to the soil, and (4) the supply of nutrients can be more carefully regulated and monitored. When fertigation is applied through the drip irrigation system, crop foliage can be kept dry thus avoiding leaf burn and delaying the development of plant pathogens.

Fertilizers management under rainfed conditions:

In dryland agriculture, limited water availability is usually the factor that ultimately limits crop production. However, it is not unusual for limited availability of one or more soil nutrients to further decrease production potential. Often, the effects of water and nutrient deficiencies are additive. Because soil used under dryland agriculture are developed under widely varying conditions, their ability to supply nutrients is highly variable.

Fertilizer practices greatly affect nutrient cycling and availability in rainfed conditions. Because of frequent dry periods, placement of soluble fertilizers with the seed is extremely hazardous in dryland soils. The higher rates of fertilizer application may result in high osmotic potentials near the germinating seed. For oil crops, applying no fertilizer N with the seed is usually recommended. however, up to 20 to 30 kg P/ha can be applied with the seed because of the considerably lower solubility of most P fertilizer. It is also reported that P availability is particularly critical for an eroded soil. In dryland soils, the surface layers often remain dry for a major part of the growing season. Such a condition might suggest that fertilizers should be placed deeper in the region of the active root zone for more of the growing season.

Timing of fertilizer application could also affect nutrient cycling. Applying N fertilizers near the time of maximum N uptake rate of the crop results in the most efficient uptake of the fertilizer. Fertilizer sources also determine the growth the crops under rainfed conditions. Most dryland experiments showed that ammonium nitrate is usually one of the most efficient N sources for dryland crops. At the other extreme, these experiments showed that urea is the least efficient form of N fertilizers. One must exercise considerable caution when using urea on dryland to avoid excessive losses by ammonia volatilization.

By concentrating the urea (liquid or solid) in a band or pellets, surface contact is reduced, reducing volatilization. Injecting or incorporating urea beneath the soil surface is by far the best way in which to apply this material to dryland soils.

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