Compendium of Lectures
(Theory cum Practical)
(2011-12)

Agron-502
Principles and Practice of Soil Fertility and Nutrient Management

10/06/2009

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Course contents

Agron 502 Principles and Practices of Soil Fertility and Nutrient Management (2+1)

Objective

To impart knowledge of fertilizers and manures as sources of plant nutrients and apprise about the integrated approach of plant nutrition and sustainability of soil fertility.

Theory

UNIT I

Soil fertility and productivity- factors affecting; Features of a good soil management; Problems of supply and factors affecting availability of nutrients; Relation between nutrient supply and crop growth; Organic farming – basic concepts and definitions

UNIT II

Criteria of essentiality of nutrients; Essential plant nutrients- their functions and deficiency symptoms; Transformation and dynamics of major plant nutrients in the soil.

UNIT III

Preparation and use of farmyard manure, compost, green manure, vermicompost, biofertilizers and other organic concentrates, their composition, availability and crop responses; Recycling of organic wastes and residue management.

UNIT IV

Commercial fertilizers; composition, relative fertilizer value and cost; crop response to different nutrients, residual effects and fertilizer use efficiency. Fertilizer mixers and grades; agronomic, chemical and physiological methods of estimating and techniques of increasing fertilizer use efficiency; nutrient interactions.

UNIT V

Time and methods of manures and fertilizers application; foliar application and its concept; relative performance of organic and inorganic manures; economics of fertilizer use; integrated nutrient management; use of vermicompost and residue wastes in crops.

Practical

- Determination of soil pH, EC, organic C, total N, available N, P, K and S in soils
- Total N, P, K and S in plants
- Interpretation of interaction effects and computation of economic yield optima.

Suggested Readings

Brady NC and Weil RR 2002. The Nature and Properties of soils. 13th Ed. Pearson Edu.

Fageria NK, Baliger VC and Jones CA 1991. Growth and mineral nutrition of Field Crops. Marcel Dekker.

Havlin JL, Beaton JD, Tisdale SL and Nelson WL. 2006. Soil Fertility and Fertilizers. 7th Ed. Prentice Hall.

Mengel, K and Kirkby EA. Principles of Plant Nutrition. Kluver Academic Publishers.

Prasad R and Power JF 1997. Soil Fertility Management for Sustainable Agriculture. CRC Press.

Yawalkar KS, Agarwal JP and Bokde S. 2000. Manures and Fertilizers. Agri-Horti Publ.

Schedule of Lectures

Agron 502 Soil Fertility and Nutrient Management 2+1

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Unit I

Soil fertility and productivity – factors affecting

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

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

Differences between soil fertility and productivity

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

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

Soil fertility evaluation methods (classified)

1. *Visual observation of deficiency symptoms*
    - *(a)* Plants
    - *(b)* Soil
2. *Microbiological studies related to soil fertility*
    - *(a) Azotobacter* plaque test
    - *(b) Aspergillus niger* test
    - *(c) Cunninghamella* plaque test
    - *(d)* Carbon dioxide evolution method.
3. *Chemical methods*
    - *(a)* Qualitative: *(i)* soil test *(ii)* plant tissue test (rapid)
    - *(b)* Quantitative:
    - *(i)* Soil analysis
    - *(ii)* Plant analysis (for total and available nutrients).
4. *Experiments related to soil fertility*
    - *(a)* Field trials: *(i)* simple *(ii)* complex
    - *(b)* Green house (pot culture) and lysimeter experiments
    - *(c)* Use of indicator plants
    - *(d)* Nutrient injection and foliar sprays.

1. Excess of elements (Mn, Cu and Zn) may be toxic to living materials (protoplasm) of the plant.
2. Excess of one plant food element may cause deficiency of another such as:
    - (a) Excess of N causes K starvation in certain crops like potato,
    - (b) Excess of K causes deficiency of Mn in tomato,

(c) Excess of P causes deficiency of Zn in most of the crops.

Apart from these, imbalanced fertilization increases cost of production because any amount more than required does not help in producing higher crop yields. Thus, the consumption of more than required quantity of elements is called **'luxury consumption'**, which is nothing but a waste. This type of loss is in addition to leaching, washing and other losses of elements.

Thus, it is necessary for an agriculturist to know the fertility status of' his soil which is to be used for crop production. For evaluating soil fertility status, several techniques are commonly employed.

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

It has been known for a very long time that certain substances (such as dung and ash), when added to the soil, improve production. These are now called fertilizers. For reasons of cost and ease of use, chemical fertilizers have replaced natural ones. Although plants can't distinguish the difference, artificial fertilizers can easily be over-used, resulting in damage to the soil, rivers and ocean. Learn to know how to produce more, while damaging the soil and environment less. What do plants need, how are nutrients formed and maintained and what can we do to increase the natural fertility of the soil?

plant needs		What do plants need? Liebig's law states that the need in shortest supply will be the main factor limiting growth. Often overlooked needs are light and warmth.
watering		A plant's most important need is water. In most places on Earth, water is a problem. There is either too much of it or too little. Water is needed by soil organisms too, so a farmer's most urgent task is to manage the supply of water.
nutrients		Nutrients are found in the rocks. Once weathered into soil, these become available to plants. This supply is not enough, the reason why all terrestrial ecosystems recycle their nutrients with minimal losses. Agricultural soil should recycle its nutrients too, but there are insurmountable problems.
fertilizing		Is fertilizing necessary and how is it done? How can the fertility of the soil be enhanced and maintained?
Diversity		Bringing variety in a monoculture can bring additional fertility. For example, trees in grassland.
Salt		Because plants do not need salt the way animals and humans do, salt is easily lost from our soils, particularly through modern farming. Produce does not only taste weak, it also contains fewer salts. Salt deficiency in society may arise from other causes too.

The base rocks from which soil is weathered, ends up quite different in composition from place to place, but in practice all fertile soils on earth follow the rather constant chemical composition of plants, which is similar to animals. This can be understood from the way plants, animals and soil form an ecosystem, cycling the available nutrients many times before they get lost. In the process, unnecessary concentrations of elements (like salt and chlorine) do get lost, resulting in concentrations of available soil elements, closely matching plants' needs, everywhere on Earth.

Although their ratios of elements are similar, soils may vary considerably as to their densities, and thus fertility.

Underground, the soil nutrients are not kept in solution but inside the bodies of the living organisms (and some are adsorbed onto clay platelets). No wonder then that the amount of life in good soils is 2-10 times more than that above ground. The nutrients become available when some organisms die, which happens frequently because they grow fast. But it does not happen in sudden boosts, as is needed for a monoculture that has been planted all at the same time, like a potato crop. In this respect, natural, productive soil appears to need more fertilizer than it actually does. Modern farming, driven by economic constraint, is force to use artificial fertilizers, often to the determent of the soil's natural fertility.

The ecologist Edward S Deevey Jr discovered that living matter consists mainly of the six element, H, O, C, N, P and S, in the ratio H:O:C:N:P:S=2960:1480:1480:16:1.8:1, which is an average for all living organisms on earth. Of these, the woody plants far outnumber all others, so the formula is biased towards these. The ratio H:O:C:N:P:S=1600:800:800:9:1:5 is often used for land plants, and 212:106:106:16:1:2 for marine plants and soil humus. From an ecological perspective, it would not be surprising if scientists discover that these ratios for terrestrial life (green matter in plants + animals) are the same as for soil biota (bacteria + fungi + animals). By comparison, the most common component of plants are the carbohydrates (sugars, starches an woody substances), represented by H:O:C = 12:6:6 atoms, or as masses 1:6:8. With C, O and N having similar atomic masses (12, 16, 14), as rule of thumb, each unit of N belongs to 200 units of life (dried) and 100 units of carbon.

What every plant need for growth is:

Sunlight: to obtain the energy for photosynthesis.

Carbon dioxide: necessary input for photosynthesis. The atmosphere cycle this effectively.

Oxygen: When plant rest at night, they need oxygen, while producing carbon dioxide. In slow growth areas such as the Boreal forests, respiration using the long winters is almost equal to photosynthesis using the short summers.

Warmth: to be able to perform the biochemical processes of life. Plants have adapted to a wide range of temperature, but the warmth of the tropics promotes highest productivity.

Water: The biochemical process of photosynthesis requires much water. Excess or lack of it, causes problems in most geographic areas.

Macronutrients: The main nutrients N, P, K, S, Ca, Mg and micronutrients, the trace elements.

The soil biota has similar requirements, but since they do not photosynthesize, they need neither light not carbon dioxide. The requirements above are often called 'limiting factors' because each could limit the plant's growth. More accurately, they should be called 'life determining factor'.

The scientist Liebig discovered that all of the above needs to be satisfied, and that the one in shortest supply will be the main cause of limiting growth. Thus in winter, when it freezes, plants do not need either carbon dioxide or water or nutrients. What they need is warmth first.

It is necessary to increase productivity to achieve the maximum to feed the ever increasing population. But actual production will remain below potential due to climate, soil and biotic constraints. Climate and soil can't be changed. Crops have to be chosen to fit to the environment. Soil fertility need to be increased and maintained on a sustained basis. The methods have to be effective and clean. As Francis Bacon said "he that will not apply new remedies must expect new evils for time is the greatest innovator”. In the following some of the ways to increase productivity by managing different factors have been suggested.

Manipulation of different factors to increase productivity

1. Climate

a	Rainfall	Manipulation
	i Quantity	Less – irrigation and moisture conservation, management of rainwater More – drainage
	ii Distribution	Adjustment of cropping time and sequence, cropping as per safe growing period; contingent plans
b	Air temperature	High – Modulation by wind breaks, shelterbelts, mulching Low- Adjusting time of planting; avoiding vulnerable
c	Light	
	quantity	Orientation of crops, spacing (increase LAI and LAD) to harvest more light and increase PAR
	intensity	Shading, avoiding coinciding grain filling period to high temperature and light intensity
	duration	Choice of short duration crops, multiple cropping to increase total yield
d	Altitude	Growing of day neutral an thermo and photo insensitive crops
e	Wind velocity	Win belt, shelter belt, establishment of sand dunes
f	CO_2 concentration	Choice between C_3 and C_4 plants, more C_4 plants (maize and sugarcane)

2. Soil factors

a	i	Organic matter	Addition of green manure and FYM, incorporation of crop residues
	ii	Texture	Cannot be changed
	iii	Structure	Addition of organic matter, tillage
	iv	Reaction	Low - green manuringt, FYM addition, cropping pattern, liming High – Application of gypsum, amendments (salinity)
	v	CEC	Addition of organic matter, can be improved within a narrow limit
	vi	Base saturation	Manuring – organic and inorganic
	vii	Soil temperature	Tillage, mulching, drainage, irrigation
b		Topography	Uneven- Agroforestry, drip and sprinkler irrigation Low lands- drainage, crop management
c		Root zone	depth of planting, controlled irrigation, fertilizer placement
d		Soil erosion	Conservation measures for soil and water, terracing, contour farming; gully and stream bank erosion, control, Agroforestry, watershed management, rainwater harvesting, sowing along contours recharging groundwater.

3. Crop factor

i	Variety, species	Improvement – introduction, breeding, genetic engineering, selection
ii	Planting date	Advance or delay as per probability of rainfall, safe growing period, available soil moisture
iii	Planting	Seed rate, intra an inter-row spacing intensity
iv	Seed quality	Seed certification, use of quality seed
v	Evapotranspiration	Irrigation time, depth and frequency
vi	Nutrition	Quantity, time an method of application, targeted yield, combination of organic and inorganic
vii	Harvest index	-Adjustment between vegetative and reproductive growth, through fertilization – time and method, change of crop variety, species – irrigation, drainage, choice of crop/variety

Features of a good soil management

Soil is defined differently for different purposes. It is the outer layer of earth crust capable of supporting plant growth. For an agronomist it is a natural body derived from rocks through weathering modified by physiography (relief) and organic matter over time. Weathering of rocks gives rise to soils. Depending on nature and properties of rocks and minerals and their response to weathering, the nature and properties of soils also vary. These properties are also modified by climate and biotic factors. Hence, soil is a function of climate, organic matter, relief, parent materials and time (s = f (cl. o.r.p.t). Parent material is in a way passive. Joffe stated "Different parent materials give rise to the same kind or type of soil whenever the principal factors of soil formation, the climate or biosphere, are the same". A corollary to this principle is that "similar parent materials give rise to a different kind or type of soil provided the principal factors are dissimilar". Depending on extent of weathering a soil is called a mature or immature soil. A mature soil is one that has reached the full development to be expected under existing biological and weathering processes. An immature soil is one that has not reached its final state of development. In a strict sense, no soil is mature because some change, development goes on. It is better to call them old or young soils. Oxisols are old soils and alluvial soils are young soils.

Soil is foundation to every field/garden. Every healthy, productive field, yard and garden starts with healthy, productive soil. Preparing the soil properly makes more difference than any other thing you can do. You cannot put on enough nutrients and water to make up for poor soil. Since soils are so different in different areas, it is necessary to know what soil is, what your soil is like and what to add to improve it.

SOIL COMPONENTS

Soil is made up of four main components: mineral, water, air and organic.

MINERAL

The mineral component is non-living material. It is divided by the size of the particles, into:

Sand: Rounded particles 1/12 to 1/500 inch (2.0 to 0.06 millimeters) in diameter.

Silt: Rounded particles 1/500 to 1/12,500 inch (0.06 to 0.002 millimeters) in diameter.

Clay: Flattened particles less than 1/12,500 inch (0.002 millimeters) in diameter.

Loam: Mixture of the above in roughly equal proportions.

Sand has large spaces between the particles, which allow air and water to move easily, so sand has good aeration and drainage. Clay packs down with only tiny spaces between particles so there is poor aeration and drainage. However, clay has about 100 times the surface area as the same volume of sand. More surface area means that clay will hold more water and more nutrients. Silt has some of the qualities of both sand and clay. Loam combines the best features of all three: aeration, drainage and storage capacity for water and nutrients. Often, soil particles are clumped together into crumbs, which create large spaces between the crumbs for aeration and drainage. Pebbles and rocks also increase drainage; sometimes so much that plants wilt from lack of water. Rocks also may interfere with root growth.

WATER

The amount of water in the soil is described in these ways:

Saturated: All of the spaces in the soil are filled with water.

Field capacity: Excess water has drained away leaving a film of water on each particle and air in the spaces.

Wilting Point: The film of water on each particle is so thin that roots can no longer pull enough water from the soil, so the leaves droop.

Plants grow best when the soil is at field capacity. Frequent watering in controlled amounts on well-drained soil to maintain field capacity has doubled vegetable yields. However, it takes careful monitoring and controlled watering to maintain field capacity so usually soil is watered to near saturation and the excess is allowed to drain away.

AIR

Air in the soil is made of the same gases as the air in the atmosphere. Air doesn’t move as freely in the soil so there may be too much or too little of certain gases in parts of the soil. Plant roots need oxygen to absorb water and nutrients. The lack of oxygen limits how deep roots can grow. Roots may grow thirty feet deep in well-drained sandy soil, but most roots are in the top foot of clay soil. Oxygen is replenished in the soil when water forces the air out of the soil, then fresh air is pulled back into the soil as the water drains away. Large spaces between soil particles and crumbs allow soil to breathe better. Deep watering helps the soil breathe much better than frequent, shallow watering.

ORGANIC

The organic component of the soil is made up of living and dead plants and animals.

Living: Bacteria, Fungi, Insects, Worms, and Roots.

Dead: All of the above as they decay.

Humus: Dead organic matter that has decomposed until it is very fine, black and sticky.

Bacteria and fungi extract nutrients from the soil minerals and make them available to plants. Mycorhizae are fungi that are partly in the soil and partly inside plant roots. They can transport a very large amount of nutrients into plant roots. Insects and worms create air passages deep into the soil. The carbon dioxide produced by roots becomes carbonic acid, which breaks down minerals to make nutrients available. Dead organic material provides rich nutrients for the living. It also holds the nutrients from applied fertilizers until the plants can use them. Humus sticks the soil particles into larger crumbs so there are bigger spaces for air and water.

Dead organic matter is decaying continually, so it needs to be replenished every year. Excessive nitrogen fertilizer will cause the dead organic matter to decay even faster; so more organic matter will have to be applied. Also, careless use of pesticides may harm or kill the living organisms and damage the soil.

SOIL TESTING

Soil testing is done to determine how much of each soil component is present in the soil. Soil testing laboratories can give a detailed and accurate measurement of the soils components. However, these simple tests can reveal much about the soil.

SOIL PROFILE TEST

Dig a hole 18" deep and wide enough that the soil can be seen. Sand can be seen or felt. Black color indicates high organic matter; gray indicates medium organic matter. Red, tan or blue color indicates little organic matter and high clay. Blue color indicates that there is no oxygen in the clay. Therefore, no roots will grow in blue clay. Normally, the organic matter is mainly in the topsoil. Forest soils have a one to four inch thick layer of organic matter on top of mineral soil.

Grassland soils have a much thicker layer of organic matter mixed with mineral soil. Wetland soil may have a layer of organic matter several feet thick because the lack of air in wet soil slows down the decay of organic matter.

SEPARATING SOIL IN WATER TEST

Fill a glass jar about half full with soil. Fill to the top with water. Shake the jar, but do not swirl. Let stand. Sand will settle in about ten seconds. Silt will settle in two minutes. Clay will take hours to settle. Larger pieces of organic matter will float for awhile. The thickness of the layers indicates the proportions of sand, silt, clay and organic matter.

SOIL pH or ACIDITY TEST

Soil pH is a measure of hydrogen ion concentration. It is tested either with a chemical pH test, or by a pH meter. 7.0 is neutral. 4.0 is very acid. 10.0 is very alkaline. High rainfall and high organic matter produces acid soil. Low rainfall and high lime or sodium produces alkaline soils. Soils naturally have a pH between 4.5 and 5.5 are fine for acid loving plants such as rhododendrons, azaleas, camellias and conifers. Lawns, roses, lilacs, fruit trees, vegetables and many flowers prefer a soil pH near neutral, 6.5 to 7.0. The majority of plant nutrients are most available at slightly acid to neutral, though iron is more available as soil is more acid. Soil can be made less acid by adding lime (calcium carbonate), or more acid by adding sulfur or aluminum sulfate. Aluminum sulfate is especially helpful to produce good blue flowers on hydrangeas. Adding lime produces pink hydrangea flowers. Lime will raise the soil pH in a few weeks or several months depending on how finely ground the lime particles are. Sulfur takes about a year to lower soil pH since bacteria are required to complete the process.

SOIL NUTRIENTS

There are thirteen essential nutrients which plants get from soil. The six that the plants need the most of are called Macronutrients. They are Nitrogen, Phosphorus and Potassium, which are abbreviated N-P-K, Calcium, Magnesium and Sulfur. The other nutrients, which are needed only in trace amounts, are called Micronutrients. They are Iron, Manganese, Boron, Zinc, Copper, Molybdenum and Chlorine.

Soil laboratories will test soils for nutrients as well as pH and organic matter. However, a general recommendation is: All soils are short on nitrogen; shallow rooted plants such as lawns and flowers need extra phosphorus and potassium; iron and sulfur are often deficient, especially around acid loving plants. Usually, the soil contains enough of the other nutrients, although some may be deficient in certain parts of the country.

The nutrients are identical whether they come from organic or synthetic sources, but the source will affect how fast the nutrients are available to plants. Organic fertilizers and specially treated synthetic fertilizers are slow release so they won’t burn and the nitrogen won’t wash away in the rain before plants can use it.

IMPROVING SOIL

The ideal soil would have sand, silt, clay and organic matter in about equal amounts. It would also be uniformly mixed to at least twelve inches deep. The subsoil would allow the excess water to drain away. No soil is ideal but soil can be improved with soil amendments and drainage.

SOIL AMENDMENTS

Soil amendments are organic or inorganic matter added to the soil to improve texture, water retention, drainage or aeration. Sandy or rocky soil requires amendments to improve the texture and add water retention properties. Clay soils require the addition of material to improve texture, aeration and drainage. Soil amendments come in a variety of sources.

Amendments that are commonly added to soil are:

Sand or Profile Soil Conditioner: to improve aeration and drainage.

Compost: to add organic matter, nutrients and to improve aeration and drainage.

Lime or Sulfur: to raise or lower pH.

Manures: to add nutrients

Composted organic matter improves the texture of the soil, increases aeration, promotes both water retention and drainage as well as adds valuable nutrients necessary for plant growth. Home compost bins provide the main source of compost for home gardeners. Vegetation added to the compost bin breaks down into rich friable soil that provides valuable nutrients to the existing soil in the garden. Compost bins provide a convenient area to deposit leaves and plant material from harvests, grass clippings and organic yard debris. Peat moss sold in large compressed bales provides organic matter to soil. It increases the ability of the soil to retain water and is ideal for sandy or rocky soil. Peat moss is acidic and will lower the PH of soil. Wood products like wood chips and shavings improve soil, but may create a nitrogen deficiency. Microorganisms in the soil use nitrogen to decompose the wood and may tie up useable nitrogen for weeks or months. Add a source of nitrogen at the time of application if you intend to cultivate crops on the soil. Composted manure improves the quality of the soil and provides nutrients necessary for plant growth. The addition of manure decreases the need for other fertilizer additives. Vermiculite, a natural balsamic mineral and perlite made from heated amorphous volcanic glass sold for horticultural use, provides an inorganic soil amendment that increases aeration, improves texture and assists in water retention. Suitable for any type of soil, vermiculite and perlite do not alter the nutrient content.

For flower bulbs and root crops, the soil should be double dug to fifteen to eighteen inches deep. Double digging involves digging up the top eight inches of soil and piling it to the side of the hole. Soil amendments are spread in the hole and worked into the lower eight inches. Then amendments are added to the piles of soil as they are shoveled back into the hole.

Soil should be worked when it is moist but not wet. Wet soil will be packed into hard clods, which are about like rocks. To check the soil for dampness, squeeze a handful of soil into a ball, then push your thumb into the ball. It should crumble, not dent like modeling clay. Dry soil is harder to work and the soil disintegrates into dust. Dust will turn into mud when watered, then dry like brick. Dry soil should be watered well then allowed to soak in for a day before tilling.

Soil should not be worked into dust. Leaving marble-sized to golf ball-sized clumps with give better aeration and drainage. Besides destroying the structure of soil, over working soil also kills off the mycorhizae which are beneficial fungi for moving nutrients from soil into roots. Roto-tilling may be required to incorporate amendments into the soil but more mycorhizae will survive if the soil is loosened with a spading fork. Simply stomp the tines into the soil and tilt back the handle to lift and fracture the soil.

Sharp sand or Mason’s sand creates spaces much better than river sand, which has rounded edges and packs down tighter. Profile Soil Conditioner is even better, since it is porous so it holds both water and nutrients. Compost is made of partially decomposed yard debris, bark dust, sawdust, manure or other organic matter. Fresh organic matter can also be used, but extra nitrogen fertilizer will be needed to help it decompose. Fresh manure may contain too much uric acid, which can burn roots. It is best if manure is aged for at least six months.

The best and easiest time to improve soil is to do an entire area at once, such as when planting a new lawn or landscape. The amendments should be spread evenly over the area and worked into the soil at least ten inches deep. A spade or spading fork works best for small areas. A roto-tiller handles large areas. For existing beds, the soil can be improved every time something is planted.

SOIL DRAINAGE AND AERATION

Drainage and aeration is improved by soil amendments, but there must be some place for the water to go. Yards should be graded so surface water drains off. Drainage sensitive plants such as Japanese maples, daphne and heather should be planted on a mound at least a foot tall or on a slope. Vegetables are best grown in raised beds, which provide better drainage and warmer soil in the spring for an earlier start.

In mostly flat yards, subsurface drainage may have to be provided. Perforated plastic drainpipe can be buried about a foot deep. It is important that drainpipes slope evenly so dirt doesn't clog up the low spots. Drain pipes can drain into down spouts if allowed by local building codes.

Aeration can be improved on existing lawns and beds without tearing up the soil. Sod core aerators cut out plugs of soil and leave holes about six inches apart and four inches deep. Root feeders can be used around trees and shrubs to create holes eighteen inches deep. These holes allow air and water to quickly penetrate deep into the soil. The holes will stay open much longer if sand or Profile Soil Conditioner is raked into the holes to fill them.

Management

Management of mega elements is highly interdependent and difficult. For these reasons agriculture (including its ancillary branches) is the most difficult enterprise. Soil is the bed for the crop to grow – its roots in the soil and upper portion on it extending to atmosphere. Solar energy falling on the green leaves helps in photosynthesis. In this process oxygen is evolved and CO_2 taken in. The animals take O_2 and give CO_2 off. This exchange continues. Soil is the store house of nutrients including water. If rainfall is not sufficient water is supplied artificially (irrigation) to the soil for the crop. How much water soil can hold depends on its water holing capacity (physical characters) and how much water crop can take up depends on its growth and development and atmosphere demand (evaporation, evapo-transpiration).

To make soil suitable for crop growth several principles and practices are followed; the aim is to grow a crop with minimum cost on a sustained basis. Practice came earlier than the principle and the practices are being improved with advancement of principles and technology. Soil, plant, water and atmosphere appear to be discrete but work together an interdependently for crop production.

In agriculture principles are many but practice are few. It is the judicious field management that is more important for successful crop production. It consists of soil, plant, atmosphere and power management (land, labour and capital).

Field management

Soil conditions must be made favourable for crop growth and development from seeding to harvesting – may be annual, biennial or perennial; management, a continuous process – may be for less than a month as in the case of short duration vegetables, for a few months as in case of annuals – green gram, black gram, rice, wheat, for 2 seasons as in case of sugarcane or for many years – more than one hundred years – as in case of coconut.

Soil is to be managed for the crop. Soil conditions must be made favourable for growth and development of the crop. It begins from sowing of seeds and continues to harvest.

Preparation of soil by cultivation is called tillage. By the term 'cultivation of crop' it means growing the crop from it sowing to harvest. For this, tilling the soil is essential (some crops can be grown without tillage, or can be grown in a chemical solution without soil called hydroponic): tillage is required to make the soil porous, to increase aeration, to incorporate the organic matter, to increase their rate of evaporation and to make it weed free and make it a home for the crop to grow. Tillage requirement is different for different crops and even for the same crop grown under different tillage requirements. Small seeded crops like ragi, onion, Lucerne and berseem require fine seed bed. But crops like jowar, rice, cotton, gram germinate well if the bed is coarse and moderately compact.

It is easier to get desire tilth in sandy and loamy sand soils of oxisol origin but difficult in clay, clay, clay loam and fine soils of vertisol origin. The soil of oxisol origin can be worked upon any time because its opportune time to work with is quite longer whereas in fine soils it is very short. Unless it is tilled at appropriate moisture it creates more problems than solves for getting a good tilth. If left too cloddy, the clods will harden on drying an after a shower of rain the clods will slake and cake. If powdered very finely, after a shower of rain the finer particles will seal the pores and permeability will decrease accelerating runoff. The problem is more if the soil is highly swelling and shrinking type as in most of the black soil areas of the country. At what moisture content the soil needs to be tilled to get required tilth depends more on experience than theory.

Tilth and tillage

Tilth is the physical condition of the soil caused by the practices of tilling called tillage. The practices are ploughing discing, harrowing etc. Tillage is the cause and tilth is the effect. The objective of tillage is to provide a soil condition favourable for growth and development of the crop. If this condition is not satisfactory, it is said the tilth is poor/bad and the soil is not prepared well. Good tilth should provide adequate aeration, warmth and moisture to the crop and ensure good infiltration, besides being favourable for supply of nutrients and growth of microbes and making the soil weed free. Soil consistency and structure provide basis for good tilth. Consistency depends on type and amount of clay and moisture content. Good tilth cannot be got if soils are tilled at their extreme moisture content (very dry or wet).

Accordingly at what stage the soil is to be tilled for good tilth depends on contents of clay (texture), moisture and structure. As the clay content increases soil plasticity increases. Plasticity is a physical property of clay that develops due to hydration and brings adhesion, cohesion consistency and swelling as its companions. Plasticity renders ability to the soil to form a ball when wet that does not come back to its original state on drying. Sandy soil has no plastic property. Ploughing a clayey soil at moisture content forms lumps and clods. These clods do not break easily, remain sharp and angular and do not produce a good tilth. As drying increases these lumps and clods becomes very hard and more power is required to break them into finer sizes. Sandy soils are less plastic. They can be made into a ball only when wet; on drying the ball collapse into single grains. This is why a sandy soil can be tilled even after a few hour of rain whereas a clayey soil needs more time to come to condition for tillage. Ploughing at very low moisture content is not possible and at very high moisture contents produces puddles.

Plasticity can be quantified by its limits and number; though appear qualitative these are reproducible.

Lower plastic limit: This represents the moisture content at which the soil can barely be rolled into thin wire that can break into small pieces. At this limit the soil has maximum film tension and cohesion. These values decrease with increase in moisture content to become practically zero at upper plastic limit. For many soils it is the ideal limit of tillage.

Upper plastic limit: It is the moisture content at which the water films become so thick that cohesion is decreased. Soil may flow under applied force. Cohesive forces are very small and adhesion is maximum.

The difference between these two limits is called plastic number and is a good number index of plasticity.

A well tilled soil is more compressible. Compressibility increases with increase in clay content and moisture contents. With increase in moisture it increases to a maximum value and then decreases. The degree of compressibility increases with decrease in plastic number. When moisture content is higher than plastic range o much water is present that needs more power and forms small and many clods. Ploughing within the moisture range of friable consistency achieves maximum granulation and requires less power.

Puddling is a state of soil tilth; at puddling soil moisture content is very high (even there remains standing water on the top). At puddling the particles separate from one another due to presence of water around all particles; there is no structure and cohesion is zero. At puddling bulk density is low; it increases as the soil particles settle. In sandy, sandy-loam, loam and loamy san soils settling occur quicker than in fine textured soils. For this reason, the coarse soils need to be planted immediately after puddling. Otherwise, the bed becomes hard and seedlings cannot be planted at desired depth.

At what stage the soil is fit to be tilled for what purpose and with what implement depends more on experience, the main principles being that the soil should be ploughed at right moisture content using the right type of implement to achieve the desired tilth.

Problems of supply and factors affecting availability of nutrients

Nitrogen. There are three major forms of nitrogen in soil: a) organic nitrogen associated with the soil humus, b) ammonium nitrogen fixed by certain clay minerals, and c) soluble inorganic ammonium and nitrate compounds.

Most of the nitrogen in surface soils is associated with the organic matter. In this form it is protected from rapid microbial release, only 2-3% a year being mineralized under normal conditions. About half the organic nitrogen is in the form of amino compounds. The form of the remainder is uncertain. Much scientific effort has been devoted to study the organic N – how it is stabilized and how it may be released to forms usable by plants. The process of tying up N in organic forms is called immobilization; its slow release – specifically, organic to inorganic conversion – is called mineralization (Fig 1). Climate, natural vegetation, texture, drainage and other soil factors and cropping are the main factors influence organic matter and nitrogen. The inherent capacity of soil to produce crops is closely and directly related to their organic matter and nitrogen content. Second, the satisfactory level of these two constituents is difficult to maintain in the majority of farm soils. Consequently, the methods of organic matter additions and upkeep should receive priority considerations in all soil management programs.

Some of the released during mineralization of organic N is converted to NO_3^-. Supply of NH_4^+, population of nitrifying organisms, soil pH, soil aeration, moisture and temperature are the important factors affecting nitrification.

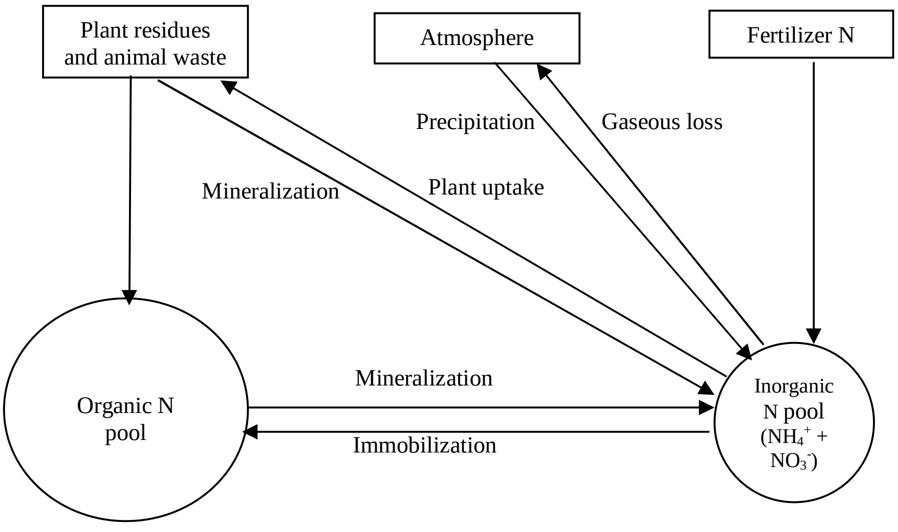


Fig 1 Two major pools of soil N, their primary sources and processes of transfer

Some of the clay minerals (e.g. vermiculite and some smectites) have the ability to fix ammonium nitrogen between their crystal units. The amount fixed varies depending on the nature and amount of clay present. Upto 8% of the total nitrogen in surface soils and 40% of that in subsoils may be in the clay fixed form. In most cases, however, both these figures would be considerably lower. Even so, the nitrogen so fixed is only slowly available to plants and microorganisms. Moisture content and temperature of the soil will affect the fixation of NH_4^+. Freezing and drying increase fixation. Alternate cycles of wetting – drying and freezing – thawing are believed to contribute to the stability of recently fixed NH_4^+. The presence of K^+ will often restrict ammonium fixation since K^+ can also fill fixation sites. There is evidence that fixed NH_4^+ is in equilibrium with exchangeable NH_4^+.

The amount of nitrogen in the form of soluble ammonium and nitrate compounds is seldom more than 1-2% of the total present, except where large applications of inorganic nitrogen fertilizers have been made. This is fortunate since inorganic nitrogen subject to loss from soils by leaching and volatilization. Only enough is needed to supply the daily requirement of the growing crops. The major losses of N from the soil are due to crop removal and leaching, however, under certain conditions, inorganic N can be converted to gases and lost to the atmosphere. The primary pathways of gaseous N losses are by denitrification and NH_3 volatilization.

Phosphorus. The availability of inorganic P is largely determined by a) soil pH, b) soluble Fe, Al and Mn,) presence of Fe, Al and Mn containing minerals, d) available Ca and Ca-minerals e) amount and decomposition of organic matter and activities of microorganisms. The first four factors are interrelated since soil pH drastically influences the reaction of P with the different ion and minerals.

The availability of phosphorus to plants is determined to no small degree by the ionic form of this element. The ionic form in turn is determined by the pH of the solution in which the ion is found. Thus, in highly acid solutions only $H_2PO_4^-$ ions are present. If the pH is increased, first HPO_4^{2-} ions and finally PO_4^{3-} ions dominate. At intermediate pH levels two of the phosphorus ions may be present simultaneously. Thus in solutions at pH 7.0, both $H_2PO_4^-$ and HPO_4^{2-} ions are found. The $H_2PO_4^-$ ion is somewhat more available to plants than is the HPO_4^{2-} ions. In soil, however, this relationship is complicated by the presence or absence of other compounds or ions. For example, the presence of soluble FE an Al under very acid conditions, or Ca at high pH value, will markedly affect the availability of the P.

In addition to pH and related factors, organic matter and microorganisms strikingly affect inorganic P availability. Just as was the case with N, the rapid decomposition of organic matter and consequent high microbial population result in the temporary tying up of inorganic P in microbial tissue. Products of organic decay such as organic acids and humus are thought to be effective in forming complexes with iron an Al compounds. This engagement of Fe and Al reduces inorganic P fixation to a remarkable degree. Apparently the manure was effective in releasing P after it has been fixed as Fe, Al and Ca phosphates.

Even though both phytin and nucleic acids can be utilized as source of P, inorganic source of this element are needed for normal production. Plants commonly suffer from a phosphorus deficiency even in the presence of considerable quantities of organic forms of this element. Just as with inorganic P, the problem is one of availability. In acid soils the phytin is rendered insoluble and thus unavailable because of reaction with Fe and Al. Under alkaline conditions Ca phytate is precipitate and its P is rendered unavailable. The fixation of nucleic acids involves an entirely different mechanism, but the end result – low P availability – is the same. Evidently, nucleic acids are strongly adsorbed by clays, especially montmorillonite.

Potassium. The various forms of K in soils can be classified on the basis of availability in three general groups a) unavailable (feldspars, micas etc), b) readily available (exchangeable and in soil solution) and c) slowly available (non-exchangeable=fixed). The potassium removed by crops is supplied by largely from non-exchangeable forms. Several soil conditions markedly influence the amounts of K fixed. Among the factors are (a) the nature of the soil colloids, (b) wetting and drying, (c) freezing and thawing and (d) the presence of excess lime.

The ability of the various soil colloids to fix K varies widely. For example, 1:1 type clay such as kaolinite and soils in which these clay minerals are dominant fix little potassium. On the other hand, clays of the 2:1 type, such as vermiculite, smectite and fine grained mica (illite), fix K very readily and in large amounts. The mechanism for K fixation is probably the same as that for fixation of the ammonium ion. These two ions do not have as high an affinity for water of hydration as do other cations such as Na^+ and Ca^{2+}. As a consequence they can easily be dehydrated and then their small size is such as to permit them to fit snugly between the silica sheets of adjoining layers in the 2:1 type clay minerals. Once in place, these ions become trapped as a part of the rigid crystal structure, thereby preventing normal crystal lattice expansion and reducing the CEC of the clay. The larger hydrated ions of cations such as Na^+, Ca^{2+} and Mg^{2+} are not able to fit between these layers and consequently escape fixation. Alternate wetting and drying, and freezing and thawing have been shown to result in the fixation of K in non-exchangeable forms as well as its ultimate release to the soil solution. Although the practical importance of this is recognized, its mechanism is not well understood. Applications of lime sometimes result in an increase in K fixation of soils. Under normal liming conditions this may be more beneficial than detrimental because of the conservation of K so affected. Thus, K in well drained soils is not as likely be leached out as drastically as is that in acid soils.

These are conditions however, under which the effects of lime on the availability of K are undesirable. For example, in soils where the negative charge is pH-dependent liming can greatly reduce the level of K in the soil solution. Furthermore, high Ca levels in the soil solution may reduce K uptake by the plant. Finally, K deficiency has been noted in soils with excess calcium carbonate. K fixation as well as cation ratios may be responsible for these adverse effects.

Calcium

Ca in acid, humid region soils occurs largely in the exchangeable form and as primary minerals. In most of these soils, Ca^{2+}, Al^{3+} and H^+ ions dominate the exchange complex. As with any other cation, the exchangeable and solution forms are in dynamic equilibrium. If the activity of solution Ca^{2+} is decreased by leaching or plant removal, Ca^{2+} will desorb to resupply solution Ca^{2+}. Other cations like H^+ and or Al^{3+}, will occupy the exchange sites left by the desorbed Ca^{2+}. Conversely, if solution Ca^{2+} is increased, the equilibrium shifts in the opposite direction, with subsequent adsorption of some of the Ca^{2+} by the exchange complex.

In soils not containing $CaCO_3$, $CaMg(CO_3)_2$, or $CaSO_4$, the amount of soil solution Ca^{2+} depends on the amount of exchangeable Ca^{2+}. Soil factors of the greatest importance in determining the Ca^{2+} availability to plants are the following:

1. Total Ca supply
2. Soil pH
3. CEC
4. Percent %Ca^{2+} saturation on CEC
5. Type of soil colloid
6. Ratio of Ca^{2+} to other cations in solution

Total Ca in very sandy, acid soils with low CEC can be too low to provide sufficient available Ca^{2+} to crops. On such soils supplemental Ca may be needed to supply Ca^{2+}, as well as to convert the acidity. High H+ activity will impede Ca^{2+} uptake. For example, much higher Ca^{2+} concentrations are require for soybean root growth as the pH is lowered from 5.6 to 4.0.

In acid soils, Ca is not readily available to plants at low saturation. For example, a low CEC soil having only 1000 ppm exchangeable Ca^{2+} but representing a high %Ca saturation might well supply plants with more Ca^{2+} compared to 2000 ppm exchangeable Ca^{2+} with a low %Ca saturation on a high CEC soil. In other words, as the %Ca^{2+} saturation decreases in proportion to the total CEC, the amount of Ca^{2+} absorbed by plants decreases.

High Ca^{2+} saturation indicates a favourable pH for plant growth and microbial activity. Also, a prominence of Ca will usually mean low concentration of undesirable exchangeable cations such as Al^{3+} in acidic soils and Na+ in sodic soils. Many crops will respond to Ca application when the %Ca^{2+} saturation falls below 25%. Ca^{2+} saturation <40 to 60% and Al^{3+} saturation > 40 to 60% have lowered cotton yields. Soybeans are reported to suffer Ca deficiency at <20% Ca^{2+} saturation and >65% Al^{3+} saturation. However, normal growth of sugarcane in Hawaii is possible with 12% Ca^{2+} saturation in volcanic soils.

The type of clay influences Ca^{2+} availability; 2:1clays require higher Ca^{2+} saturation than 1:1 clays. Specifically, Montmorillonitic clay require a >70% Ca^{2+} saturation for adequate Ca availability, whereas kaolinitic clays are able to supply sufficient Ca^{2+} at 40 to 50% Ca^{2+} saturation.

Increasing the Al^{3+} concentration in the soil solution reduces Ca^{2+} uptake by corn, cotton, soybeans and wheat. Ca availability and uptake by plants are also influenced by the ratios between Ca^{2+} and other cations in the soil solution. A Ca/total cation ratio of 0.10 to 0.15 is desirable for an adequate Ca^{2+} supply to most crops.

While Ca2+ uptake is depressed by NH^{+}, K^{+}, Mg^{2+}, Mn^{2+} an Al^{3+}, its absorption is increased when plants are supplie with NO_3^- -N. A high level of NO_3^- nutrition stimulates organic anion synthesis and the resultant accumulation of cations, particularly Ca^{2+}.

Magnesium

Mg occurs predominantly as exchangeable and solution Mg^{2+}. The absorption of Mg by plants depends on the amount of solution Mg_{2+}, soil pH, the %Mg saturation on the CEC, the quantity of other exchangeable ions and the type of clay.

Like K, but to a lesser extent, Mg occurs in soils in a slowly available form, which is in equilibrium with exchangeable Mg^{2+}. The formation of these relatively unavailable forms in acid soils is favoured by the presence of soluble Mg compounds and 2:1 clay. Presumably Mg^{2+} could be trapped in the interlayer of expanding and contracting minerals.

Large changes in exchangeable Mg^{2+} can occur following the addition of an Mg liming material. At first, Mg^{2+} levels increase, but as the pH approaches neutrality they decrease. This reduction in attributed to Mg^{2+} fixation through reactions with soluble silica or aluminum chloride and to co-precipitation with $Al(OH)_3$.

Coarse-textured soils in humid regions exhibit the greatest potential for Mg deficiency. These soils normally contain small amounts of total and exchangeable Mg^{2+}. Soils are probably deficient when they contain less than 25 to 50 ppm exchangeable Mg^{2+}.

Exchangeable Mg normally accounts for 4 to 20% of the CEC of soils, but in soils derived from serpentine rock, exchangeable Mg^{2+} can exceed Ca^{2+}. The critical Mg saturation for optimum plant growth coincides closely with this range, but in most instances, %Mg saturation should not be less than 10%.

Reduced Mg uptake in many strongly acid soils is caused by high levels of exchangeable Al^{3+}. Al saturation of 65 to 70% is often associated by high H^{+}. Al saturation of 65 to 70% is often associated with Mg deficiency. The availability of Mg^{2+} can also be adversely affected by high H^{+} activity in acid organic soils where exchangeable Al3+ is not a major cause of the acidity. Mg deficiencies also can occur in soils with high ratios of exchangeable Ca/Mg, where this ration should not exceed 10/1 to 15/1. On many humid region, coarse-textured soils the continued use of high calcic liming materials may increase the Ca/Mg ratio and induce Mg efficiency on certain crops.

High levels of exchangeable K can interfere with Mg uptake by crops. Generally, the recommended K/Mg ratios are <5/1 for fiel crops, 3/1 for vegetables and sugar beets and 2/1 fruit and green house crops.

Competition between NH^{4+} and Mg^{2+} also can lower the Mg^{2+} availability to crops. Ammonium-induced Mg^{2+} stress is greatest when high rates of NH_4^+ fertilizers are applied to low exchangeable Mg^{2+} soils. This interaction may contribute to grass tetany problems. The mechanism of this interaction probably involves the H+ ions released when NH_4^+ is absorbed by roots, as well as the direct effect of NH_4^+.

Sulphur

S is present in soil in both organic and inorganic forms, although nearly 90% of the total S in most non-calcarious surface soils exists in organic forms. The inorganic forms are SO_4^{2-}, adsorbed SO_4^{2-}, insoluble SO_4^{2-} and reduced inorganic S compounds. Solution plus adsorbed SO_4^{2-} represents the readily available fraction of S utilized by plants. There are the similarities between the N and S cycles in that both have gaseous components and their occurrence in soils is associated with OM.

Solution SO_4^{2-} . S is absorbed by roots as SO_4^{2-} ions that reach roots by diffusion and mass flow. Because of anionic nature and solubility of SO_4^{2-} salts, SO_4^{2-} like NO_3^- can readily leached from surface soil. Another factor influencing the loss of SO_4^{2-} is the nature of the cation in the soil solution. Leaching losses of SO_4^{2-} are greatest when monovalent ions such as K^+ and Na^+ predominate, next in the order are Ca^{2+} and Mg^{2+} ions; least in acid soils with appreciable amount of exchangeable Al^{3+}.

Adsorbed SO_4^{2-}. Adsorbed SO_4^{2-} is an important fraction in soils containing large amount of Al and Fe oxides. Adsorbed in highly weathered soils can contribute significantly to the S needs of plants because it is usually readily available but not as rapidly as solution SO_4^{2-}. Sulphate adsorption is readily reversible and is influenced by the following soil properties

1. Clay content and type of clay mineral
2. Hydrous oxides
3. Soil horizon or depth
4. Effect of pH
5. SO_4^{2-} concentration
6. Effect of time
7. Presence of other anions
8. Effect of cations
9. Organic matter

Of all these fractions, the amount and type of soil colloids, pH, SO_4^{2-} concentration and the presence of other ions in the equilibrium solution influence SO_4^{2-} adsorption most significantly.

SO_4^{2-} coprecipitated with $CaCO_3$. This is an important fraction of the total S in calcarious soils. Solubility and availability of SO_4^{2-} coprecipitated with $CaCO_3$ are influenced by several factors including particle size of the $CaCO_3$, soil moisture content, common ion effects and ionic strength.

Reduced inorganic S (S^{2-} and S^o). Sulphides do not exist in well drained upland soils. Under anaerobic conditions in waterlogged soils, there may be accumulations of H_2S formed by the decay of OM, Also SO_4^{2-} present in the soil serves as an electron acceptor for SO_4^{2-} reducing bacteria and is usually reduced to H_2S. Little or no S^{2-} accumulates in oxidized soil (> -150 mv) or with a pH outside the range 6.5 to 8.5. In normal submerged soils well supplied with Fe, the H_2S liberated from OM and from SO_4^{2-} is almost completely removed from solution by reaction with Fe^{2+} from amorphous FeS, which undergoes conversion to pyrire (FeS_2), a substance of longer persistence. In contrast, oxidation of amorphous FeS precipitates may be complete after only a few hours of exposure to the atmosphere. Sulphates added to waterlogged soils are reduced to H_2S. If H_2S is not subsequently precipitated by Fe and other metals, it escapes to the atmosphere.

Elemental S is not a direct product of SO_4^{2-} reduction in reduced soils, but is an intermediate formed during chemical oxidation of S^{2-}. Accumulation of S^o may occur, however, in soils where oxidation of reduced forms of S is interrupted by periodic flooding.

Factors affecting S^o oxidation in soils. Elemental S^o, S^{2-} and other inorganic S compounds can be oxidized in the soil by purely chemical means, but these are usually much slower and therefore of less importance than microbial oxidation. The rate of biological S^o oxidation depends on the interaction of three factors: (1) the microbial population in soil, (2) characteristics of the S source, and (3) soil environmental conditions.

Organic S. Most of the S in surface horizons of well drained agricultural soils is present in organic forms, which account for over 90% of the total S in most noncalcareous surface soils. The proportion of total S existing in organic forms varies considerably according to soil type and depth in the soil profile. There is close relationship between organic C, total N and total S in soils. The C/N/S ratio in most well drained, noncalcarious soils is approximately 120/10/1.4. Generally more variability exists in C/S ratio in soils than in N/S ratio. Differences in the C/N/S ratio among and within types of soils are related to variations in parent material and other soil forming factors such as climate, vegetation, leaching intensity and drainage. The N/S ratio in most soils falls within the narrow range 6 to 8:1. The nature and properties of the organic S fraction in soils are important since they govern the release of plant available S. While much of the organic S in soils remains uncharacterized, three broad groups of S compounds are recognized. These are HI reducible S, C bonded S and residual or inert S.

Micronutrients

Micronutrients are most apt to limit crop growth under the following conditions: a) highly leached acid sandy soils, b) muck soils, c) soils very high in pH and d) soils that have been very intensively cropped and heavily fertilized with macronutrients only. Strongly leached acid sandy soils are low in micronutrients for the same reasons they are deficient in most of the macronutrients. Their parent materials were originally deficient in the elements and acid leaching has removed much of the small quantity of micronutrients originally present. In the case of molybdenum, acid soil conditions also have a markedly depressing effect on availability. The micronutrient contents of organic soils are dependent upon the extent of the washing or leaching of these elements into the bog area as the deposits were formed. In most cases, this rate of movement was too slow to give deposits as high in micronutrients as are the surrounding mineral soils. Intensive cropping of muck soils and their ability to bind certain elements, notably copper, also accentuate trace element deficiencies. Much of the harvested crops, especially vegetables are removed from the land. Eventually the micro-as well as macronutrients must be supplied in the form of fertilizers if good crop yields are to be maintained. Intensive cropping of heavily fertilize mineral soils can also hasten the onset of micronutrient shortage especially if the soils are coarse in texture.

The soil pH has a decided influence on the availability of all the micronutrients except chlorine especially in well aerated soils. Under very acid conditions, molybdenum is rendered unavailable; at high pH values all the cations are unfavourably affected. Over liming or a naturally high pH is associated with deficiencies of Fe, Mn, Zn, Cu and even B. Such conditions occur in nature in many of the calcareous soils of the west.

Factors influencing the availability of micronutrient cations

Each of the four micronutrient cations (Fe, Mn, Zn, Cu) and Co are influenced in a characteristic way by the soil environment. However certain soil factors have the same general effects on the availability of all of them.

Soil pH. The micronutrient cations are most soluble and available under acid conditions. In very acid soils there is abundance of the ions of Fe, Mn, Zn, and Cu. In fact, under these conditions the concentrations of one or more of these elements is often sufficiently high to be toxic to common plants. As the pH is increased, the ionic forms of the micronutrient cations are changed first to the hydroxyl ions of the elements and finally to the insoluble hydroxides. All of the hydroxides of the trace element cations are insoluble, some more so than others. The exact pH at which precipitation occurs varies from element to element an even between oxidation states of a given element.

Oxidation state and pH. Three of the trace element cations (Fe, Mn and Cu) are found in soils in more than one valent state. The lower valent states are encourage by conditions of low oxygen supply and relatively higher moisture level. They are responsible for the subdued subsoil colours, grays and blues in poorly drained soils in contrast to the bright reds, browns, and yellows of well drained mineral soils. The changes from one valent state to another are in most cases brought about by microorganisms an organic matter. In some cases the organisms may obtain their energy directly from the inorganic reactions. In other cases, organic compounds formed by the microbes may be responsible for the oxidation or reduction. In general, high pH favours oxidation, whereas acid conditions are more conducive to reduction.

At pH values common in soils the oxidized states of Fe, Mn and Cu are generally much less soluble than are the reduced states. The hydroxides of these high valent forms precipitate at lower pH values and are extremely insoluble. For example, the hydroxide of trivalent ferric cations precipitate at pH 3.0, whereas ferrous hydroxides does not precipitate until a pH of 6.0 or higher is reached.

Other inorganic reactions. Micronutrient cations interact with silicate clay in two ways. First they may be involved in cation exchange reactions much like those of Ca an H. Second they may be more tightly bound or fixed to certain silicate clays, especially of the 2:1 type. Zinc, manganese, Co and Fe are found as integral elements in these clays. Depending on the conditions, they may be released from the clays or fixed by them. The fixation may be serious in the case of Co and sometimes Zn since these two elements are present in soil in such small amounts.

The application of large quantities of phosphate fertilizers can adversely affect the supply of some of the micronutrients. The uptake of both iron and Zn may be reduced in the presence of excess phosphates. From a practical standpoint, phosphate fertilizers should be used in only those quantities that are required for good plant growth.

Lime induced chlorosis (Fe deficiency) in fruit trees is encouraged by the presence of the bicarbonate ion. The chlorosis apparently results from iron deficiency in soils with high pH. In some way the bicarbonate ion interferes with iron metabolism.

Organic combinations. Each of the four micronutrient cations may be held in organic combination. Microorganisms also assimilate them since they are apparently require for many microbial transformations. The organic compounds in which these trace elements are combined undoubtedly vary considerably, but they include proteins, amino acis and constituents of humus, including the humic acids and acids such as citric and tartaric. Among the most important are the organic complexes, combinations of the micronutrients and certain groups. Such complexes (chelates) may protect the micronutrients from certain harmful reactions, such as the precipitation of Fe by phosphates and vice versa. On the other hand complex formation may reduce micronutrient availability below that necessary for normal plant needs.

Factors influencing the availability of micronutrient anions

Chlorine. Most of the chlorine in soils is in the form of simple, soluble chlorine salts such as potassium chloride. The chloride ions are not tightly adsorbed by negatively charged clays and subject to movement both upward and downward with the water in the profile. In humid regions, one would expect little chlorine to remain in the soil since it would be leached out. In semiarid and arid regions, a higher concentration might be expected, the amount reaching the point of salt toxicity in some of the poorly drained saline soils. In most well drained areas, however, one would not expect high chlorine content in the surface of arid region soils. Accretions of Cl from the atmosphere are believed to be sufficient to meet crop needs. Salt spray alongside ocean beaches evaporates, leaving sodium chloride dust, which move into the atmosphere, to be returned later dissolved in snow and rain. The amount added to the soil in this way varies (20 kg/ha/year) according to the distance from the salty boy of water and other factors. In any case, this form of accretion plus that commonly added as an incidental component of commercial fertilizers, should largely prevent a field deficiency of chlorine.

Boron. Boron is most soluble under acid conditions. It apparently occurs in acid soils in part as boric acid (H_3BO_3), which is readily available to plants. In quite acid sandy soils, soluble B fertilizers may be leached downward with comparable ease. In heavier soils, especially if they are not too acid, this rapid leaching does not occur. At higher pH B is less easily utilized by plants. This may be due to lime induced fixation of this element by clay and other minerals, since the Ca and Na borates are reasonably soluble. In any case over liming can and often does result in a deficiency of B. B is held in organic combinations from which it may be released for crop use. The content of this nutrient in the top soil is generally higher than that in the subsoil. This may in part account for the noticeably greater B deficiency in periods of dry weather. Apparently, during drought periods plant roots are forced to exploit only the lower soil horizons, where the B content is quite low. When the rains come, plant roots again can absorb B from the topsoil, when its concentration is highest.

Molybdenum. Soil pH is the most important factor influencing the availability and plant uptake of molybdenum. At low pH the relatively unavailable H_2MoO_4 and $HMoO_4^-$ forms are prevalent, whereas the more readily available MoO_4^{2-} anions is dominant at pH above 5 or 6. The MoO_4^{2-} ion is subject to adsorption by oxides of iron and possibly aluminum just as is phosphate, but calcium molybdate is much more soluble than its phosphorus counterpart. The liming of acid soils will usually increase the availability of Mo. The utilization of P by plant seems to favour that of Mo and vice versa. For this reason, Mo salts are often applied along with superphosphate to Mo deficient soils. The practice apparently encourages the uptake of both elements and is a convenient way to add the extremely small quantities of Mo required. A second common anion, the sulphate, seed to have the opposite effect on plant uptake of Mo. Sulphate reduces Mo uptake, although the specific mechanisms for this antagonism is not yet known.

Relation between nutrient supply and crop growth

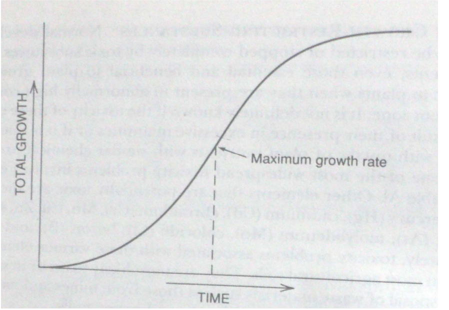


Fig 1. Generalized curve illustrating the growth pattern of an annual plant

Growth is defined as the progressive development of an organism, and there are several ways in which this development can be expressed. There have been various mathematical models to describe or define plant growth. These models can be useful in predicting the crop response to plant nutrients and other growth factors. The rate of plant growth changes with time and the maximum growth rate occurs at a point on the curve where the slope is maximum. Although the general shape of the curve is determined by the genetic constitution of each plant species and by the environment, numerous growth factors can alter the shape of the growth curve. Although the growth curves are helpful in understanding the general pattern of plant development, they indicate nothing about the factors affecting growth.

Plant growth is a function of various growth factors, which may be expressed as

$G= f(x_1,x_2,x_3, \ldots\ldots\ldots\ldots, x_n)$ (1)

Where, G is some measure of plant growth and $x_1,x_2,x_3, \ldots\ldots\ldots\ldots, x_n$ the various growth factors.

If all but one of the growth factors are present in adequate amounts, an increase in the quantity of this limiting factor will generally increase plant growth. This relationship was renamed the law of minimum by Liebig. This however, is not a simple linear relationship. Although linear responses occur over small portions of the yield response curve, the addition of each successive increment of a growth factor results in a progressive smaller increase in growth (Fig 1.).

In 1909, E A Mitscherlich of Germany was among the first to quantify the relationship between plant growth response and the addition of a growth factor. He state that “ yield can be increased by each single growth factor even when it is not present in the minimum as long as it is not present in the optimum” and that an “increase in yield of crop as a result of increasing a single growth factor is proportional to the decrement from the maximum yield obtainable by increasing the particular growth factor”.

Mitscherlich’s Equation

The growth equation defined in the preceding section is a generalized expression relating growth to all the factors involved. Mitscherlich developed an equation that related growth to the supply of plant nutrients. He observed that when plant were supplied with adequate amounts of all but one nutrient, their growth was proportional to the amount of this one limiting element that was supplied to the soil. Plant growth increased as more of this element was added, but the increase in growth was progressively smaller with each successful addition of the element (Fig 2).

Mitscherlich expressed this mathematically as

$dy/dx= (A-y)c$, (2)

where dy is the increase in yield resulting from an increment dx of the growth factor x, A is the maximum possible yield obtained by supplying all growth factor in optimum amounts, y is the yield obtained after any given quantity of the factor x has been applied, and c is a proportionality constant that might be considered as an efficient factor.

The Mitscherlich equation could be reduced to

$Y= A(1-10^{-cx})$ (3)

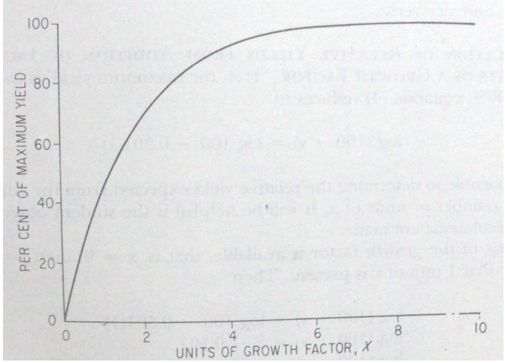


Fig 2 Percentage of maximum yield as function of increasing aditions of a growth factor, x

None of these expressions is conviently hanle as written, but they may also be stated as the integral of Eq 2 using common logarithms:

$Log(A-y)= \log A – c(x)$ (4)

The symbols used are the same as those in Eq 2. If the function is graphed the curve obtained appears as shown in Fig 2.

Calculation of the value of the proportionality factor c

The constant c is Eq 4 becomes 0.301 when yields are expressed on relative basis of A=100 and x is a quantity of a growth factor. This is shown by first rewriting Eq 4 as follows:

$\log A – \log (A-y) = cx$ or $\log (A/(A-y) =cx)$

When nutrient supply (x) is increased to produce 50% of the maximum yield,

$A/(A-y) = 100/50 = 2$

Thus $\log 2 = c(1)$ and $c = 0.301$

The value of c varies with the particular growth factor. Mitscherlich found that the value of c was 0.122 for N, 0.60 for P and 0.4 for K. He claimed that it was constant for each fertilizer nutrient, independent of the crop, the soil, or other conditions. The average value for c in British experiments conducted before 1940 was 1.1 for N, 0.80 for P, and 0.80 for K. in numerous other investigations, it has been observed that c is not a constant term and that it varies rather widely for different crops grown under different conditions.

The significance of the c term is that it gives an indication of whether the maximum yield level can be achieved by a relatively low or high quantity of the specific growth factor. When the value of c is small, a large quantity is needed and vice versa.

Calculation of relative yields from addition of increasing amounts of a growth factor

If A, the maximum yield, is considered to be 100%, Eq 4 reduces to

$Log(100-y) = \log 100 – 0.301(x)$ (5)

It is possible to determine the relative yield expected from the addition of a given number of units of x. if none of the growth factor is available, that is, x = 0, then y = 0; but suppose that 1 unit of x is present. Then

$\log (100 – y) = \log 100 – 0.301 (1)$

$\log (100 - y) = 2 - 0.301$
$\log (100 - y) = 1.699$
$100 - y = 50$
$y = 50$
and the addition of 1 unit of the growth factor x results in ayield that is 50% of the maximum. Assume, however, that 2 units of the growth factor were present. In this instance
$\log (100 - y) = \log 100 - 0.301\ (2)$
$\log (100 - y) = 2 - 0.602$
$\log (100 - y) = 1.398$
$100 - y = 25$
$y = 75$

The same operation may be repeated until 10 units of the growth factor have been added. The result of such a series of calculation is given in Table 1.

Table 1 Example of diminishing returns to increasing addition of factor x described by the Mitscherlich Equation

Units of growth factor, x	Yield (%)	Increase in yield (%)
0	0	
1	50	50
2	75	25
3	87.5	12.5
4	93.75	6.25
5	96.88	3.125
6	98.44	1.562
7	99.22	0.781
8	99.61	0.390
9	99.80	0.195
10	99.90	0.098

It is obvious that the successive increases of a growth factor result in a yield increase that 50% of that resulting from addition of the preceding unit until a point is reached at which further increases are of no consequence. Again this relationship is shown in Fig 2.

Plant growth as a function of nutrient input is logarithmic and generally follows a pattern of diminishing increase, as expressed in the Mitscherlich equation (Fig 2). The growth of annual plants does tend to reach a maximum with increasing input of nutrients under a particular set of environmental conditions and often the plants that produce the highest yield of dry matter have the lowest percentage of N in their tissues. However, it remains for posterity to determine whether a single expression can be developed that will universally predict the amount of growth that can be produced from the input of a given quantity of plant nutrients when environmental and genetic growth factors adequately described.

Bray’s Nutrient Mobility Concept

A modification of the Mitcherlich concept was proposed by R bray and co-workers at the University of Illinois. In brief, crop yields obey the percentage sufficiency law of Mitcherlich for such elements as P and K, which are relatively immobile in the soil. This concept, in turn, is based on Bray’s nutrient mobility concept, which states that

> as the mobility of a nutrient in the soil decreases, the amount of that nutrient needed in the soil to produce a maximum yield (the soil nutrient requirement) increases from a value determine by the magnitude of the yield and the optimum percentage composition of the crop, to a constant value.

The magnitude of this constant is independent of the amount of crop yield, provided that the kind of plant, planting pattern and rate, and fertility pattern remain constant and that similar soil and seasonal conditions prevail. Bray further states that for a mobile element such as NO3-N, Liebig's law of the minimum best expresses the growth of a crop. Bray has modified the Mitscherlich equation to

$\log(A-y) = \log A - C_1b - Cx$

where A, Y and x have the connotations already given; C_1 is a constant representing the efficiency of b for yields in which b represents the amount of an immobile but available form of nutrient, such as P or K, measureable by some suitable soil test; an C represents the efficiency factor for x, which is the added fertilizer form of the nutrient b.

Bray showed that the values for C_1 and C are specific and fairly constant over a wide area, regardless of yield and season, for each of the following crops: corn, wheat and soybeans. The factors that will alter the values, however, are wide differences in soil series, plant population and planting patterns, and distribution in the soil of the immobile nutrient under study. Hence, as management practices and fertilizer placement methods are changed to obtain higher yields, the value change and must be reexamined.

Limited Applications of Growth Expressions

Numerous equations or functions have been used to describe the relation between plant growth and nutrient input. Steenbjerg and Jakobsen of Denmark, in commenting the variability among growth response curves, point out that "the constants in formulas are not constants because the variables in the formulas are not independent variables." Factors other than nutrient interactions obviously affect the shape of yield curves. They include other environmental factors, which were discussed in the preceding sections. The change in the shape and position of yield-plant nutrient input curves with changes in environmental condition is of the greatest importance to the practical agriculturalist. Understanding the interactions between these crop growth factors is essential to identifying and crop management practises needed for profitable crop production.

The term *limiting growth factor* has been clearly illustrated by the variable nature of the response curves and surfaces previously discussed. If, for example, a crop has inadequate moisture, the application of a given amount of fertilizer will provide a lower yield than if moisture were adequate. Another example and an important one, is the application of fertilizer to a crop growing on a soil that is too acid for maximum growth, regardless of the amount of fertilizer added. If lime is not applied, acidity becomes the limiting factor that reduces the yield response to fertilizer and the farmer's return on the investment. The importance to practical farm operations of the concept of growth patterns and how it may be altered by various limiting factors cannot be overstated.

Organic farming – Basic concepts and definitions

Sustainable development has caught the imagination and action all over the world for more than a decade. Sustainable agriculture is necessary to attain the goal of sustainable development. According to the Food and Agriculture Organization (FAO), sustainable agriculture "is the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of environment and conserving natural resources". All definitions of sustainable agriculture lay great emphasis on maintaining an agriculture growth rate, which can meet the demand for food of all living things without draining the basic resources. Organic farming is one of the several approaches found to meet the objectives of sustainable agriculture. Many techniques used in organic farming like inter-cropping, mulching and integration of crops and livestock are not alien to various agriculture systems including the traditional agriculture practiced in old countries like India. However, organic farming is based on various laws and certification programmes, which prohibit the use of almost all synthetic inputs, and health of the soil is recognized as the central theme of the method. Organic products are grown under a system of agriculture without the use of chemical fertilizers and pesticides with an environmentally and socially responsible approach. This is a method of farming that works at grass root level preserving the reproductive and regenerative capacity of the soil, good plant nutrition, and sound soil management, produces nutritious food rich in vitality which has resistance to diseases.

The farming being practiced for the last three decades in India has increasingly been found non-sustainable. The system is oriented towards high production without much concern for ecology and the very existence of man himself. Adverse effects of modern agricultural practices not only on the farm but also on the health of all living things and thus on the environment have been well documented all over the world. Application of technology, particularly in terms of the use of chemical fertilizers and pesticides all around us has persuaded people to think aloud. Their negative effects on the environment are manifested through soil erosion, water shortages, salination, soil contamination, genetic erosion, etc.

Organic farming is one of the widely used methods, which is thought of as the best alternative to avoid the ill effects of chemical farming. Organic farming is often associated directly with, *"Sustainable farming."* However, organic farming and sustainable farming, policy and ethics-wise are two different terms. The origin of organic farming goes back, in its recent history, to 1940s. During this period, the path breaking literature on the subject published by J.I. Rodale in the United States, Lady Balfour in England and Sir Albert Howard in India contributed to the cause of organic farming.

There is not one universally accepted definition of organic farming. Most organic farmers and organic consumers expect that organic farming methods should include natural, not chemical growth and production methods such as crop rotation, mechanical cultivation, animal manures, green manure and integrated pest management.

In 1980, the USDA released a landmark report of organic farming. The report defined organic farming as a production system, which avoids or largely excludes the use of synthetic organic fertilizers, pesticides, growth regulators and livestock feed additives. Organic farming systems largely depends on crop rotations, crop residues, animal manures, green manures, off-farm organic wastes, mechanical cultivation, mineral bearing rocks and aspects of biological control to maintain soil productivity, supply plant nutrients and to control insects, pathogens and weeds (Sharma 2002).

According to Codex definition (FAO), organic agriculture is production management system, which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and biological activity. It emphasizes the use of management practices in preferences to the use of off-farm inputs, taking into account that regional conditions require locally adopted systems. This is accomplished by using, where possible, agronomic, biological and mechanical methods, as opposed to using synthetic materials to fulfill any specific function within the system.

Organic farming is the form of agriculture that relies on crop rotation, green manure, compost, biological pest control, organically approved pesticide application and mechanical cultivation to maintain soil productivity and control pests, excluding or strictly limiting the use of synthetic fertilizers and synthetic pesticides, plant growth regulators, livestock antibiotics, food additives, and genetically modified organisms**.**

Organic agricultural methods are internationally regulated and legally enforced by many nations, based in large part on the standards set by the International Federation of Organic Agriculture Movements (IFOAM), an international umbrella organization for organic organizations established in 1972. IFOAM defines the overarching goal of organic farming as follows:

"Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.." —International Federation of Organic Agriculture Movements.

In the NPOP **document ORGANIC AGRICULTURE is defined** as "a system of farm design and management to create an eco system, which can achieve sustainable productivity without the use of artificial external inputs such as chemical fertilizers and pesticides".

Principles of organic agriculture:

Principle of health: Organic agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one an indivisible.

Principle of ecology: Organic agriculture should be based on living ecological systems and cycles, work with them and help sustain them.

Principle of fairness: Organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.

Principle of care: Organic agriculture should be managed in a precautionary and responsible manner to protect the health and well being of current and future generations and the environment

Concept of organic farming

Organic farming endorses the concept that the soil, plant, animals and human beings are linked. Therefore, its goal is to create an integrated, environmentally sound, safe and economically sustainable agriculture production system. Soil is a living system linked to an organism with different components. Human interact with these natural components (minerals, organic matter, micro-organisms, animals and plants) to achieve harmony with nature and create a sustainable agricultural production. A key feature of organic farming is the primary dependence on natural resource and those developed locally (green manures, crop residues, farm wastes etc.), rather than external inputs (especially synthetics). The farmer manages self-regulating ecological and biological processes for sustainable and economic production of products. Organic farming systems do not use toxic agrochemical inputs (pesticides, fungicides, herbicides and fertilizers). Instead, they are based on development of biological diversity and the maintenance and replenishment of soil productivity.

Organic farming is very much native to this land. Whosoever tries to write a history of organic farming will have to refer India and China. The farmers of these two countries are farmers of 40 centuries and it is organic farming that sustained them. This concept of organic farming is based on following principles:

- Nature is the best role model for farming, since it does not use any input nor demand unreasonable quantities of water.
- The entire system is based on intimate understanding of nature's way. The system does not believe in mining of the soil of its nutrients and do not degrade it in any way for today's needs.
- The soil in this system is a living entity.
- The soils living populations of microbes and other organisms are significant contributor to its fertility on a sustained basis and must be protecte and nurtured at all cost.
- The total environment of the soil, from soil structure to soil cover is more important.

Organic farming describes two major aspects of alternative agriculture:

- Substitution of manures, farm organic resources and biofertilizers (INM) for inorganic fertilizers.
- Biological and cultural pest, diseases and weed management (IPM, IDM and IWM) instead of chemical control.

The key characterization of organic farming in relation to soil fertility and crop production includes:

- Protecting the long-term fertility of soil by maintaining soil organic matter levels, fostering soil and biological activity and careful mechanical inversion,
- Plant nutrients supply through relatively insoluble nutrient sources (organic sources) made available by the action of soil microbes,
- Meeting crop need of nitrogen through nitrogen fixation by leguminous crops in the cropping systems and recycling of farm organic materials including crop residues and livestock wastes,
- Importance of crop rotation, natural predators, resistance varieties and other agronomic manipulations of plant protection including weed management, and
- Biodiversity management, soil and environmental health.

Organic agriculture is viable alternative to conventional agriculture. It protects the soil from erosion, improves natural resource base and sustains production at levels commensurate with carrying capacity of managed agro-ecosystem because of reduced dependence on fertilizers and plant protection chemicals. It minimizes environmental pollution and aids in regeneration of ecosystem.

Organic farming is one of several to sustainable agriculture and many of the techniques used (intercropping, crop rotation, ploughing, mulching, integration of crops and livestock etc) are practices under various agricultural systems. What makes organic farming unique is that almost all synthetic inputs are prohibited and soil health improving agronomic practices are mandated.

Organic farming is the pathway that leads to live in harmony with nature. Organic agriculture is the key to sound development and sustainable environment. It minimizes environmental pollution and the use of non-conventional natural resources (resources other than traditional resources). It conserves soil fertility and soil erosion through implementation of appropriate conservation practices.

DEFINITIONS

ACCREDITATION: Accreditation means Registration by the National Accreditation Body for certifying organic farms, products and processes as per the National Standards for Organic Products and as per the guidelines of the National Accreditation Policy and Programme for organic products.

ACCREDITED PROGRAMME: Means programme of accrediting Inspection and Certification Agencies which have been accredited by the Accreditation Agency and which have agreed to comply with the Accreditation contract.

APPEAL: Shall be the process by which an Inspection and Certification Agency can request reconsideration of a decision taken by the Accreditation Agency or an operator can request reconsideration of a decision by the Certification Agency.

BUFFER ZONE: A clearly defined and identifiable boundary area bordering an organic production site that is established to limit application of, or contact with, prohibited substances from an adjacent area.

CERTIFICATE: Would mean a document issued by an accredited agency declaring that the operator is carrying out the activities or the stated products have been produced in accordance with the specified requirements in accordance with the National Standards for Organic Products.

CERTIFICATE OF REGISTRATION: Shall mean the document issued by the Inspection and Certification Agency, declaring that the operator is licensed to use the certificate on specified products.

CERTIFICATION: Shall be the procedure by which a written assurance is given by the Certification Agency that a clearly identified production or processing system has been methodically assessed and conforms to the specified requirements.

CERTIFICATION MARK: Shall mean certification programme’s sign, symbol or logo which identifies the products as being certified according to the National Standards for Organic Products.

CERTIFICATION PROGRAMME: Shall mean the system operated by an Inspection and Certification Agency in accordance with the criteria for carrying out certification of conformity as laid down herein.

CERTIFICATION TRANSFERENCE: The formal recognition by an Inspection and Certification Agency of another Certification programme or Agency or projects or products certified by that programme or Agency, for the purpose of permitting its own certified operators to trade or process under the programme’s own certification mark, the products which are certified by the other programme.

CHAIN OF CUSTODY: All relevant steps in the production chain including growing, harvesting, processing, handling and related activities detailed in Section 4 of the accreditation criteria that have been inspected and certified, as appropriate.

CONVERSION: The process of changing an agricultural farm from conventional to organic farm. This is also called transition.

CONVERSION PERIOD: The time between the start of organic management, and the certification of crops as organic.

DECLARATION OF INTEREST: Declaration of no personal / commercial conflict of interest by all concerned involved in the process of inspection and certification.

GROUP CERTIFICATION: Certification of an organized group of producers, processors and exporters with similar farming and production systems and which are in geographical proximity.

HAZARD ANALYSIS CRITICAL CONTROL POINT (HACCP): A systematic process that identifies food safety hazards, critical control points, critical limits, corrective actions and documentation and integrates monitoring procedures to ensure food safety.

OR

The Hazard Analysis Critical Control Point (HACCP) system is a science based on systematic approach to producing safe food. Food safety management systems based on HACCP are internationally recognized as the most effective way to ensure food safety and minimize the risks of food poisoning.

INPUTS BANNED: Those items, the use of which is prohibited in organic farming.

INPUTS PERMITTED: Those items that can be used in organic farming.

INPUTS RESTRICTED: Those items that are allowed in organic farming, in a restricted manner, after a careful assessment of contamination risk, natural imbalance and other factors arising out of their use. Farmers should consult the certifying agency.

INSPECTION: Shall include the site visit to verify that the performance of an operation is in accordance with the production or processing standards.

INSPECTION AND CERTIFICATION AGENCY: Shall be the organization responsible for Inspection and Certification.

INSPECTION AGENCY: Shall mean the agency that performs inspection services as per the National Accreditation Policy and Programme.

INTERNAL CONTROL SYSTEM: A documented quality assurance system that allows the external certification body to delegate the inspection of individual group members to a body identified from within the operators of the group.

INTERNAL REVIEW: Shall mean an assessment of the objectives and performance of a programme by the Certification or the Accreditation Agency itself.

LABELLING: Means any written, printed or graphic matter that is present on the label, accompanies the food, or is displayed near the food, including that for the purpose of promoting its sale or disposal.

NATIONAL ACCREDITATION BODY (NAB): Shall be the agency set up by the Steering Committee for National Programme for Organic Production for accrediting Inspection and Certification Agencies.

PARALLEL PRODUCTION: Shall mean any production where the same unit is growing, breeding, handling or processing the same products both in a certified organic and a non-certified organic system. Similarly a situation with “organic” and “in conversion” production of the same product is also parallel production.

PART CONVERSION: Shall be when part of a conventional farm or unit has already been converted to organic production or processing and a part is in the process of conversion.

SPLIT PRODUCTION: Where only part of the farm or processing unit is certified as organic. The remainder of the property can be (a) non-organic, (b) in conversion or (c) organic but not certified. Also see parallel production.

TRANSACTION / IMPORT CERTIFICATE: Document issued by a certification body declaring that the specified lot or consignment of goods is derived from production and / or processing system that has been certified.

Unit II

Criteria of essentiality of nutrients; essential plant nutrients- their functions and deficiency symptom

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

Criteria of essentiality

Plant analysis reveals that plant body contains about 30 elements and in some cases as many as 60 elements. The presence of several elements in plant does not mean that all these are essential for plants. Arnon and Stout (1939) proposed criteria of essentiality which was refined by Arnon (1954). An element is considered as essential, when plants cannot complete vegetative or reproductive stage of life cycle due to its deficiency; when this deficiency can be corrected or prevented only by supplying this element; and when the element is directly involved in the metabolism of the plant. This criterion is considered as too rigid from practical point of view. According to this criterion, sodium is considered as nonessential. However, sodium is known to increase yield of several crops such as sugar beet, turnip and celery. Therefore, a farmer considers sodium as an essential element. Nicholas (1961) proposed the term 'functional nutrient’ for any mineral element that functions in plant metabolism whether or not its action is specific. With this criterion, sodium, cobalt, vanadium, nickel and silicon are also considered as functional nutrients in addition to 16 essential elements. Although, Al is not an essential plant nutrient, its concentrations in plant can be high when soils contain relatively large amounts of Al in soil solution. In fact, plants absorb many non-essential elements and over 60 elements have been identified in plant materials. When plant material is burned, the remaining plant ash contains all the essential and non-essential mineral elements except C, H, O, N and S which are burned off as gases. The plant content of mineral elements is affected by many factors and their concentration in crops varies considerably. Plant nutrient data are valuable to successful fertilizer management programs and can be used to help establish fertilizer recommendations.

Essential elements

Human beings (19): C, H, O, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, Cl, Na, I, Co, and F.
Farm animals (18): C, H, O, N, P, K, Ca, Mg, S, Fe, Mn, Na, Zn, Cu, Mo, Cl, I, and Co.
Plants (16): C, H, O, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, Cl and B.

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

Table: Forms of mineral elements absorbed by plants

Mineral element	Ionic form	Non-ionic form
Nitrogen (N)	$NH_4{}^{+}$, NO_3^{-},	$CO\ (NH_2)_2$
Phosphorus (P)	$H_2PO_4{}^{-}$. HPO_4^{--}	Nucleic acid, phytin
Potassium (Kalium-K)	K^{+}	
Calcium (Ca)	Ca^{2+}	
Magnesium (Mg)	Mg^{2+}	
Sulphur (S)	$S0^{4''}$	SO_2
Iron (Fe)	Fe^{2+}, $Fe3^{+}$	$FeSO_4$ with EDTA
Manganese (Mn)	Mn^{2+}	$MnSO_4$ with EDTA
Zinc (Zn)	Zn^{2+}	$ZnSO_4$ with EDTA
Copper (Cu)	Cu^{2+}	$CuSO_4$ with EDTA
Boron (8)	$B_4O_7{}^{2-}$, $H_2BO_3^{-}$, $HB0_3{}^{2-}$	
Molybdenum (Mo)	$Mo\ O_4{}^{2-}$	
Chlorine (CI)	CI^{-}	

EDTA = ethylenediaminetetraeetic acid

CLASSIFICATION OF ESSENTIAL ELEMENTS

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

Amount of Nutrients

Depending on the quantity of nutrients present in plants, they can be grouped into three:

Basic Nutrients. The basic nutrients viz. carbon, hydrogen and oxygen, constitute 96 per cent of total dry matter of plants. Among them, carbon and oxygen constitute 45 per cent each. The total dry matter produced by rice crop in one season is about 12 t/ha. In this 5.4 t is carbon, 5.4 t is oxygen and 0.7 t is hydrogen.

Macronutrienls. The nutrients required in large quantities are known as macronutrients. They are N, P, K, Ca, Mg, and S. Among these, N, P and K are called primary nutrients and Ca, Mg and S are known" as secondary nutrients. The later are known as secondary nutrients as they are inadvertently applied to the soils when N, P and K fertilizers, which contain these nutrients, are used.

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

Functions in the Plant

Based on the functions, nutrients are grouped into four:

1. (1) Elements that provide basic structure to the plant-C, H and O.
2. (2) Elements useful in energy storage, transfer and bonding-N, S and P. These are accessory structural elements which are more active and vital for" living tissues.
3. (3) Elements necessary for charge balance-K, Ca and Mg. These elements act as regulators and carriers.
4. (4) Elements involved in enzyme activation and electron transport_Fe, Mn, Zn, Cu, B, Mn and Cl. These elements are catalysers and activators.

Mobility in the Soil

Mobility of nutrients in the soil has considerable influence on availability of nutrients to plants and method of fertilizer application. For plants to take up these nutrients, two processes are important: (1) movement of nutrient ions to the absorbing root surface, and (2) roots reaching the area where nutrients are available. In the case of immobile nutrients, the roots have to reach the area of nutrient availability and forage volume is limited to root surface area. For highly mobile nutrients, the entire volume of the root zone is forage area.

Based on the mobility in the soil, the nutrient ions can be grouped as mobile, less mobile and immobile. The mobile nutrients are highly soluble and are not adsorbed on clay complex; e.g.: $N0_3^-$, $S0_4^{2-}$, $B0_3^-$, Cl^-, Mn^{2+}. Less mobile nutrients are also soluble, but they are adsorbed on clay complex and so their mobility is reduced; e.g.: NH^+, K^+, Ca+, Mg^{++}, Cu^{++}. Immobile nutrient ions are highly reactive and get fixed in the soil; e.g.: HPO_4^{2-}, $H_2PO_4^-$, Zn^{++}.

Mobility in Plants

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

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

Chemical Nature

The nutrients can be classified into cations and anions and metals and non-metals based on their chemical nature.

Cations: K, Ca, Mg, Fe, Mn, Zn, Cu,
Anions: NO_3, H_2, PO_4, SO_4
Metals: K, Ca, Mg, Fe, Mo, Zn, Cu,
Non-metals: N, P, S, B, Mo, Cl

Functions/Role of plant nutrients

Every nutrient plays a specific role in nutrition, growth and development of plants. These roles may be described as under:

Carbon. It is available in abundance from air. Green plants for photosynthetic activities use CO_2. It is also required for cell formation in plants. About 45% or more part, of the plant tissues is made up of carbon.

Hydrogen. It is essential for cell and tissue formation in plants. This is obtained from water and is required for energetic reactions. It forms about 6% parts of the plant tissues.

Oxygen. Plants take oxygen from air and water. It forms about 43% parts of the plant structure. It is required for photosynthetic and respiratory activities. It helps in formation of tissues and cells.

Mineral elements

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Nutrient deficiency symptoms

Short supply of any nutrient leads to adverse cellular metabolism, growth and development of plants. Such plants bear abnormal symptoms termed as visual deficiency symptoms. The deficiency can be corrected or prevented by supplying that nutrient. Visual nutrient deficiency symptoms can be caused by many other plant stress factors, therefore, caution should be exercised when diagnosing deficiency symptoms. The following terms are commonly used to describe levels of nutrients in plants:

Deficient: When the concentration of an essential element is low enough to limit yield severely and distinct deficient symptoms are visible. Extreme deficiency can result in plant death. With moderate or slight deficiency symptoms are visible, but yields will still be reduced.

Critical range: The nutrient concentration in the plant below, which a yield response to added nutrient occurs. Critical levels or ranges vary among plants and nutrients, but occurs somewhere in the transition between nutrient deficiency and sufficiency.

Sufficient: The nutrient concentration range in which added nutrient will not increase yield but can increase nutrient concentration. The term luxury consumption is often used to describe nutrient absorption by the plant that does not influence yield.

Excessive or toxic: when the concentration of essential or other element is high enough to reduce plant growth and yield. Excessive nutrient concentration can cause an imbalance in other essential nutrients, which also can reduce yield.

Yield is severely affected when a nutrient is deficient, and when the nutrient deficiency is corrected, growth increases more rapidly than nutrient concentration. Under severe deficiency, rapid increases in yield with added nutrient can cause a small decrease in nutrient concentration. This is called the Steenberg effect and results from dilution of nutrient in the plant by the rapid plant growth. When the concentration reaches the critical range, plant yield is generally maximized. Nutrient sufficiency occurs over a wide range, wherein yield is unaffected. Increases in nutrient concentration above the critical range indicate that the plant is absorbing nutrients above that needed for maximum yield. This luxury consumption is common in most plants. Elements absorbed in excessive quantities can reduce plant yield directly through toxicity or indirectly by reducing concentrations of other nutrients below their critical ranges.

Identification of deficiency symptoms

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

The region of appearance of deficiency symptoms depends on mobility of nutrient in plants.

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

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

Deficiency symptoms on old leaves

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

Without dead spots. The characteristic deficiency symptom of nitrogen is uniform yellowing of the leaves including the veins. The leaves become stiff and erect especially in cereals. The leaf may detach after a little forceful pull in extreme deficiency in dicotyledonous crops. Cereal crops show characteristic 'V' shaped yellowing at the tip of lower leaves.

In phosphorus deficiency, leaves are small, erect, unusually dark green with a greenish red, greenish brown or purplish tinge. The rear side develops bronzy appearance.

Magnesium deficiency also causes yellowing, but differs from that of nitrogen. The yellowing takes place in between the veins and the veins remain green. The leaf is not erect. The leaf detaches very easily and may be shed by blowing wind. Necrosis (death of tissues) occurs in extreme cases only in the margins.

With dead spots. In potassium deficiency, yellowing starts from tips or margins of leaves extending to the centre of leaf base. These yellow parts become necrotic (dead spots) very soon. There is sharp difference between green and yellow and yellow and necrotic portions. The dead spots appear particularly on margins and tips. .

Molybdenum deficiency causes translucent spots of irregular shape in between the veins of leaves. These spots are light green, yellow or brown in colour. The affected spots are impregnated with resinous gum which exudes from rear side of the leaf from the reddish brown spots.

Defficiency diseases of Mo

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

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

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

Deficiency symptoms on new leaves

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

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

Manganese deficiency diseases:

Grey spec of oats: Middle and old leaves of oats develop small grey or buff coloured patches which are prominent near the margins and come upto slightly above the base. These patches convert into brown streaks of necrotic areas and leaves wither. The growth of both top and roots is stunted and grain yield becomes miserably poor.

Speckled yellows of sugar beet: In this interveinal areas of sugar beet develop yellowish-green chlorotic mottled areas. The chlorotic areas turn into necrotic ones resulting into breaking of lamina. The leaf margins of such leaves roll upwards and turn into triangular or an arrow-shaped outline which remain upright.

Marsh spot of peas: When plants of garden peas and other beans are affected with Mn deficiency at fruiting stage, the central part of the cotyledons become brown and necrotic which disintegrate and become hollow at later stages.

Pahala blight of sugarcane: The interveinal space of middle and young leaves of the affected sugarcane plants develop chlorotic tripes which first turn into necrotic spots and later into red stripes. These leaves split and dry later.

Frenching of tung trees: Manganese deficiency causes chlorotic mottling between the veins, which later turn into necrotic spots and affected leaves shed prematurely.

Veins not Remaining Green. The leaf becomes yellowish due to sulphur deficiency, but looks like nitrogen deficient leaf. The leaf is small and the veins are paler than interveinal portion. No dead spots appear. Plant does not lose the lower leaves as in the case of N deficiency.

In copper deficiency, leaf. is yellowish tending towards whiteness. In extreme deficiency, chlorosis of veins occur and leaf loses lustre. Leaf is unable to retain its turgidity and hence, wilting occurs. Leaf detaches due to water soaked conditions of the .base of petiole. .

Terminal buds

The deficiency symptoms of Ca and B are many times seen on new leaves. However, it is easy to recognize their deficiency symptoms on the terminal buds or growing points than on new leaves.

In calcium deficiency, the bud leaf becomes chlorotic white with the base remaining green. About one-third chlorotic portion of the tip hooks downward and becomes brittle. Death of terminal bud occurs in extreme cases.

Boron deficiency causes yellowing or chlorosis which starts from the base to tip. The tip becomes very much elongated into a whip like structure and becomes brownish or blackish brown. Death of the terminal bud occurs in extreme cases.

Boron deficiency diseases:

Heart-rot of sugar beet and marigold. The young central leaves of the crown do not expand and become severely curled. The petiole and the basal part of the midrib turn brown or black and become very brittle. Older leaves turn yellow with scorched or withered appearance. The entire crown becomes necrotic and starts decaying.

Browning or hollow stem of cauliflower. Leaf margins becomes chlorotic and curled and lamina becomes brittle. The curd enlarges, turns brown, necrotic and starts decaying. The pith becomes hollow, necrotic and forms a large cavity.

Top sickness of tobacco. The youngest leaves fail to open and remain pale green for some time which afterwards turn necrotic and disintegrate. The older leaves become thicker and very brittle. The auxiliary buds sprout and show same symptoms.

Deficiency on both old and new leaves

In zinc deficiency, the leaf becomes narrow and small. Lamina becomes, chlorotic, and veins remain green. Subsequently, dead spots develop all over the leaf including veins, tips and margins. In cereals, zinc deficiency generally appears in 24 leaves from the top during vegetative stage. Plants appear bushy due to reduced internodal elongation. Subsequently, panicle fails to emerge completely or emerges partially.

Zinc deficiency diseases:

Mottle leaf (little leaf type) or frenching of citrus: The young emerging leaves remain smaller, chlorotic and shoots die back. .

White bud of maize. The seedlings, soon after sprouting, develop interveinal yellowing followed by white necrotic spots and later the seedlings die. '

Khaira disease of rice. Rice seedlings of 3-4 weeks of age develop reddish brown pigmentation starting from middle then it spreads over entire lamina. These spots become papery and necrotic resulting into collapse of entire mass of leaves and growth of plants is arrested. The hybrid maize and wheat new genotypes are worst affected crops from zinc deficiency.

Transformation and dynamics of major plant nutrients in the soil

Carbon, hydrogen and oxygen are mainly obtained from water and air. A part of the carbon is obtained from carbonates present in the soils. The important sources for the rest of plant nutrients are organic and mineral matter. The plants obtain nitrogen mainly from organic matter. Some plants are capable of fixing nitrogen. For the rest of the nutrients, minerals are main source and to some extent organic matter (Table below).

Source of plant nutrients in soil

Nutrient	Source	Nutrient	Source
C	Carbamate	Fe	Pyrites, Magnetite
N	Organic matter	B	Tourmaline
P	Apatite (Calcium phosphate minerals), Fe or Al phosphates, organic matter	Cu	Chalcopyrite, Olivine, Hornblende, Augite, Biotite
K	Micas, Feldspars	Mn	Manganite, Pyrolusite, Olivine, Hornblende, Augite
Ca	Dolamite, Calcite, Apatite, Calcium carbonate, Gypsum, Augite	Mo	Olivine
Mg	Dolamite, Muscovite, Biotite, Olivine, Augite, Hornblende	Zn	Sphalerite, Olivine, Hornblende, Augite, Biotite
S	Pyrites, Gypsum. Organic matter, Olivine, Hornblende, Augite	Cl	Apatite

Plant nutrients present in minerals and organic matter are in non-available form. Weathering of minerals and mineralization of organic matter make the nutrients available to plants. The available nutrients applied in the form of fertilizers may become non-available by precipitation in the soil or by immobilization by organisms.

Dynamics of Nutrient Availability

The rate of absorption depends on nutrient concentration in soil solution. As the roots absorb nutrients, depletion occurs near the root zone and it is replenished by mass flow or diffusion of nutrients. The ability of the soil to maintain sufficient concentration of nutrients is important.

For most of the nutrients, an idealized reaction sequence can be formulated in terms of transfer rate between forms.

$$\text{Unavailable} \overset{a}{\Longleftrightarrow} \text{Intermediate} \overset{b}{\Longleftrightarrow} \text{Labile} \overset{c}{\Longleftrightarrow} \text{Nutrient in solution}$$

The constants a, b and c are rate constants. The equilibrium between unavailable and intermediate form is established slowly, perhaps over many decades. The intermediate forms are the long-term reserves that can be replenished slowly from inert forms or more rapidly by fertilizer reactions with soil minerals. Some examples of intermediate forms are potassium ions in clay inter layers and phosphate ions in dicalcium phosphate crystals. The equilibrium between intermediate and labile forms' is established over a short period, perhaps a few months to a year. Labile nutrient, which is loosely held, is a fraction of a soil nutrient that comes to equilibrium with soil solution rapidly, within hours or days. In general, the labile pool represents the major component of the quantity factor while the nutrient concentration of the soil solution is the intensity factor. Nutrient absorption by plant roots is directly dependent on the concentration of the soil solution (intensity factor), which in turn is regulated by the labile pool (quantity factor).

Transformation

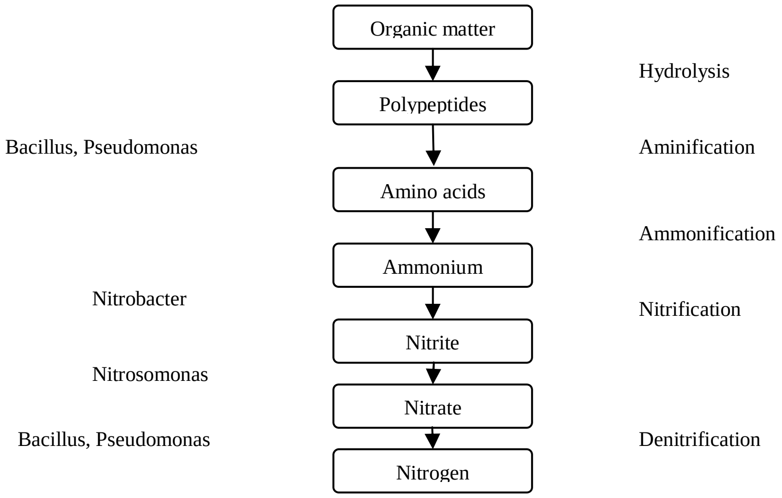
The nutrients present in the soil are subjected to physical, chemical and biological changes or transformations. Several substances are produced during these transformations. Some may be toxic and others are harmless. These transformations may either release or fix nutrients.

Nitrogen Transformation. On mineralization, organic matter releases ammonium and nitrate and these are available to plants, 'Nitrate may be further transformed into molecular nitrogen and escape into the atmosphere. The optimum soil moisture for mineralization is 50 to 70 per cent water holding capacity of soils. Mineralization is temperature dependent process and rate of mineralization is more at high temperatures. A variety of bacteria are involved in breaking down complex organic matter to mineral form of nutrients. During this process, N, P, K, S and several micronutrients are made available to plants.

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

Plant compositions	
Compound	Range (%)
Cellulose	20-30
Hemicellulose	10-30
Lignins	10-30
Proteins	1-15
Fats and waxes	1-8

They are decomposed by cellulose decomposing bacteria viz. *Cytophaga. Sporocytophaga. Angiococus. Polyangium.* These bacteria secrete cellulases, which convert cellulose into mono- and disaccharides. Anaerobic bacteria belonging to the genus *Clostridium* decompose cellulose.



Flow chart showing organisms involved in mineralization of nitrogen

The proteins present in organic matter are hydrolysed into polypeptides which are subsequently broken down into amino acids by the activity of *Bacillus* and *Pseudomonas* (Fig. 1). The amino acids are further broken down, into ammonium by the process known as ammonification, The ammonium thus released is first attacked by *Nitrobacter* and converted into nitrite. Nitrite is attacked by *Nitrosomonas* and the end product is nitrate.

The heterotrophic organisms feed on organic carbon for their energy. While mineralising the proteins, part of mineral nitrogen is utilized by these microorganisms for their tissue build up. Materials such as cereal straw, stubbles of sorghum and other millets contain high C: N ratio. As sufficient quantity of carbon material is available, bacteria multiply using the mineralized nitrogen. The nitrogen mineralized from the plant residues ends up as protein in microorganisms and available form of nitrogen is not released into the soil. Thus, there is a temporary lock up of nitrogen, which is made available after decomposition of dead microorganisms.

Aeration is very important for nitrification, as these bacteria are aerobic. Nitrification ceases below pH 5.0, the optimum being 6.5 to 7.5. The optimum temperature for nitrification is 30°C to 35°C. Nitrates are further attacked by denitrifying bacteria and reduced to elemental nitrogen. It is a wasteful practice from the agricultural point of view, but it is an essential step in nitrogen cycle to maintain constant level of atmospheric nitrogen. The important denitrifying bacteria are *Pseudomonas* and *Bacillus.* These bacteria are aerobic, but denitrification is more under anaerobic conditions.

Fertilizer materials added to the soils are transformed and several losses occur during this process. Immediately after application of urea, it is hydrolyzed in the presence of urease and forms ammonium carbonate. Most of the arable soils have enough urease to cause rapid hydrolysis.

$$CO(NH_2)_2 + H_2O \xrightarrow{\text{Urease}} (NH_4)_2CO_3$$

Ammonium carbonate is an unstable compound and decomposes into ammonium and carbon dioxide. Ammonium is adsorbed on the clay complex, a portion is absorbed by the crop and around 11 per cent is lost as volatilization. Since urea is soluble, leaching losses occur especially under lowland conditions. Therefore, mixing urea with soil and incubating for 24 to 48 hours before application is suggested. During this period, urea is converted into ammoniacal ion and adsorbed on the complex. This reduces leaching losses. This technique is applicable only to acid and neutral rice soil. In alkaline soils, this method increases volatilization. .

The applied and native forms of nitrogen are subjected to several losses. They are volatilization, leaching, denitrification, ammonium fixation and immobilization.

Change of material from solid to vapour form is called volatilization. Urea and ammoniacal fertilizers are subjected to volatilization. Urea hydrolyses and ammonium carbonate is formed which dissociates and increases the pH around urea granules. The increase in pH initiates volatilization losses.

$$NH_4 + H_2O \longrightarrow NH_3$$

Volatilization of ammonia is maintained by soil alkalinity. Otherwise volatilization of ammonia decreases pH. In the case of ammonium fertilizers, external source of alkalinity i.e., soil alkalinity, is necessary for initiating volatilization. Ammonium ions react with water and hydroxyl ions and form ammonia and water. Ammonia gas escapes into the atmosphere.

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

Volatilization losses increase (1) with increase in pH due to OH ions, (2) decrease in CEC due to less adsorption, (3) increase in temperature due to high rate of reaction, (4) increase in $CaCO_3$ content, and (5) increase in dose of nitrogen. Volatilization losses range from 0.1 to 20.0 per cent. It can be reduced by incorporation of fertilizers or by placement

Loss of nutrients beyond root zone along with water is known as leaching. Soluble fertilizers move along with water into deeper layers. Nitrate forms of nitrogenous fertilizers are subjected to higher leaching losses compared to other forms. The leaching losses with urea are around 7.5 per cent of applied nitrogen where urease activity is less. They are less with ammoniacal fertilizers as ammonium ions are adsorbed on clay complex. Leaching losses of these fertilizers occur in submerged soils and in soils with less CEC. The leaching losses that occur in a 12 week period from different fertilizer sources applied in 3 splits in sandy soils are high with ammonium nitrate (19.5 per cent) and lowest with urea (7.4 per cent). The leaching losses during this period are around 9.7 per cent with ammonium sulphate nitrate, 9.4 per cent with calcium ammonium nitrate and 7.7 per cent with ammonium sulphate.

Nitrates present in the soil are converted into elemental nitrogen, which is lost into the atmosphere. Denitrificaton losses are more in submerged soils.

Fixation of ammonium is due to trapping of these ions within crystal lattice of montmorillonite, illite, and vermiculite minerals. They fix more ammonium when the soil is dry due to contraction of these minerals. On expansion, NH_4^+ is released by exchanging with Ca^{++}, Mg^{++}, Na^+ and H^+ ions. Fixed ammonium is available to microorganisms, which convert them to nitrate and also to some plants, which absorb them. Therefore, there is very little difference between fixed NH_4^+, and exchangeable NH_4^+. The amount of nitrogen fixed ranges from 4 to 54 per cent of total N content.

Mineralisation is faster in aerobic soils and is carried out by fungi, actinomycetes and bacteria. When large quantities of organic matter are added to the soils, the microorganisms utilize available nitrogen in the soil for their multiplication. This temporary locking up of nitrogen in microorganisms is called immobilization. It is reverse process of mineralization.

Phosphorus Transformation. Phosphorous is present in the soils in organic and inorganic forms. Inorganic phosphorous is more than organic phosphorus. Mineralization of organic matter releases phosphorus in available form. The organo-phosphorus compounds of organic matter are phytin, phospholipids, nucleoproteins, nucleic acids, phosphorylated sugars, coenzymes etc. Bacteria, fungi and actinomycetes act on these materials by secreting phosphatases and break them down into simpler compounds. The optimum C: N: P ratio is 100: 10: 1 and if the C: P ratio is more than 100: 1, immobilization of phosphorus occurs.

The inorganic forms of soil phosphorus are Ca-P, Fe-P and AI-P. The dominant form of phosphorus in vertisols is Ca-P and in alfisols Fe-P. In Indian soils, Ca-P is around 40 to 50 per cent of total phosphorus in neutral and alkaline soils and more than 50 per cent in alkaline soils. Fe-P and Al-P are less than 10 per cent in these soils. Phosphorus in soil solution is in the form of primary and secondary orthophosphates ($H_2PO_4^-$ and HPO_4^{2-}). Primary orthophosphate ($H_2PO_4^-$) is more in acid soils and secondary orthophosphate (HPO_4^{2-}) more in alkaline soils. Phosphorus in soil solution depends on rate of decomposition of organic matter and rate of reaction with inorganic fraction. Organic and inorganic phosphorus is in equilibrium with phosphorus in soil solution.

$$\text{Organic P} \quad \Longleftrightarrow \quad \text{Solution P} \quad \Longleftrightarrow \quad \text{Insoluble Inorganic P}$$

Phosphorus equilibrium is temporarily altered by addition of soluble fertilizers or by rapid mineralization due to cultivation. When fertilizers, containing soluble phosphates are added to the Soil, it is retained or fixed by different mechanisms. Fixation of phosphorus is by adsorption, isomorphous substitution and double decomposition. Insoluble phosphates are weathered and phosphates are released into the soil solution. Thus equilibrium is maintained.

Fixation is influenced by pH, nature and amount of clay, free oxides of 'Fe and AI, calcium carbonate and organic matter. Acidic soils fix more phosphates than neutral, alkaline and calcareous soils. At pH 2 to 5, fixation is mainly by formation of insoluble Fe and Al phosphates as Fe and Al are more active in acid soils. Within the pH range of 4.5 to 7.5, phosphate is fixed on clay particles. It *occurs* in two ways: (1) by replacing two hydroxyl ions to aluminium in clay with one ion of primary orthophosphate, and (2) by forming clay phosphate linkage. Within the pH range of 6 to 10, phosphate is precipitated as phosphates of calcium or magnesium as calcium and magnesium are more in alkaline, range. Phosphorus fixation is more when the clay content is high. Vermiculite and smectite clay fix more phosphates than kaolinite. Black soils have higher fixing capacity than red soils. Presence of oxides of Fe and Al results in formation of sparingly soluble phosphate. Aluminium oxides are more important than iron oxides in fixation. Phosphate fixation is high in soils with high calcium carbonate. Soluble phosphates are first converted in to tricalcium phosphates and subsequently to carbonate apatite. The exchangeable calcium forms clay-calcium phosphate linkage or calcium enters soil solution and combines with phosphate.

Potassium Transformation. Mineralization of organic matter releases potassium *from* organic matter. Some bacteria and fungi are capable of acting on alumino silicates and release potassium. Iron present in organic matter is released during mineralization by bacteria.

Water-soluble potassium is present in the soil solution as K^+ ion. It is in equilibrium with exchangeable K. Exchangeable K is present on soil clay complex which is adsorbed. It is only one per cent of K present in mineral soil. Fixed potassium is bound between the units of clay minerals. These three forms viz. fixed, exchangeable and water soluble K are in dynamic equilibrium in the soil.

$$\text{Fixed K} \Longleftrightarrow \text{Exchange K} \Longleftrightarrow \text{Water soluble K}$$

If one form is depleted, it is replenished from the other forms. Unavailable K or fixed K in mica and feldspars are made available slowly due to the weathering process.

$$K\,Al\,Si_3\,O_8 + H_2O \longrightarrow KOH + H\,AI\,Si_3\,O_3$$

On an average, four-fifths of the K removed by the cropping system of wheat-pearl millet is from non-exchangeable form in sandy loam soils containing mainly illite clay mineral. Exchangeable K adsorbed on clay complex is released into soil solution when its concentration is decreased due to plant absorption. When fertilizer is added. K in the soil solution is increased. A fraction of it goes to exchangeable form and in due course even to fixed form.

Calcium Transformation. The important sources of calcium are dolamite, calcite, apatite and calcium feldspars. On their disintegration and decomposition, calcium is made available to plants. It may be taken up by plants, lost in drainage, re-adsorbed by clay or a small fraction may be re-precipitated as secondary calcium compound. Calcium is not fixed or made unavailable in the soil. Calcium in soil solution and in exchangeable complex is in a state of dynamic equilibrium. Higher concentration of calcium in solution is adsorbed on clay complex. Exchangeable calcium is released into soil solution when its concentration is low in soil solution.

Magnesium Transformation. Magnesium is available to plants due to weathering of biotite, dolamite, chlorate, serpentine and olivine. The released magnesium may be absorbed by plants and microorganisms, lost in drainage or re-precipitated as secondary minerals. Magnesium in soil solution and exchangeable form are in dynamic equilibrium, similar to calcium.

Sulphur Transformation. Plant residues contain sulphur in the form of proteins, amino acids and vitamins. Mineralization of these compounds releases sulphates. The C: S ratio of 50: 1 is critical. Decomposition of plant materials with wider C: S ratio causes immobilization of sulphur. In anaerobic soils, sulphates are reduced to hydrogen sulphide by the action of *Desulfovibro* spp of bacteria. Hydrogen sulphide is toxic to crops. Elemental sulphur when applied to the soil is converted to sulphate by *Thiobacillus* spp.

Earth's crust contains about 0.06 per cent of sulphur. It is present as sulphides, sulphates and in organic combination with carbon and nitrogen. The original source of sulphur in soil is sulphides of metals in plutonic rocks. During weathering process, these sulphides are oxidised to sulphates. These sulphates are present as insoluble sulphate salts in arid and semiarid regions.

The nature of applied sulphur is in the form of sulphates of Ca, Mg, K, Na or NH_4 in soil solution in arable soils. These sulphates may be adsorbed on 1: 1 clay or hydrous oxides of Fe and AI. It may be absorbed by plants and microorganisms. Sulphates are reduced to sulphides in waterlogged soils and form H_2S, FeS etc. Elemental sulphur is oxidized to sulphates by microorganisms in aerated soils.

UNIT III

Preparation and use of farmyard manure, compost, green manure, vermicompost, biofertilizers and other organic concentrates, their composition, availability and crop responses

MANURES

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

BULKY ORGANIC MANURES

Bulky organic manures contain small percentage of nutrients and they are applied in huge quantities. Farmyard manure (FYM), compost and green manure are the most important and widely used bulky organic manures. Use of bulky organic manures have several advantages: (1) they supply plant nutrients including micronutrients, (2) they improve soil physical properties like structure, water holding capacity etc., (3) they increase the availability of nutrients, (4) carbon dioxide released during decomposition acts as a CO_2 fertilizer, and (5) plant parasitic nematodes and fungi are controlled to some extent by altering the balance of microorganisms in the soil.

Farmyard Manure

Farmyard manure refers to the decomposed mixture of dung and urine of farm animals along with litter and left over material from roughages or fodder fed to the cattle. On an average well decomposed farmyard manure contains 0.5 per cent N, 0.2 per cent P_2O_5 and 0.5 percent K_2O. The present method of preparing farmyard manure by the farmers is defective. Urine, which is wasted, contains 1% N and 1.35% K. Nitrogen present in urine is mostly in the form of urea which is subjected to volatilization losses. Even during storage, nutrients are lost due to leaching and volatilization. However, it is practically impossible to avoid losses altogether, but can be reduced by following improved method of preparation of farmyard manure.

Trenches of size 6 m to 7.5 m length, 1.5 m to 2.0 m width and 1.0 m deep are dug. All available litter and refuse is mixed with soil and spread in the shed so as to absorb urine. The next morning, urine soaked refuse along with dung is collected and placed in the trench. A section of the trench from one end should be taken up for filling with daily collection. When the section is filled up to a height of 45 cm to 60 cm above the ground level, the top of the heap is made into a dome and plastered with cow dung earth slurry. The process is continued and when the first trench is completely filled, second trench is prepared. The manure becomes ready for use in about four to five months after plastering.

If urine is not collected in the bedding, it can be collected along with washings of the cattle shed in a cemented pit from which it is later added to the farmyard manure pit. Chemical preservatives can also be used to reduce losses and enrich farmyard manure. The commonly used chemicals are gypsum and superphosphate. Gypsum is spread in the cattle shed which absorbs urine and prevents volatilization loss of urea present in the urine and also adds calcium and sulphur. Superphosphate also acts similarly in reducing losses and also increases phosphorus content.

Partially rotten farmyard manure has to be applied three to four weeks before sowing while well rotten manure can be applied immediately before sowing. Generally 10 to 20 t/ha is applied, but more than 20 t/ha is applied to fodder grasses and vegetables. In such cases farmyard manure should be applied at least 15 days in advance to avoid immobilization of nitrogen. The existing practice of leaving manure in small heaps scattered in the field for a very long period leads to loss of nutrients. These losses can be reduced by spreading and incorporating by ploughing immediately after application.

Vegetable crops like potato, tomato, sweet-potato, carrot, radish, onion etc., respond well to the farmyard manure. The other responsive crops are sugarcane, rice, Napier grass and orchard crops like oranges, banana, mango and plantation crop like coconut. The entire amount of nutrients present in farmyard manure is not available immediately. About 30% N, 60-70% P and 70% K are available to the first crop.

Compost

A mass of rotted organic matter made from waste is called compost. The compost made from farm waste like sugarcane trash, paddy straw, weeds and other plants and other waste is called farm compost. The average nutrient content of farm compost is 0.5 per cent N, 0.15 per cent P_2O_5 and 0.5 per cent K_2O. The nutrient value of farm compost can be increased by application of superphosphate or rock phosphate at 10 to 15 kg/t of raw material at the initial stage of filling the compost pit. The compost made from town refuses like night soil, street sweepings and dustbin refuse is called town compost. It contains 1.4 per cent N, 1.00 per cent P_2O_5 and 1.4 per cent K_2O.

Farm compost is made by placing farm wastes in trenches of suitable size, say, 4.5 m to 5.0 m long, 1.5 m to 2.0 m wide and 1.0 m to 2.0 m deep. Farm waste is placed in the trenches layer by layer. Each layer is well moistened by sprinkling cow-dung slurry or water. Trenches are filled up to a height of 0.5 m above the ground. The compost is ready for application within five to six months.

Green Manure

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

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

Nutrient content of green manure crops and green leaf manure				
Plant	Scientific name	Nutrient content (%) air dry weight basis		
		N	P_2O_5	K_2O
Green manure crops				
Sunnhemp	*Crotalaria juncea*	2.30	0.50	1.80
Dhaincha	*Sesbania aculeata*	3.50	0.60	1.20
Sesbania	*Sesbania speciosa*	2.7.1	053	2.21
Green leaf manure				
Forest tree leaf		1.20	0.60	0.40
Green weeds		0.80	0.30	0.20
Pongamia leaf	*Pongamia glabra*	3.31	0.44	2.39

Several advantages accrue due to the addition of green manures. Organic matter and nitrogen are added to the soil. Growing deep rooted green-manure crops and their incorporation facilitates in bringing nutrients to the top layer from deeper layers. Nutrient availability increases due to production of carbon dioxide and organic acids during decomposition. Green manuring improves soil structure, increases water-holding capacity and decreases soil loss by erosion. Growing of green-manure crops in the off season reduces weed proliferation and weed growth. Green manuring helps in reclamation of alkaline soils. Root-knot nematodes can be controlled by green manuring.

Vermicompost

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

Night Soil

Night soil is human excreta, both solid and liquid. It is richer in N, P and K than farmyard manure and compost. Night soil contains on an average 5.5 per cent N, 4.0 per cent P_2O_5 and 2.0 per cent K_2O.

Sewage and Sludge

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

Sheep and Goat Manure

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

Poultry Manure

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

CONCENTRATED ORGANIC MANURES

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

Oil-cakes

Average nutrient contents of oil-cakes

Oil cakes	Nutrient content (%)		
	N	P_2O_5	K_2O
Non-edible oil-cakes			
Castor cake	4.3	1.8	1.3
Cotton seed cake (un-decorticated)	3.9	1.8	1.6
Karanj cake	3.9	0.9	1.2
Mahua cake	2.5	0.8	1.2
Safflower cake (un-decorticated)	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
Niger cake	4.7	1.8	1.3
Rape seed cake	5.2	1.8	1.2
Safflower cake (Decorticated)	7.9	2.2	1.9,
Sesamum cake	6.2	2.0	1.2

After oil is extracted from oilseeds, the remaining solid portion is dried as cake which can be used as manure. The oil-cakes are of two types:

i. Edible oil-cakes which can be safely fed to livestock *e.g.* Groundnut cake, coconut cake etc., and
ii. Non-edible oil-cakes which are not fit for feeding livestock *e.g.* Castor cake, neem cake, mahua cake etc.,

Both edible and non-edible oil-cakes can be used as manures. However, edible oil cakes are fed to cattle and non-edible oil cakes are used as manures especially for horticultural crops. Nutrients present in oil-cakes, after mineralization, are made available to crops 7 to 10 days after application. Oilcakes need to be well powdered before application for even distribution and quicker decomposition. The average nutrient content of different oil-cakes is presented in Table.

Other Concentrated Organic Manures

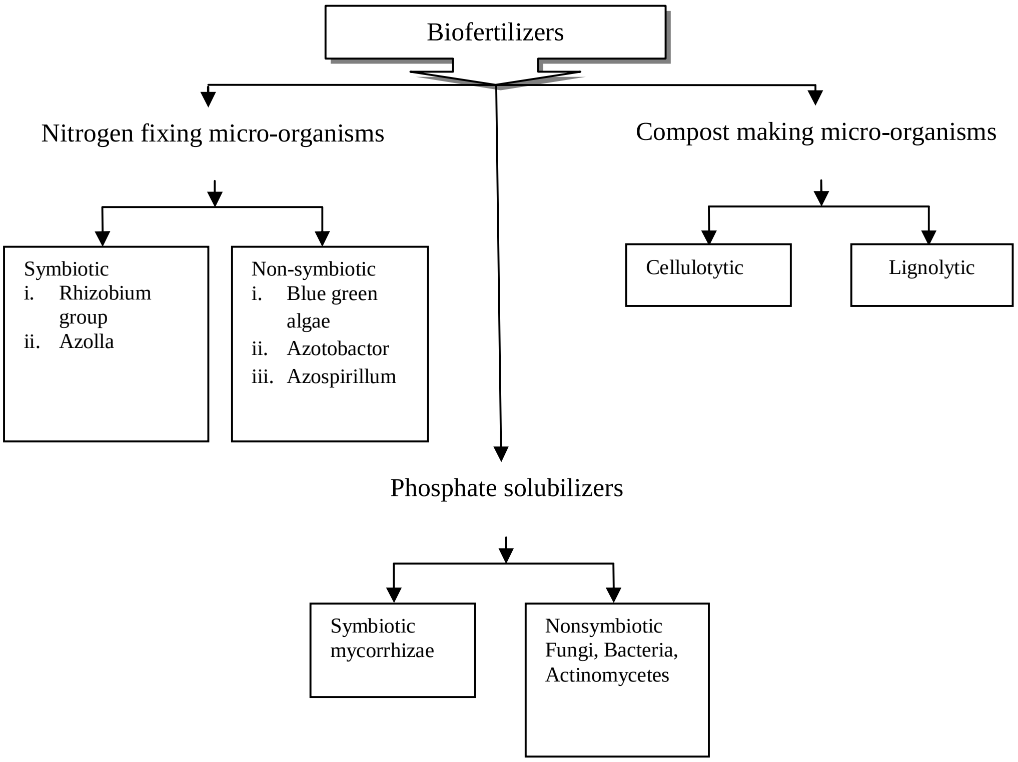
Average nutrient content of animal based concentrated organic manures

Organic manure	Nutrient content (%)		
	N	P_2O_5	K_2O
Blood-meal	10-12	1-2	1.0
Meat-meal	10.5	2.5	0.5
Fish-meal	4-10	3-9	0.3-15
Horn and hoof meal	13	...	…
Raw bone-meal	3-4	20-25	…
Steamed bone meal	1-2	25-30	…

Blood-meal when dried and powdered can be used as manure. The meat of dead animals is dried and converted into meat-meal which is a good source of nitrogen (Table).

BIOFERTILISERS

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



SAPROPHYTES

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

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

Symbiotic Bacteria

Rhizobium species suitable for different crops	
Rhizobium sp	*Crops*
R. leguminosarum	Peas *(Pisum)*, lathyrus, vicia, lentil *(Lens)*
R. tripoli	Berseem *(Trifolium)*
R. phaseoli	Kidney bean *(Phaseolus)*
R. lupini	*Lupinus. Ornithopus*
R. japonicum	Soybean *(Glycine)*
R. meliloti	*Melilotus,* Lucerne *(Medicago),* Fenugreek *(Trigonella)*
Cowpea miscellany	Cowpea, clusterbean, greengram, blackgram, redgram, groundnul, moth bean, dhaincha, sunnhemp, *Glyricidia, Acacia, Prosopis, Dalbergi, Albizzia, Indigofera, Tephrosia, Atylosia,* stylo
Separate group	Bengal gram (gram)

Bacteria belonging to the genus *Rhizobium* are capable of fixing atmospheric nitrogen in association with leguminous crops. Different species of *Rhizobium* are used for treating the leguminous crops (Table).

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

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

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

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

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FREE LIVING ORGANISMS

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

Blue-green Algae (BGA)

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

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

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

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

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

Azotobacter and Azospirillum

Azotobacter chroccum is capable of fixing 20 to 30 kg N/ha. It can be applied by seed inoculation, seedling dip or by soil application. The inoculum required is 3 to 5 kg/ha.

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

Mycorrhiza and Phospho-micro Organisms

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

Recycling of organic wastes and residue management

Crop residues of different crops and their nutrient value

Crop	Total yield (Grain + straw) (kg/ha)	Stubble weight (kg/ha)	Nutrient content (%)		
			N	P_2O_5	K_2O
Rice	15,536	4,200	0.42	0.066	0.66
Sorghum	5,150	2,889	0.21	0.086	0.33
Maize	14,950	667	0.21	0.060	0.83
Finger millet	18,800	3,111	1.40	0.120	0.66
Foxtail millet	6,500	1,200	0.98	0.070	0.17
Gingelly	500	338	0.70	0.098	0.17

The contribution from crop residues is generally ignored. However, crop residues add considerable amount of nutrients and the amount depends on the crop (Table). Finger millet crop residues add about 43 kg N/ha, while rice crop residues add 17 kg N/ha. The addition of phosphorus is 3.7 and 2.9 kg P_2O_5/ha by finger millet and rice residues respectively. By estimating the appropriate amount of nutrients added to the soil by crop residues, chemical fertilizer application can be reduced.

Application of organic matter in any form reduces the loss of nitrogen fertilizer and increases fertilizer use efficiency.

Large amounts of agricultural wastes are available and there is need to properly use them for some industrial purpose or recycle them to replenish soil fertility. Agricultural residues like paddy straw, rice husk, *jute/cotton/arhar* sticks, wheat straw, groundnut shells, maize straw, sugarcane trash, etc. are left in the fields which create many ecological problems. Perpetuation of diseases and other insect pests is helped by such wastes/residues. For example, cotton sticks left in the field harbour pests to affect the next season cotton crop seriously. Burning of rice husk near rice shellers, in the vicinity of towns, creates air pollution. Burning of paddy straw by farmers in their fields also gives out lot of smoke adding in pollution leading to enhanced incidence of deaths due to increased respiratory diseases.

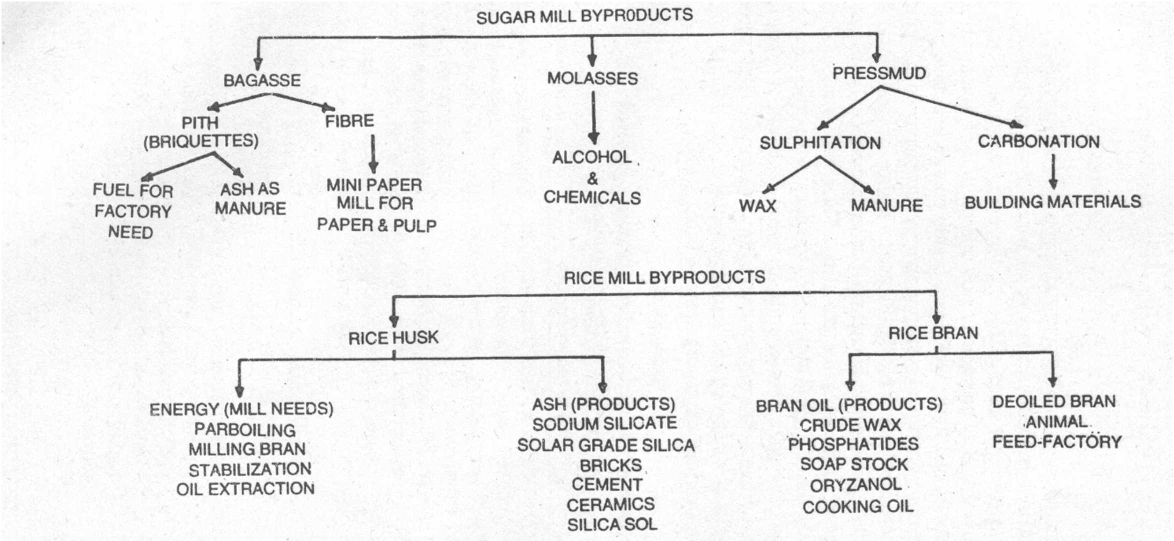
Agricultural residues offer a potential scope to meet our growing needs through their recycling. Crop residues are important energy source. About 2000 million t of straw is produced annually in India. Only rice, wheat, sorghum, maize and pearl millet leave 173 million t of crop residues (Gaur, 1979). Though bulk of such crop straw is used as cattle feed in India, 51 million t of only paddy straw remains unutilized, particularly in wheat belt. Another 16 million tonnes of sugarcane trash is not utilized properly. Such surplus farm wastes have an estimated potential of

100 million t/year for recycling of nutrients in agriculture (Gaur and Singh, 1982), which would be equivalent to 2.6 million t of NPK after proper decomposition, and maintenance of proper C:N ratio through the use of cellulolitic fungal culture inoculation. Water hyacinth, an aquatic weed of 2,92,000 hectares is a nuisance and creates serious problem in normal flow of water, fish transport and human health. Water hyacinth can be used as compost, green manuring, soil mulch, etc. It can contribute about 0.17 million t equivalent of NPK (Gaur and Singh, 1982). Water hyacinth on dry weight basis can yield 370 l of biogas with average methane content of 69 per cent (Gaur, 1979).

Industrial wastes like rice husk, rice bran, bagasse, press mud, cotton dust, oil cakes, slaughter house wastes, faecal matter, marine residues, city garbage, night soil, etc. could also provide NPK equivalent to about 4.72 million t for increasing agricultural production. Thus, after developing a sound system of their use and recycling, it become a vast source of energy. About 247 million t of agricultural byproducts like wood, dung and crop residues are burnt annually in India due to fire needs. This vast source of energy, thus, could not be recycled back into the ecosystem, until an alternative source of energy is provided for home consumption. Biogas technology may help to provide valuable energy source for cooking and would also provide digested slurry as a valuable source of organic manure. Systematic, efficient and safe collection and disposal of city garbage like rubbish, dead animals, tanneries wastes, street sweeping, night soil, etc. cou1d be economical, besides, reducing environmental pollution, foul smell and nuisance for health hazard. With proper treatment such garbage could be turned to valuable compost.

Agro-industries generate residues like husk, hull, shell, peel, testa, skin, fibre, bran, linter, stone, seed, cob, prawn, head, frog legs, low grade fish, leather waste, hair, bones, coir dust, saw dust, bamboo dust, etc. which could be recycled or used efficiently through agro-processing centres. In the last three decades, rice and sugarcane residues have increased by 162 and 172 per cent, respectively. Their disposal problem needs serious rethinking (Vimal, 1981). To some extent these organic residues are used as soil conditioner, animal feed, fuel, thatching and packing materials. These can also be put to new uses for manufacture of various chemicals and specific products (like silica, alcohol, tannins, glue, gelatine, wax, etc), feed, pharmaceuticals (lycogenin, antibiotics, vitamins, etc.), fertilizers, energy, construction materials, paper pulp, handicraft materials etc. Residues from fruit and vegetable industries, fish and marine industries and slaughter houses leave a stinking smell. Similarly, presence of bitter components in non-edible oil seeds, wax in sulphitation press mud, tannins in cashew testa and potassium oxalate in rice straw decrease their efficiency without pretreatment.

Agro-industrial byproducts can be utilized only through the development of secondary and tertiary industries. The operation of this concept can be illustrated with respect to the utilization of the byproducts of sugar and rice factories (Fig. below) with minimized pollution hazards and sanitary conditions at the mill premises. Adoption of an integrated system utilizing cattle shed wastes, biogas slurry, crop residues, weeds, fallow leaves, etc. can provide gas for milk processing, feed for animals and manure for soil. Efficient utilization of agricultural residues would conserve non-renewable resources, establish secondary and tertiary industries, create employment opportunities, provide economical products, reduce the overall cost of production, minimize environmental pollution, satisfy local needs as well as promote science and technology in the country.



Integrated use of byproducts of sugar/rice mill after conversion into a complex of secondary and tertiary industries (After Vimal, 1981).

Organic matter cannot supply all nutrients to meet the crop requirement. Certain nutrients are needed in large quantities than others. To meet these requirements, fertilizers that contain one or more nutrients are applied.

UNIT IV

Commercial fertilizers; composition, relative fertilizer value and cost; Fertilizer mixers and grades

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

Classification of fertilizers

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

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

NPK complex fertilizers as per Fertilizer (control) Order 1957	
1. NPK (10-26-26)	8. NPK (11-22-22)
2. NPK (12-32-16)	9. NPK (19-19-19)
3. NPK (14-36-12)	10. NPK (14-14-14)
4. NPK (22-22-11)	11. NPK (11-11-11)
5. NPK (14-35-14)	12. NPK (17-17-16)
6. NPK (17-17-17)	13. NPK (20-10-10)
7. NPK (14-28-14)	14. NPK (13-13-20)

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

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

Fertilizer mixtures are formulated products made by mixing together two or more fertilizer materials. In all the States of India, fertilizer mixtures containing two or three major nutrients have been introduced.

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

Types of Fertilizer Mixtures

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

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

Grades of fertilizer mixtures approved by various north Indian State Departments of Agriculture

North zone state	N	P_2O_5	K_2O
Haryana	10	10	10
	15	15	7.5
	16	9	0
	12	32	0
Himachal Pradesh	15	15	15
	12	32	16
	15	7.5	15
	15	15	7.5
Jammu and Kashmir	12	32	16
Punjab	15	15	7.5
	12	25	6
Uttar Pradesh	20	20	10
	15	15	7.5
	16	9	0
	12	32	0
	12	6	0
	10	10	10
	8	8	8
	7	10	0
Chandigarh	12	32	16
Delhi	15	15	7.5
	12	32	16
	12	32	6
	8	8	8

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

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

Acid equivalents of acid-forming fertilizers

Fertilizer	Acid equivalent
Ammonium chloride	128
Ammonium sulphate	110
Ammonium sulphate nitrate	93
Ammonium phosphate	86
Urea	80

Acidity and Basicity of Fertilizers

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

For example, 100 kg of ammonium sulphate produces acidity which needs 110 kg of calcium carbonate to neutralize it. Therefore, the acid equivalent of ammonium sulphate is 110.

Fertilizers which leave alkaline residue in the soil are called alkaline forming fertilizers or basic fertilizers.

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

NITROGENOUS FERTILIZERS

The fertilizer materials containing N are called nitrogenous fertilizers. They may contain secondary nutrients like calcium and sulphur. Nitrogenous fertilizers are classified into four groups based on the chemical form of N in the fertilizer. Fertilizers containing N in the form of nitrate (NO_3) are called nitrate fertilizers. Examples of nitrate fertilizers are: sodium nitrate ($NaNO_3$) and calcium nitrate $Ca(NO_3)_3$. The general characteristics of nitrate fertilizers are: (1) they are highly mobile in soils and are, therefore, suitable for top dressing, (2) highly soluble and subjected to leaching, (3) subjected to denitrification in waterlogged soils, and (4) increase alkalinity as they are basic in their residual effect. Fertilizers containing nitrogen in the form of ammonium are called ammoniacal fertilizers. The general characteristics of these fertilizers are: (1) easily available to plants as they are readily soluble in water, (2) leaching losses are less as ammonium ions are adsorbed on clay complex, and (3) reduce alkalinity as they are acidic in their residual effect on the soils. These fertilizers are well suited to submerged soils. Some ammoniacal fertilizers are: ammonium sulphate $(NH_4)_2SO_4$ (20% N), ammonium chloride NH_4Cl (24 to 26% N), anhydrous ammonia NH_3 (82% N). Nitrate and ammoniacal fertilizers contain N in the form of both nitrate and ammonium. These are acidic in nature. Leaching losses are less. Nitrate N is readily available to plants for rapid growth and ammoniacal nitrogen is available at a later stage of the crop. Example of nitrate-ammoniacal fertilizers are: Ammonium nitrate, NH_4NO_3 (33 to 34% N) and calcium ammonium nitrate, $CaNH_4NO_3$ (20% N).

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

Slow Release Nitrogenous Fertilizers

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

Nitrification Inhibitors

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

Composition of some common chemical sources of N (%)							
Source	N	P_2O_5	K_2O	CaO	MgO	S	Cl
Ammonium sulfate	21.0	-	-	-	-	24.0	-
Anhydrous Ammonia	82.0	-	-	-	-	-	-
Ammonium chloride	25.0-26.0	-	-	-	-	-	66.0
Ammonium nitrate	33.0-34.0	-	-	-	-	-	-
Ammonium nitrate sulfate	30.0	-	-	-	-	5.0-6.0	-
Ammonium nitrate with lime (ANL)	20.5	-	-	10.0	7.0	0.6	-
Ammoniated ordinary superphosphate	4.0	16.0	-	23.0	0.5	10.0	0.3
Mono-ammonium phosphate	11.0	48.0-55.0	-	2.0	0.5	1.0-3.0	-
Diammonium phosphate	18.0-21.0	46.0-54.0	-	-	-	-	-
Ammonium phosphate sulfate	13.0-16.0	20.0-39.0	-	-	-	3.0-14.0	-
Ammonium polyphosphate solution	10.0-11.0	34.0-37.0	-	-	-	-	-
Ammonium thiosulphate solution	12.0	-	-	-	-	26.0	-
Calcium nitrate	15.0	-	-	34.0	-	-	-
Potassium nitrate	13.0	-	44.0	0.5	0.5	0.2	1.2
Sodium nitrate	16.0	-	-	-	-	-	0.6
Urea	45.0-46.0	-	-	-	-	-	-
Urea-sulfate	30.0-40.0	-	-	-	-	6.0-11.0	-
Urea-ammonium nitrate (solution)	28.0-32.0	-	-	-	-	-	-
Urea-ammonium phosphate	21.0-38.0	13.0-42.0	-	-	-	-	-
Urea-phosphate	17.0	43.0-44.0	-	-	-	-	-

PHOSPIIATIC FERTILIZERS

Phosphorus content in fertilizers is expressed in oxidized form (P_2O_5), while its content in soil and plant is expressed in elemental form. The conversion factors for elemental to oxidized form and vice-versa are 2.29 and 0.43, respectively.

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

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

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

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

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

Common commercially available P fertilizers							
Material	Analysis (%)				Form of P	% total P available	Formula of main P compound
	N	P_2O_5	K_2O	S			
Rock phosphate (RP)	-	25-40	-	-	Ortho	14-65	$[Ca_3(PO_4)_2]_3$. CaF_2. $(CaCO3)_x.(Ca(OH_2)_x$
Single super phosphate (SSP)	-	16-22	-	11-12	Ortho	97-100	$Ca(H_2PO_4)_2$
Wet process phosphoric acid	-	48-53	-	-	Ortho	100	H_3PO_4
Triple super phosphate (TSP)	-	44-53	-	1.1.5	Ortho	97-100	$Ca(H_2PO_4)_2$
Ammonium phosphates							
Monoammonium phosphate (MAP)	11-13	48-62	-	0.2	Ortho	100	$NH_4H_2PO_4$
Diammonium phosphate (DAP)	18-21	46-53	-	0-2	Ortho	100	$(NH_4)_2HPO_4$
Ammonium polyphosphate (APP)	10-15	35-62	-	-	Mix of ortho & poly-P	100	$(NH_4)_3HP_2O_7$+$NH_4H_2PO_4$ + others
Urea-ammonium phosphate (UAP or UAPP)	21-34	16-42	-	-	-do-	100	$NH_4H_2PO_4.(NH_4)_3HP_2O_7$
Nitric phosphates (NP)	14-29	14-28	0-20	-	Ortho	80-100	$CaHPO_4.NH_4H_2P_2O_7$
Ammonium normal superphosphate	2-5	14-21	-	9-11	Ortho	97-100	$NH_4H_2P_2O_7.CaHPO_4$
Ammoniated triple super phosphate	4-6	44-53	-	0-1	Ortho	96-100	$CaHPO_4.NH_4H_2P_2O_7$
Potassium phosphates							
Monopotassium phosphate		51	35	-	Ortho	100	KH_2PO_4
Dipotassium phosphate		41	54	-	Ortho	100	K_2HPO_4
Potassium polyphosphate		51	40	-	Poly & Ortho	100	$K_3HP_2O_7.KH_2PO_4$.others

POTASSIC FERTILIZERS

Potassic or potash or potassium fertilizers are grouped into two: chloride form and nonchloride form. Potassium chloride belongs to the first group and potassium sulphate, potassium magnesium sulphate, potassium nitrate etc., belong to the second group. From the potassium nutrition point of view, all these fertilizers are equally efficient, but the accompanying anions do make some difference. Presence of chloride in the fertilizer makes it unsuitable for sugar crops, tobacco and potato. In nonchloride fertilizers, sulphate or nitrate anions add to the nutrition of the plant, but they are considered as costly per unit of K_2O. Potassium in the fertilizer is expressed as K_2O (potassium oxide). The conversion factor to express in elemental form (K) is 0.83 and oxide form 1.2.

Potassium chloride or muriate of potash is the most common and cheap fertilizer among potassic fertilizers. It contains 58-60 per cent K_2O. It is suitable for most of the crops except sugarcane, sugar beet, potato and tobacco. In sugar crops, accumulation of sugar is affected due to chloride ion present in the fertilizers. Higher content of chloride in tobacco leaf reduces its burning quality. This fertilizer is suitable for acidic and heavy soils but not for alkaline soils.

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

Nutrient content of common fertilizers and other sources

Material	N (%)	P_2O_5 (%)	K_2O (%)	S (%)	Mg (%)
Potassium chloride	-	-	60-62	-	-
Potassium sulfate	-	-	50-52	17	-
Potassium magnesium sulfate	-	-	22	22	11
Potassium nitrate	13	-	44	-	-
Potassium and sodium nitrate	15	-	14	-	-
Manure salts	-	-	22-27	-	-
Potassium hydroxide	-	-	83	-	-
Potassium carbonate	-	-	<68	-	-
Potassium orthophosphate	-	30-60	30-50	-	-
Potassium polyphosphate	-	40-60	22-48	-	-
Potassium metaphosphate	-	55-57	38	-	-
Potassium calcium pyrophosphate	-	39-54	25-26	-	-
Potassium thiophosphate	-	-	25	17	-
Potassium polysulfide	-	-	22	23	-

SECONDARY NUTRIENTS: CALCIUM, MAGNESIUM AND SULPHUR FERTILIZERS

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

Ca, Mg and S contents of different fertilizer materials

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

MICRONUTRIENTS

Range of micronutrient concentrations for normal plant growth

Trace element	Concentration (ppm)
Fe (Iron)	0.5 to 5.0
Mn (Manganese)	0.1 to 0.5
B (Boron)	0.1 to 0.2
Zn (Zinc)	0.02 to 0.2
Cu (Copper)	0.01 to 0.05
Mo (Molybdenum)	0.01 to 0.05

Of the sixteen elements essential for plant growth, six nutrients are required in much smaller quantities and they are referred to as micronutrients. They are: Fe, Mn, B, Zn, Cu and Mo. Several micronutrient salts are highly reactive and soluble rendering them unavailable to plants.

Micronutrient salts are fused with special type of glass and shattered into small bits which are called frits. When these frits are applied to the soil, the glass slowly dissolves and releases the nutrient salts. Frits extend period of nutrient availability by reducing the reactivity and solubility. Borosilicate glass, manganese ammonium frits, zinc frits, and copper frits are available. Some of the metallic micronutrient salts when applied to the soil are transformed into non-available forms due to their high reactivity. Organic compounds like EDTA (Ethylene diamine tetraacetic acid), DTPA (Diethylene triamine pentaacetic acid), CDTA (Cyclohexane diamine tetraacetic acid) have the ability to chelate or loosely hold metallic ions in their cyclic structure and these metal-organic complexes are called metal chelates. Metal chelates are soluble in water, but they do not ionize in soil solution. Metal ions, therefore, do not react with soil constituents. Chelate forms of nutrients are more available than those from ordinary salts. Iron, copper, zinc and manganese fertilizers are available in chelated forms.

Iron Fertilizers

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

Sources of fertilizer iron	
Source	Iron content (%)
Ferrous sulphate	19
Ferric sulphate	23
Ferrous oxide	77
Ferric oxide	69
Ferrous ammonium phosphate	29
Ferrous ammonium sulphate	14
Iron ammonium polyphosphate	22
Iron chelates	14
Iron frits	22

Manganese Fertilizers

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

Sources of manganese	
Source	Manganese (%)
Manganese sulphate	26
Manganous oxide	41
Manganese oxide	63
Manganese chelates	12
Manganese frits	10

Molybdenum Fertilizers

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

Zinc Fertilizers

Zinc sulphate which contains 36 per cent zinc is the most commonly used zinc fertilizer. Zinc sulphate is applied both to soil (at 30-50 kg per hectare) and plant (0.5 per cent as spray). Zinc oxide containing 78 per cent zinc is used for seed treatment. Organic compounds have also been used successfully to correct deficiency of zinc. These include several zinc chelates like EDTA type or zinc polyflavanoid or lignin-sulfonate types. Soil application of the various zinc compounds is the suitable way of overcoming zinc deficiency. Foliar application is a temporary measure.

Sources of zinc	
Source	Zinc (%)
Zinc sulphate monohydrate ($ZnSO_4$ H_2O)	35
Zinc sulphate hepta -hydrate ($ZnSO_4$,$7H_2O$)	23
Basic Zinc sulphate ($ZnSO_4.4Zn(OH)_2$)	55
Zinc oxide (ZnO)	78
Zinc sulphide (ZnS)	67
Zinc phosphate $Zn(PO_4)_2$	51
Zinc chelate (Na_2Zn EDT A)	14
Zinc polyflavanoid	10
Zinc ligninsulfonate	5

Boron Fertilizers

Borax is the most commonly used boron fertilizer which is white compound containing 11 per cent boron. Because of its high solubility in water, it is lost by leaching. To avoid this loss, boron frits are developed which contain 2 to 6 per cent boron. Borosilicate glass is one such material and it is advantageous to apply this than borax in sandy soils under high rainfall conditions, Boric acid and solubor (a soluble commercial borate) are boron fertilizers for foliar application.

Sources of boron	
Source	*Boron* (%)
Borax	11
Sodium pentaborate	18
Sodium tetraborate	14
Boric acid	17
Solubor	20
Borosilicate glass (Frits)	6

Copper Fertilizers

Copper can be applied by spraying soluble salts on crops or by applying copper fertilizer material to the soil. Copper sulphate is commonly used for both the purposes. It contains 25.5 percent copper. Copper ammonium phosphate can also be used either for soil application or as a foliar spray. It is slightly soluble in water, but can be suspended in water for spraying. Copper chelates are also available for correcting copper deficiency symptoms.

Sources of copper	
Source	Copper (%)
Copper sulphate	21
Copper ammonium phosphate	30
Copper chelates (Cu EDTA)	Varying

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

Crop response to nutrients

In a well drained acidic soil (pH 4.5-5) and low in organic carbon, upland rice can utilize only 4.3%, 14.5%, and 24.5% from soil source and 23.3% 13.5% and 93.6% from fertilizer source as N, P, and K, respectively (Table). In general, 5-10% N, 28-30% P_2O_5 and 70-75% K_2O under un-irrigated conditions and 10-15% N, 50% P_2O_5 and 25% K_2O under irrigated conditions are the contributions from soil source.

Nutrient efficiency (%) based on actual grain yield obtained under different yield targets of paddy		
Nutrient	Soil source	Fertilizer source
N	4.25	23.3
P	14.6	13.5
K	23.4	93.6
Source: Misra, C. and Misra, B.K. 1982.Oryza 19: 144-147		

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

In sandy loam oxisols response of medium-land- irrigated-rice crop to one kg N is 14-16 kg grains in summer and 8-10 kg in wet season. Response to P and K is less than that to N and is 5 kg grain to 1 kg P and 4-5 kg grain to 1 kg K. Response to P & K in wet seasons is also less than that in summer. Crop response varies with the soils type too, the order being red and yellow soil>

alluvial soil> laterite soil. Crop responses are determined from field experiments applying different quantities of nutrients either single or in combination (N, P, K, NP, NK, NPK, etc.) and recording yields obtained under each treatment.

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

Response of Rice to Nitrogen

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

Upland rice receives little or no fertilizer because of the risk involved in input investment. Traditional varieties are unresponsive to nitrogen, which tend to increase dry matter production without increasing grain production. However, many experiments with improved varieties have shown response to increased nitrogen supply. In general, application of 40-60 kg N ha^{-1} in three splits is optimum both for rainfed upland and rainfed lowland situations during monsoon season. Irrigated rice responds to higher levels of nitrogen since drought or deep flooding are not the problems either during monsoon season or dry season. Response to nitrogen, in general, varies from 40-60 kg ha^{-1} in fertile soils of delta areas to 80-100 kg ha^{-1} in light soils of low fertility during *kharif.* In dry season, optimum rate of application, in general, is 100 and 120 kg N ha-l for short duration varieties and medium and long duration varieties, respectively. In delta areas, optimum rate is 80-100 kg ha^{-1}. There are instances of latest medium and long duration varieties responding up to 200 kg ha^{-1} or even higher in the recent past. As such there is need for revising fertilizer recommendations based on the location specific responses. On equal nitrogen basis all the fertilizers are equally effective in increasing the yield, provided losses from applied fertilizers are minimized.

Response of Rice to Phosphorus

Many investigations around the world report that lowland rice fails to respond to phosphatic fertilizers even though upland rice grown on the same soil show positive response, since flooding usually increases the availability of soil phosphorus as discussed already. Application of 30-40 kg P_2O_5 ha^{-1} is the general recommendation for rainfed rice. For irrigated rice, the recommended rate is 40-60 kg P_2O_5 ha^{-1} depending on the rate of nitrogen application.

Response of Rice to Potassium

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

Response of Rice to Sulphur

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

Residual Effect of fertilizers

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

Fertilizer use efficiency

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

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

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

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

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

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

$$\text{FUE in terms of NR (\%)} = \frac{\text{Quantity of the nutrient of fertilizer taken up by the crop}}{\text{Quantity of nutrient applied through fertilizer}} \times \text{I00}$$

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

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

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

Agronomists usually express the efficiency of fertilizer nutrient in kg of grain yield produced kg^{-1} of applied nutrient, Agronomic efficiency (AE). It refers to the additional produce obtained in kg per kg of an applied nutrient. It is calculated as follows:

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

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

Physiologists, define the efficiency of nutrient utilization in kg of grain yield produced kg^{-1} of nutrient absorbed. These two efficiencies (Agronomic and physiological) can be related by introducing, percentage of nutrient recovery (a third parameter worked out as above).

$$\begin{matrix}\text{Efficiency of} \\ \text{fertilizer nutrient} \\ (\text{kg yield kg}^{-1}\text{ nutrient applied})\end{matrix} = \begin{matrix}\text{Percentage of nutrient} \\ \text{recovery (kg absorbed nutrient} \\ \text{kg}^{-1}\text{ applied nutrient)}\end{matrix} \times \begin{matrix}\text{Efficiency of} \\ \text{utilization (kg yield} \\ \text{kg}^{-1}\text{ nutrient absorbed)}\end{matrix}$$

The percentage nitrogen recovery varies with soil properties; methods, amounts and timing of fertilizer application and other management practices. It usually ranges from 30 to 50 per cent in the tropics (Yoshida 1981). The efficiency of utilization for grain production in the tropics is about 50 kg rough rice kg^{-1} nitrogen absorbed and this appears to be constant regardless of the yields achieved. In temperate regions, the efficiency is about 20 per cent higher than in tropics. Using values for the recovery percentage and utilization efficiency obtained for tropics, the efficiency of fertilizer nitrogen can be calculated.

Efficiency of fertilizer nitrogen = (0.3 ~ 0.5) x 50
15 ~ 25 kg rice kg^{-1} applied N.

The efficiency of applied fertilizer is low both in terms of nutrient recovery by the plants and in terms of productivity of nutrients recovered. The efficiency is low in tropical and sub-tropical countries, particularly, in wet-rice lands. Not more than 25-40% of applied nitrogen is recovered by plants; especially by rice under Asian conditions. Nitrogen recovery for upland crops is about 50%. The crop takes up approximately 15-20% of applied P fertilizer. The rest of P gets fixed in the soil and continues to become available to the succeeding crops for 10-20 years. The behaviour of K fertilizer appears to be somewhat in between N & P after application and its utilization is more than either.

There are two stages in the growth of rice crop when nitrogen is most needed: early vegetative and panicle initiation stages. Fertilizing the crop during early vegetative growth promotes tillering leading to higher yield. Application at panicle initiation or early booting stage will help the plant produce more and heavier grains per panicle. Panicle initiation occurs approximately 55 days before expected maturity date. Generally, rice plants, regardless of variety, mature in about 30 days after flowering. Panicle initiation begins approximately 25 days before flowering. Normally, these three stages: panicle initiation, flowering and maturity are more or less constant in duration regardless of time of planting. The panicle initiation stage, thus, may be determined approximately by adding the duration of these three stages.

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

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

where,

Y (n) = grain weight of the treatment corresponding to period (n)
Y (n-l) = grain weight of the treatment corresponding to period (n-1)
N (n) = total nitrogen uptake of the treatment corresponding to period (n)
N (n-l) = total nitrogen uptake of the treatment correspol1ding to period (n-l).

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

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

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

Techniques of increasing fertilizer use efficiency

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

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

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

How Much

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

What and Which (Type of fertilizer)

Fertilizers vary with respect to their solubility besides their grade. Choice of fertilizer is location specific and needs to be found out by field experimentation. The choice is more with respect to nitrogen and phosphatic fertilizers than for potassic. Studies on crop response is also more for N than for P or K fertilizers because leaching loss is more in nitrogenous fertilizer and its residual effect is nil or negligible. In case of P, its indirect, residual and cumulative effects are more important.

Nitrogen in form of NO_3^- is subject to more leaching. Leaching loss is also more in wet *(kharif)* than in summer and in sandy soils than in clayey soils. Losses can be minimized by choosing suitable time and method of application.

When to apply

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

Where to apply (placements)

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

Other considerations

- Proper control of pests and diseases is must for realizing maximum effectiveness from fertilizers.
- Weeds, if not controlled effectively particularly during early stages (7-21 days) of crop growth in kharif season, take away about 25 to 30 per cent of the applied plant nutrients. Therefore, the weed control, particularly during early stages of crop growth is essential.
- When the soils are acidic or saline or alkali, appropriate amendments viz. lime, gypsum etc. should be applied before using fertilizers. In alkali soils 3 to 5 tonnes of gypsum per acre (8 to 12 t/ha) should be applied broadcast only once and mixed with the top 10 cm of the soil layer.
- Rock phosphates can be profitably used in acid soils and in low land rice and legumes.
- Deficiency of Zn is becoming increasingly widespread. In such cases 25-50 kg zinc sulphate should be applied through soil as basal application. If symptoms of zinc deficiency appear in standing crop, it should be sprayed with 0.3 to 0.5 per cent solution of zinc sulphate mixed with 0.3 percent solution of lime for quick recovery.
- Under adverse soil and climatic conditions e.g. light permeable soils, rainfed conditions or where the crop is grown under deep standing water, application of fertilizers (particularly N) through foliage along with insecticides and pesticides (if needed will lead to higher utilization efficiency by plants.
- For rice crop, wherever possible, mix urea with available nitrification inhibitors such as neem cake and karanj cake (1 kg of cake blend with 5 kg of urea). This will reduce N losses from the soil.

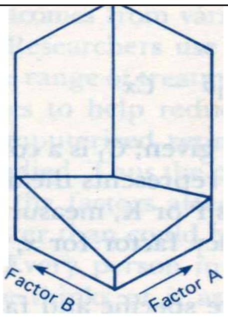
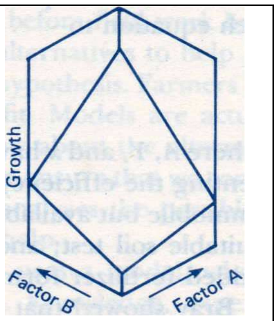
- Curing urea with soil for top-dressing reduces N loss. Mixing one part of urea with 5 to 10 parts of moist soil thoroughly and keeping it for 24 hours can cure urea for its better efficiency.
- Fertilizer recommendations should preferably be based on crop sequence for multiple cropping. Application of FYM and phosphate should preferably be made in wet and dry season, respectively. Intercropping with green gram, blackgram, soybean, onion and groundnut prove highly remunerative in wide row crops like cotton and red gram as compared to pure crop stand and need no extra fertilizers.
- Balanced fertilization should be practiced based on the soil test.
- To the extent possible, using just enough water at different physiological growth stages as recommended for the crop being grown controls irrigation rate. It is better to give priority to irrigated fields as compared to un-irrigated fields/crops as irrigated crops respond better to fertilizers.
- The introduction of leguminous crops in diverse rotational and inter-cropping sequence and use of bacterial and algal cultures play a very important role in meeting the fertilizer need of the crop.
- To the extent possible, green manuring with daincha (*Sesbania aculeata*) or sunhemp (*Crotalaria juncea*) should be practiced in low land paddy cultivation.
- For the compost made from straw and leaves having wide C:N ratio, add small quantity of N to increase N availability to young crop. Incorporation of finely ground rock phosphate or super phosphate with organic manures will make the manure more balanced.
- It is desirable to properly conserve and use organic waste. They should be incorporated 3-4 weeks before sowing the crop. It is preferable to apply FYM in kharif.
- Ensure proper plant spacing.
- Plant/sow the crop timely to get maximum benefit from fertilizers.
- Higher yielding varieties should be preferred over local varieties. Most responsive and best-suited crops should be selected to get maximum benefits of the limited quantity of fertilizers.

Nutrient Interactions

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

Two or more growth factors are said to interact when their influence individually is modified by the presence of one or more of the others. An interaction takes place when the response of two or more inputs used in combination is unequal to the sum of their individual responses. There can be both positive and negative interactions in soil fertility studies (Fig. below). In addition, there can be circumstances where there is no interaction, with the action of factors being only additive.

In negative interactions, the two nutrients combined increase yields less than when they are applied separately. This kind of interaction can be the result of substitution for and/or interference of one treatment with the other. Lime x P, lime x Mo, Mo x P, and Na x K are common negative interactions involving apparent substitution effects. Changes in soil pH will result in numerous interactions where one ion or nutrient interferes with or competes with the uptake and utilization of other nutrients by plants.

		
Negative interaction (Antagonism)	Zero interaction (Factors additive)	Positive interaction (Synergism)

Influence of interactions between two nutrient factors on the growth of a crop. *Sumner and Farina, in J. K. Syers, Ed.*, Phosphorus in Agricultural Systems, *Elsevier, New York*, 1983.

Positive interactions are in accordance with Liebig's law of the minimum. If two factors are limiting, or nearly so, addition of one will have little effect on growth, whereas provision of both together will have a much greater influence. In severe deficiencies of two or more nutrients, all fertilizer responses will result in strong positive interactions.

Yield increases from an application of one nutrient can reduce the concentration of a second nutrient, but the higher yields result in greater uptake of the second nutrient. This is a dilution effect, which should be distinguished from an antagonistic effect.

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

Interactions between Nutrients

N-K and N-P interactions are commonly observed. For example, under low yield conditions when other nutrients are limiting or management practices are inadequate, plant growth is slow, and unless K is seriously limiting, some soils will release K at a rate adequate to meet the needs of the crop. With adequate N and P and improved management practices, there is more rapid growth and the potential response to K, S, and other nutrients is greater. With 30 kg/ha of N there was little response by rice to K; however, when 90 kg/ha of N was applied, the response to K was linear up to the highest rate applied.

Interactions with micronutrients can be dramatic. On a low-P, low-Zn soil leveled for irrigation, adding P or Zn separately decreased corn yields. When both were applied a substantial positive interaction occurred.

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

Crop response to N is greatly reduced when P is limiting. The data in Figure 13.20 on irrigated corn illustrate that the N rate required for an optimum yield is considerably higher with 40 Ib/a of P_20_5 (160 lb/a of N) compared with no added P (80 lb/a of N). When both N and P were adequate, crop recovery of fertilizer N was approximately 75% compared to about 40% without adequate P fertilization.

Maximizing crop recovery of fertilizer N reduces the quantity of profile NO_3^- after harvesting. The rooting depth is about 6 ft; thus, a significant quantity of fertilizer N moved below the root zone and could potentially reach the groundwater. Thus, adequate N and P fertilization will optimize yield and profitability and maximize the fertilizer N recovered while minimizing the environmental impact of fertilizer N use.

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

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

Interactions between Nutrients and Plant Population

Increasing the plant population may not optimize yield unless there is an adequate quantity of available plant nutrients. Similarly, increasing plant nutrients without a sufficient number of plants will not maximize the return. For example, increasing the plant population with 80 lb/a of N increased the corn yield 46 bu/a; however, with 240 lb/a of N, increasing the plant population increased the yield 76 bu/a. At 12,000 plants/a, increasing N to 240 lb/a resulted in 37 bu/a increase, but with 36,000 plants the increase was 67 bu/a.

Interactions between Nutrients and Planting Date

Planting date has a marked effect on the response to nutrients (Table below). Earlier planting dates for spring-planted crops result in higher yields. There was greater response of soybeans to increased K soil-test level with earlier planting. Also, the K level had a greater effect on increasing seed size and on decreasing seed disease.

Similar planting date interactions with both N and P fertilization have been observed. The increased N and P response is related to the increased yield potential associated with timely planting and the longer growth period.

Effect of the Planting Date on the Response of Soybeans to K

Planting date	Yield (bu/a) at soil K level			Increase (bu/a)
	Low	Medium	High	
May 27	40	47	53	13
June 16	40	44	46	6
July 8	31	36	37	6

SOURCE: Peaslee, Univ. of Kentucky, personal communication.

Interactions between Nutrients and Placement

Crop response to fertilization can be greatly increased if nutrients are applied properly. The response of soybeans to P placement is shown in Figure 13.23. At the highest rate, broadcast application gave only a 4-bu/a response, but drilling below the seed gave a 28-bu/a response.

Under dry conditions, broadcast P will be in the dry surface soil and positionally unavailable to the roots. When placed below the seed, the probability is greater that the P will be in moist soil and more available to the roots.

Interactions between Nutrient Placement and Conservation Tillage

Soil and water conservation practices to reduce soil erosion include any system that increases surface residues.

Surface accumulations of residues and nutrients, cooler temperatures, and higher moisture in the spring can require a change in fertilizer use. In some situations, higher levels of nutrients applied below the soil surface may be needed. For example, a 42 bu/a corn response to 40-40-40 banded beside the row occurred where the soil was not plowed compared to 16 bu/a where the soil was plowed. Even with higher broadcast rates, the responses were 20 and 9 bu/a, respectively.

In general, higher rates of N and perhaps S are required under no-till systems than under conventional tillage. Under no-till, the broadcast NH_4NO_3 is partially immobilized and/or denitrified. To avoid fertilizer N interactions with surface residues, N must be placed below the residue. The data in Table below show increased grain yield with N placed below the surface (knife) compared to broadcast N. Surface band-applied N (dribble) was only partially effective in minimizing N losses. These data also show that reducing immobilization/denitrification losses by subsurface N placement increased the percentage of fertilizer N recovered by the crop. Increasing fertilizer N efficiency will greatly reduce the residual profile N content after harvest and the potential for NO_3^- movement to groundwater.

N Placement Effect on Average Grain Sorghum Yield and Apparent Fertilizer N Recovery at Two Locations in Kansas

N	Riley Co. (1986-88)		Greenwood Co. (1987-89)	
Placement	Yield (Bu/a)	AFNR*(%)	Yield (Bu/a)	AFNR*(%)
Broadcast	110	64	78	54
Dribble	117	70	81	56
Knife	130	87	89	65

*AFNR = apparent fertilizer N recovery. SOURCE: Lamond et al. *Prod. Ag.*, 4:531-535 (1991).

The following points summarize the available information on N management in reduced-tillage systems:

1. Subsurface placement of N can avoid N losses and increase N removal by the crop.
2. After several years in no-tillage systems, the differences in N needs between no-tillage and conventional tillage diminish.
3. Under some conditions, the yield potential is greater under no-till, thus requiring more N.
4. Soil sampling for profile NO3 - prior to planting can help predict the fertilizer N need.

Interactions between Nutrients and Hybrid or Variety

Within a given environment, one hybrid or variety may produce a greater response to applied nutrients than another. Dare soybean variety produced a higher yield and responded more to K than did the Bragg variety on very-low-K soil.

Some corn hybrids are genetically able to produce much greater yields from higher rates of applied nutrients than others (Table below). At the lower fertility level the corn hybrids differed by 19 bu/a. At the higher fertility level there was an 85-bu/a difference between the hybrids. Selection of hybrids or varieties that respond to a high-yield environment is essential for maximum productivity.

Interaction of Fertility and Corn Hybrids to Increase Yields					
N (lb/a)	P_2O_5	K_2O	Yield (bu/a) of :		Increase (bu/a)
			Hybrid A	Hybrid B	
250	125	125	199	218	19
500	300	300	227	312	85

SOURCE: R. L. Flannery, New Jersey Agricultural Experiment Station, personal communication.

The importance of exploiting interactions in maximizing productivity and profitability cannot be overemphasized. When one practice or group of practices increases the yield potential, the nutrient requirement will be increased. Also, as breakthroughs occur in genetic engineering, rhizosphere technology, plant growth regulators, and related areas, they will be successful only if the technology is integrated in a manner that allows positive interactions to be expressed.

Soil moisture-nutrient interactions

An interaction occurs when the response of one factor is modified by the effect of another factor. A positive interaction occurs when the response to two or more inputs used together is greater than the sum of their individual responses. Negative interactions also occur. Interactions have been observed between

1. Two or more nutrients.
2. Nutrients and a cultural practice such as planting date, placement, tillage, plant population, or pest control.
3. Nutrient rate and hybrid or variety.
4. Hybrid or variety and row width or plant population.
5. Nutrients and the environment (water, temperature, etc.).

Many interactions are not significant with average yields; however, with high yields, increasing pressure or stress is being placed on the plant, and the interactions between the various factors contributing to those yields are often observed. Thus, in the future, interactions and their recognition will be the key to significant progress toward optimum yields and efficient utilization of inputs.

Plant-nutrient response is often difficult to separate from the influence of other management practices due to the numerous positive interactions between fertility and other inputs.

A fundamental objective of agronomic technology development and transfer must be to lead growers from one level of improved practices to the next. For example, fertilizer contributed most to the increase in yields of wheat and teff; in the case of corn, introduction of an improved variety in the recommended practice gave a marked yield increase (Table).

Yield Improvements from Fertilization and Management in Ethiopia			
	Yield Increase over Check (%)		
Crop	Farmer Practice + Fertilizer	Recommended Practice - fertilizer	Recommended Practice - fertilizer
Wheat	64	18	91
Corn	81	80	156
Teff	84	2	94

SOURCE: Mathieu, Progress Report. Third Consultation on the FAD Fertilizer Programme. Rome: FAO, 1978.

The potential exists for greatly increasing agricultural output through improvement and integration of the numerous components of yield. General Carlos P. Romulo, in *Strategy for the Conquest of Hunger* (1968), stated the challenge concisely:

The test of technology is yield. Unless scientists can produce yields which are high by world standards, we can be sure that we have not yet mastered the technical problems confronting the producer. If the yields are high on the experiment stations but national average yields are low, we can be equally sure that the scientific advances are on the shelf and that for some reason the farmer is unable to make profitable use of them. .

Future increases in agricultural productivity will likely be related to manipulation of the interactions between the numerous management inputs and factors. It is essential that growers and consultants recognize and take advantage of these interactions.

Nutrient- Water Interactions

Even in regions where annual precipitation exceeds growing season evapotranspiration, water stress frequently limits crop production on the majority of agricultural lands. Stresses caused by nutrient deficiencies, pests, and other factors reduce the plants' ability to use water efficiently, which reduces productivity and profit. As pressures grow for increased industrial, recreational, and urban use of water, agriculture will have less access to water for irrigation.

Increasing water use efficiency is a major challenge to agriculture. It is estimated that overall efficiency of water in irrigated and dry land farming is 20 to 50%. In general, any growth factor that increases yield will improve the efficiency of water use.

Water Use Efficiency

Water use efficiency (WUE) is the yield of crop per unit of water-from the soil, rainfall, and irrigation. When management practices increase yields, WUE is increased. Yields of crops have increased greatly in the past 20 years on essentially the same amount of water, which is directly related to improved soil and crop management practices. For example, tillage systems that leave large amounts of surface residues conserve water by

1. Increased water infiltration.
2. Decreased evaporation from the surface.
3. Increased snow collection.
4. Reduced runoff.

In many parts of the world irrigation has stabilized production, but yields per unit of land have not increased greatly. After the lack of moisture is eliminated by irrigation, many factors may limit yields. Because of these other factors, there can be many disappointments. If yields of 300 bu/a rather than 150 bu/a of corn or 14 tons/a rather than 7 tons/a of alfalfa are to be obtained, the nutrient removal is at least doubled. This means that the crop must obtain more nutrients from some source, whether from native soil supply, manures, or fertilizers.

How Water Is Lost from the Soil

Water in a soil is lost in three ways:

1. From the soil surface by evaporation.
2. Through the plant by transpiration.
3. By percolation beyond the rooting zone.

The sum of the water used in transpiration and evaporation from soil plus intercepted precipitation is called evapotranspiration. With more complete cover, less water evaporates from the soil and more goes through the plant. Adequate fertility and satisfactory stands are among those factors that help to provide more plant cover rapidly and thus realize more benefit from the water.

After the lack of moisture is eliminated by irrigation, many factors may limit yield. Careful attention is needed to get the greatest return from the water, fertilizer, and other inputs.

With a sparse stand or growth, more sunlight will reach the soil, and a considerable amount of water may be evaporated directly from a moist soil. With a heavy crop canopy, the surface is shaded and less evaporative energy reaches the soil. The soil temperature is reduced and the crop provides insulation to maintain higher humidity just above the soil because of less air movement. These three effects reduce evaporation from the soil. It should be kept in mind, however, that even with a heavy canopy a considerable amount of energy still reaches the soil.

Nutrient availability affects plant size, total leaf area, and often the color of the foliage. Close rows and adequate stands, along with adequate nutrition, provide a heavy crop canopy. For example, water use would be less in 21-in. rows than in 42-in. rows. Differences in evapotranspiration among crops may be small once a complete cover is developed. Daily use of water with a growing crop on the soil varies greatly from one day to another, depending on soil and environmental conditions (temperature, moisture, and wind); however, daily losses of 0.1 to 0.3 in. of water per acre are common.

Evaporation from the soil may account for 30 to 60% of the total water loss in a crop year in humid areas where the soil is wet. With local droughts or in arid regions the soil surface is dry, and very little water is lost from the soil. The moisture films between the particles are thin, and little water is transported to the soil surface by capillarity or diffusion of water vapor. Hence in dry soils most of the water use is by transpiration, although most of the water received in a light shower would be evaporated quickly.

Heat advection, in which there is horizontal and vertical movement of air in a turbulent fashion, brings in more heat. In a hot, dry area with a strong wind, the heat from the air may contribute to 25 to 50% of the total evapotranspiration. In arid and semiarid areas advection is great, and thus quite variable evapotranspiration may occur.

Fertilization and Water Extraction by Roots

Most crops use water more slowly from the lower root zone than from the upper soil. The surface soil is the first to be exhausted of available water; subsequently the plant must draw water from the lower three-fourths of the root depth (Fig below).

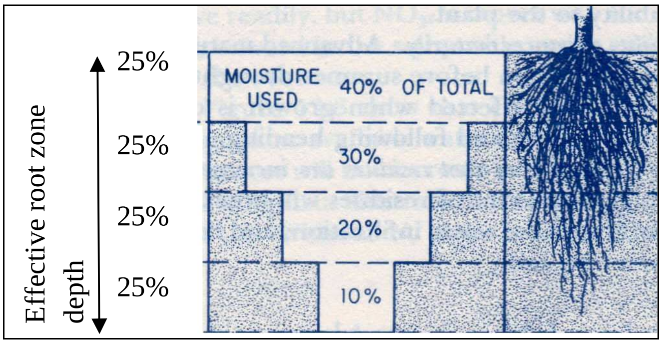


FIGURE: The top one-quarter of the root zone is the first to be exhausted of available moisture. Certain management practices, including adequate fertilization, help to develop a deeper root system to use the moisture from the lower root zone. USDA, SCS. BulL, 199.

The effects of fertilization on the mass and distribution of roots when soils are nutrient deficient are fayorable. Under nutrient stress the plant may extract water from a depth of only 3 to 4 ft. With fertilization the plant roots may be effective to a depth of 5 to 7 ft or more. If the plant can utilize an extra 4 to 6 in. of water from the subsoil, the crop can endure droughts for a longer period of time without reducing the yield. It should be emphasized that in areas in which the subsoil is dry, increased fertilization will not help crops penetrate the soil farther to get more water. .

Soil texture, soil structure, and OM content influence the water-holding capacity of soils, which may vary from less than 1 in/ft on sandy soils to more than 2 in./ft of soil on silt and day loams. The capacities in the surface 5 ft of several soils are in Table.

Oquawka sand	5 in.
Ridgeville fine sandy loam	7 in.
Swygert silt loam	9 in.
Muscatine silt loam	12 in.

However, crops root differently in soils because of compact soil horizons, zones of unfavorable pH, inadequate nutrient supply, and other factors. The accompanying data illustrate the approximate rooting depth in three soils and the difference in available water.

	Depth of roots (ft)	Water Available (in.)
Clarence silt loam	3	6.5
Saybrook silt loam	4.5	10.5
Muscatine silt loam	5+	14

The importance of adequate fertility for efficient crop water use and improvement of crop tolerance to low-rainfall conditions can be explained by the following conditions:

1. *Root exploration of the soil is increased.* Adequate fertility favors expanded root growth and proliferation. When roots explore the soil a foot deeper, another inch or two of water will be obtained.
2. *The major portion of the P and K moves to roots by diffusion through the water films around the soil particles.* Under moisture stress the films are thin and path length increases, reducing P and K diffusion to the roots. Increasing the concentration of P and K in the soil solution increases their diffusion to the roots.
3. *Increased soil moisture tension (lower moisture) exerts a physiological effect on the roots.* Elongation, turgidity, and the number of root hairs decrease with increasing tension. Mitochondria development slows, and carrier concentration and phosphorylation decrease, which reduces nutrient uptake.
4. *Adequate fertility decreases the water requirement.* K has been shown to aid in dosing the stomata, thus reducing water loss by transpiration.
5. *The foliage canopy is increased and the soil is covered more quickly.* Rapid canopy development reduces water evaporation from the soil, which increases water availability to the plant.
6. *Adequate fertility advances maturity.* Advanced maturity in sorghum and corn helps ensure pollination before summer drought periods. Similarly, small grains are adversely affected when growth is delayed, so that summer drought occurs during and following heading.
7. *The amounts of plant and root residues are increased.* With any given tillage practice, a higher amount of residues will break the impact of raindrops, reduce runoff, increase water infiltration, and reduce the erosive effect of wind and water on soil.

Soil Moisture Level and Nutrient Absorption

Water is a key factor in nutrient uptake by root interception, mass flow and diffusion. Roots intercept more nutrients, especially Ca^{2+} and Mg^{2+}, when growing in a moist soil than in a drier one because growth is more extensive. Mass flow of soil water to supply the transpiration stream transports most of the $NO^{3\,-}$, SO^{4-}, Ca^{2+}, and Mg^{2+} to roots. Nutrients slowly diffuse from areas of higher concentration to areas of lower concentration but at distances no greater than 1/8 to 1/4 in. The rate of diffusion depends partly on the soil water content; therefore, with thicker water films or with a higher nutrient content, nutrients diffuse more readily.

Nutrient absorption is affected directly by the level of soil moisture, as well as indirectly by the effect of water on the metabolic activity of the plant, soil aeration, and the salt concentration of the soil solution.

Of course, crop yield potential is greater with normal or higher moisture availability. Substantial responses in grain yield and WUE to fertilization occurred in the dry years, as well as in the normal rainfall years. Although, the response to fertilization was less in dry years than in, normal years, adequate nutrient availability greatly reduced drought-related yield losses.

Dryland Soils

Moisture is the most limiting factor in crop productivity in semiarid and arid regions. In crop-fallow systems, conserving soil water may not always increase the grain yield in some crops, but increased soil water conservation will reduce the dependence on fallowing through more intensive cropping.

N and P are particularly important for high yields when water is limiting.

NITROGEN Although absorption of N is definitely reduced on dry soils, it is usually not reduced as much as that of P and K. Under drought conditions, OM decomposition and hence N mineralization are reduced. Also, when water is limiting, uptake of soluble nutrients in the water is reduced. Ammoniacal N does not move readily, but NO_3-N moves with the soil water. In heavy rains NO_3^- moves downward in the soil profile and is available for later use, unless it moves below the root zone.

Evidences show that (I) fertilizer N will not increase yield without sufficient plant-available water and (2) increasing stored soil water by conservation practices will not increase production without adequate fertility.

The accompanying data illustrate that N increased wheat yield, evapotranspiration, and WUE. Without N, water extraction was largely limited to the upper 3 ft.

	0 N	60 lb N	240 lb N
Yield of wheat (bu/a)	24	46	54
Evapotranspiration (in.)	8.7	10.7	12.4
Water remaining in 7-ft profile (in.)	7.1	5.2	3.8
Bushels per inch of H_2O	5.1	6.7	6.4

Some of the positive effects of fertilization on improved water use that occur under moisture stress are due to placement of the nutrients deeper in the soil where the soil is more likely to be moist.

PHOSPHORUS Crop yield response to P and other nutrients varies from year to year and can be related to the amount of rainfall. The lower the rainfall, the greater the percentage response to P. The same relationship was found for K. .

In low-P soils the majority of wheat response to N-P fertilization in dry years is due to P. In wet years, wheat yields dramatically increase, with both N and P contributing to the wheat response. The inverse relation between the response of cereals to P and rainfall was demonstrated. The percent yield response to P is greater with low rainfall.

POTASSIUM Adequate K availability reduces some of the water stress. Generally, the lower the rainfall, the greater the K response, which is related to the following factors:

1. Most of the K absorbed moves to the roots by diffusion through the water films, and with low water content, K diffusion is reduced. Therefore, K fertilization will increase the K content in the water films and increase diffusion. The same is true for P.
2. In some soils the subsoil contains less K than the surface. When the surface soil is exhausted of water in dry periods, the plant roots must feed in the subsoil, where they cannot absorb as much K; this is also true for P.

In wet periods, the K response can also be large and is related to restricted aeration. Plant roots respire to obtain energy to absorb nutrients. Respiration requires O_2. Adequate K helps to meet the needs of the plant even when root respiration is restricted.

The effect of normal rainfall and dry years on the response by corn and soybeans to K is shown in Table 2. On a medium-K soil there was little or no yield response or profit in years of good rainfall. In stress years, K gave a 48-bu response on corn and an 18-bu response on soybeans, with excellent profits.

In dry years, the K content in the corn or soybean leaves is below the sufficiency K level even with high K rates. The inability to take up adequate amounts of nutrients probably contributes to lower yields in dry years.

Increasing fertility and peanut hulls increased corn yields in both dry and wet seasons (Table below). Even in a dry year, added fertility and hulls increased yields to 157 bu/a. With good rainfall, yields were 266 bu/a. Peanut hulls greatly increased K uptake. Moisture content was increased in the 0- to 15cm depth by reduced evaporation and runoff and increased infiltration.

Effect of K on Corn and Soybean Yields and Profits in Years of Good Rainfall and in Dry Years

	Corn (bu/a)		Soybeans (bu/a)		
K2O (lb/a)	Good Year	Stress Year	Good Year	Stress Year	K Soil Test, Initial 162 (lb/a)
0	163	81	56	30	129
50	163	113	59	42	152
100	167	121	60	48	196
200	163	129	58	48	236
Response	0	48	4	18	-
Profit ($/a)	0	87	18	104	-

SOURCE: Johnson and Wallingford, *Crops and Soils*, 36(6):15 (1983).

MICRONUTRIENTS Since transport of micronutrients to plant roots is by diffusion (and some mass transport), low soil moisture content will reduce micronutrient uptake in dry weather, as with P uptake. The only difference is that the quantity of micronutrients required by plants is much less than for P; thus, drought stress effects are probably not as great as for P.

Temporary B deficiency during periods of dry weather is quite common. Explanations include the following:

1. Much of the B is in the organic matter, and under dry conditions mineralization is reduced.
2. In some areas the subsoil is lower in B than the surface soil. Under dry conditions, water uptake is predominately from the subsoil; thus, plants take up less B. In contrast, in sandy soils, excessive rainfall may leach some of the available soil B.

Low soil moisture can also induce deficiencies of Mn and Mo, although Fe and Zn deficiencies are often associated with high soil moisture. Increased soil moisture results in greater amounts of Mo uptake. Mn becomes more available under moist conditions because of conversion to reduced, more soluble forms.

Placement and Nutrient Absorption

In general, deep placement of nutrients, where moist soil exists during a greater portion of the season, will increase utilization of fertilizer nutrients. Of course, if a soil is very dry, deeper placement will not be effective. Deeper fertilizer placement increased N absorption under dry conditions. There was no effect under wet conditions.

Irrigated Soils

Fertility is one of the important controllable factors influencing water use in irrigated soils. Adequate N increased the forage yield, while the amount of water use decreased from 18 in./ton with no N to 3 in./ton with 1,000 lb/a of N. Under irrigated, high-fertility, conditions, WUE in corn was 11.6 bu/in. water, compared to 8.3 bu/in with medium fertility (Table below).

When N is deficient, increasing N fertilization will increase yield and water use. More irrigation water was required with increasing N rate; however, the WUE also increased.

Effect of Adequate Fertility on Corn Yields (hula) in Good- and Poor-Rainfall Years

Peanut Hulls Applied Annually (tons/a)	1975 (Good Year)		1976 (Poor Year)	
	Unfertilized	100-100-100	Unfertilized	100-100-100
0	126	205	53	111
10	188	196	100	129
20	161	239	107	138
40	231	266	136	157
Average	176	226	99	134

SOURCE: Lutz and Jones, *Awan.* 70:784 (1978).

Stored Water and Fertilizer Recommendations

The relation of stored soil water to crop responses to fertilizer has received much attention in low-rainfall regions. In general, a systematic survey of the moisture in the soil profile to the rooting depth, 4 to 6 ft, is made in late fall or early spring. This information must then be weighed against the probability of summer rainfall.

Thus, N recommendations in some areas are based on stored soil moisture and on the residual NO_3-N in the soil profile. This approach is based on the concept that adequate fertility will increase the use of available water. With a low amount of water in the profile, the probability of a large response to nutrients is reduced.

Additional water supply (stored plus rainfall) will increase yield of wheat to a point, but if fertility is limiting, additional water will not be beneficial. However, even with a very low supply of water, fertilizer is beneficial.

Effect of Fertility Level on Com Yield, Amounts of Residues, and Bushels per Inch of Water *			
	Corn Yield (bu/a)	Residues Returned (tons/a)	Bushels per Inch of H_2O
Medium fertility. irrigated	214	5.0	8.3
High fertility. irrigated	299	6.4	11.6

* High-P and high-K soil. 2-yr average.

SOURCE: R. L. Flannery. New Jersey Agricultural Experiment Station, personal communication.

Fertilizers have an indirect effect on the amount of stored water in the soil profile. When there is a response to fertilizer, an increased amount of vegetative cover is produced in the growing crop. Runoff of intense rains is retarded and infiltration increased. In the fallow season the greater amount of residues on the soil surface helps retain the water.

In some irrigated regions, fall irrigation after harvesting is practiced as an insurance policy, particularly with flood irrigation. On deep soils, up to 12 in. of water can be stored for the next year's crop. This has several advantages. Water is usually lower in price in the fall, and sometimes water is short during the growing season.

Maximum Increase in Yield of Wheat (bu/a) from N-P on Non fallow Land as Related to Stored Moisture at Seeding and to Rainfall During the Growing Season (66 Trials)			
Rainfall from Seeding to 20 Days Before Harvest (in.)	Available Soil Moisture (in./4 ft soil)		
	0-2 (Low)	2-4 (Medium)	4-6 (High)
>8	7.1	10.0	15.0
6-8	5.0	9.5	16.4
<6	2.4	5.9	10.5

SOURCE: Norum, Better Crops Plnnt Food, 47(1):40 (1963).

Unit V

Time and Methods of manures and fertilizer application

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

TIME OF APPLICATION

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

Crop uptake

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

Soil properties and nature of fertilizers

Nitrogenous fertilizers are soluble and highly mobile in soil. Nitrogenous fertilizers are lost into deeper layers beyond root zone if the entire quantity of fertilizer is applied especially in light textured soils. Phosphatic fertilizers which are highly reactive are fixed in the soil and become immobile. Potassium fertilizers are less mobile since they are adsorbed on the clay complex. The entire quantity of phosphatic and potassium fertilizers are, therefore, applied in one dose at the time of sowing.

Utilization of carbohydrates

The level of carbohydrates and nitrogen in the plants are inversely related. When large quantities of nitrogenous fertilizers are applied, the level of carbohydrates in the plants decreases. With less nitrogen in plants, carbohydrate level in the plants increases. Under a sufficient level of nitrogen in the plant, carbohydrates are utilized for the synthesis of proteins. The assimilation of nitrogen requires energy which is obtained either from light or the breakdown of carbohydrates.

The time of application of nitrogen, therefore, depends on the end product of the crop. In fodder crops, leafy succulent crop with higher level of proteins are preferred compared to fibrous crop with higher carbohydrates. Hence, application of nitrogen in several splits is necessary. If the fodder crop is grown for silage, it should have higher carbohydrates just before cutting for better quality silage. Application of nitrogen should be curtailed in the last stage. Similarly, nitrogen should not be applied for sugarcane during maturation as the economic product is carbohydrate (sugar).

Basal application

Application of fertilizers before or at the time of sowing is known as basal application. A portion of a recommended dose of nitrogen and entire quantity of phosphatic and potassium fertilizers are applied as basal. Modified forms of urea like urea super granules, sulphur-coated urea, neem-coated urea etc. are used for basal application.

Split application

Optimum time of application of nitrogen for different crops

Crop	Time of application
Rice	Basal, at tillering and panicle initiation (PI) (1/3 at each stage or 1/2 + 1/4 + 1/4)
Sorghum	Basal, PI
Pearl millet	Basal. PI
Finger millet	Basal, tillering and PI
Wheat	Basal. crown root initiation and PI
Groundnut and pulses	Basal
Sugarcane	60, 90 and 120 days after planting.

Application of recommended dose of fertilizers in two or three splits during crop period is known as split application of fertilizers. Application of fertilizers in the-standing crop is known as top dressing. The number of split applications has to be more in light soils and less in heavy soils. Nitrogen is applied in more splits for long duration crops.

The stage of application is also important. In cereals, nitrogen is applied at tillering and panicle initiation stages in addition to basal application. Basal application is sufficient in pulses while for sugarcane, it is not necessary. Nitrogen is applied at 60, 90 and 120 days after sowing for sugarcane.

Fertilizers are applied by different methods mainly for three purposes: (1) to make the nutrients easily available to crops (2) to reduce fertilizer losses, and (3) for ease of application.

Factors influencing methods of application

Suitable method for a particular situation depends on the nature of the soil, crop and fertilizer material.

Nature of the Soil

Soil properties like texture, pH, CEC, nutrient and moisture status are important factors to be considered for selecting suitable method of application. Soil texture influences the mobility of the fertilizer material. Soil pH increases volatilization of ammoniacal fertilizers when it is more than 8 pH. The soils with high CEC retain the cations present in the fertilizer material and thus reduce leaching tosses. In soils low in phosphorus status, band placement of phosphatic fertilizer reduces fixation, while in soils of medium phosphorus status, incorporation of phosphorus fertilizer after broadcasting is better for higher availability. For crops grown on residual moisture, deep placement of fertilizer in the moist zone is essential and when it is not possible foliar application is resorted to.

Nature of the Crop

Depending on the type of root system and spacing adopted for the crop, different methods of fertilizer application are practiced. In crops with fibrous root system and those grown with closer spacing, most of top layer of the soil is occupied by the root system. In such a situation, broadcasting of fertilizer is resorted to followed by irrigation. In widely spaced crops with initial slow growth, point placement is adopted instead of broadcasting over the entire field.

Nature of the fertilizer

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

Different methods

Soil Application

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

Different methods of applying fertilizers		
1. Application of fertilizers in solid form		
	a. Broadcast	i. Broadcasting at planting ii. Top dressing
	b. Placement	i. Plough sole placement ii. Deep placement iii. Subsoil placement
	c. Localized placement	i. Contact placement, combined drilling or drill placement ii. Band placement (Hill or row placement) iii. Pellet application iv. Side dressing
2. Application of fertilizers in liquid form		
	a. Starter solutions b. Foliar application or spray fertilization c. Direct application to the soil d. Application through irrigation water (Fertigation)	

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

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

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

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

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

Application to plant

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

Foliar application. Application of fertilizers to foliage of the crop as spray solution is known as foliar spray of fertilizers. It is also called non-root feeding. These solutions may be prepared in a low concentration to apply any one of plant nutrient or a combination of nutrients. This method is suitable for application of small quantities of fertilizers, especially micronutrients. Major nutrients can also be applied by this method when there is not adequate moisture in the top layer of soil. Among the nutrients N is most frequently foliarly applied. Absorption of N by foliage I more rapid and nearly 80% of the spray material is absorbed by most of the crops within 24 hours of application. Spray of urea 4-6% solution, is common in many cereals excluding maize which is very susceptible to foliar injury. Some thick-cuticle leaf fruit crops can also be sprayed with urea concentration as high as 15-20%. For feed crops foliar application to be effective need to be sprayed at low concentration (2-4%) when LAI is high to retain the spray. Foliar application of urea just before flowering or at flowering increases grain quality and leaf area duration (LAD). It should be preferably sprayed during evening hours to reduce failure of fertility and grain sterility. Foliar feeding is an efficient method of fertilization supplementary to soil feeding. It is not a substitute for soil application, but only a supplement to it. Precautions are taken to avoid scorching. Stickers can be mixed for retaining fertilizers on the foliage. To avoid any injury or to increase absorption wetting agent like teepol (1.0%) can be used.

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

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

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

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

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

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

Fertilizer dose

Recommended Fertilizer Dose (kg/ha) for different field crops, horticultural crops, and grasslands in HP

Crop	N	P_2O_5	K_2O	Other
Rice	90	40	40	25 Zn
Wheat	120	60	30	
Maize	120	60	40	
Grassland	80	60	-	-

Crop nutrient requirements are met by soil contribution and fertilizer application. The soil contribution is estimated by soil tests. Although soil testing is generally accepted as a workable practice, there are some differences in interpreting the tests. This results in radically different fertilizer recommendations to the farmers. There are three major concepts for making fertilizer recommendations: maintenance, cation saturation ratio and sufficiency level.

Maintenance concept implies that whatever may be the soil supplying capacity, a quantity of nutrient has to be applied to replace that amount removed by the crop. Even though the soil supplying capacity of a given nutrient is adequate for top yields, still fertilizers are recommended based on the maintenance concept.

As per the cation ratio concept, a soil is considered as an ideal one with the following distribution of exchangeable cations: 65 per cent Ca, 10 per cent Mg, 5 per cent K and 20 per cent H so as to have ratios of Ca: Mg as 6.5: 1; Ca: K as 13: 1, and Mg: K as 2 : 1. Fertilizers are recommended to maintain this ratio. However, vide variations in these ratios have no adverse effect. In sufficiency level concept, crop response to applied nutrients is considered. This concept is followed in most of the fertilizer recommending approaches.

Several approaches are followed for recommending fertilizers and each approach has advantages and disadvantages.

Blanket recommendation

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

Soil test based fertilizer recommendations

The soil samples analyzed for available N, P and K are categorized into low, medium and high fertility classes with respect to each nutrient. These fertility classes for available N, P and K are given in Table 1 for the soils of Himachal Pradesh. The state level fertilizer recommendations for a particular crop are given from time to time in the package of practices for kharif and rabi crops and the same are meant for medium soil fertility class. If the test shows a particular nutrient in low fertility class then the state level fertilizer dose with respect to that particular nutrient has to be increased by 25%. If the soil test shows a particular nutrient in high class, then the state level fertilizer dose has to be decreased by 25%.

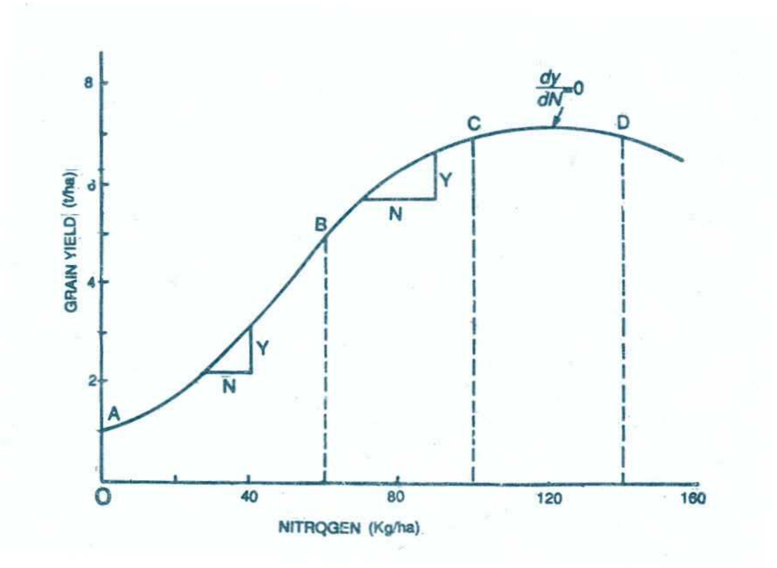
Table 1. Fertility classes with respect to available N, P and K in Himachal Pradesh

	Fertility class		
Nutrient (kg/ha)	Low	Medium	High
N	<280	280-560	>560
P	<10	10-25	>25
K	<118	118-280	>280
OC%	<0.50	0.50-1.00	>1.00

The rating limits for classifying the soils are very wide and without considering this fact same fertilizer dose is recommended over a wide range of available nutrient. This means that there are too many discrepancies in the interpretation and fertilizer recommendations on the basis of soil test rating. Moreover, these rating limits are of general nature and do not take into account either crop/variety, soil type or climatic conditions existing in a particular area. The crop variety differ greatly in its requirement for each nutrient and efficiency of each soil available as well as added fertilizer nutrient is a function of soil type and climatic conditions. Therefore, the above method of fertilizer recommendation on the basis of soil test rating may not give the precise dose of fertilizer nutrient. Because of this type of oil test interpretation and fertilizer recommendation, two type of situations arise. In the first case, fertilizer nutrients are applied beyond the requirement of the crop which leads to mere wastage of costly inputs like fertilizers. In the second case, fertilizer nutrient are applied much less than the actual requirement of the crop which in turn, is responsible for not harvesting the full potential of the crop.

Response equations

Field experiments are conducted with different levels of fertilizers. The yield responses to different levels of fertilizers are fitted into a mathematical equation based on the shape of the curve. From the equation, economic optimum dose is calculated and recommended to the farmer.



Response of rice to nitrogen

Curve Fitting. Generally, the response to fertilizers is quadratic i.e. yield increases at increasing rate with increase in fertilizer dose upto a certain level and at a decreasing rate with subsequent doses of fertilizers. At a particular level, yield approaches a plateau and further increase in fertilizer dose decreases the yield.

From Fig. above, it can be seen that even with no fertilizer application, one t/ha of grain yield can be obtained due to inherent soil fertility. There is linear increase in yield upto 60 kg

N/ha (from A to B). Subsequently, the response line is curvilinear (from B to C) i.e. for every increase in fertilizer dose, the yield increased at a decreasing rate. Beyond 100 kg N/ha, the grain yield does not increase with increase in fertilizers which is called as plateau (C to D). Further increase in fertilizer dose beyond 140 kg N/ha, yield decreases and is considered as toxic level.

This curve can be expressed as a mathematical equation.

$Y = a + bN + cN^2$

Where Y is grain yield (kg/ha), N, nitrogen dose (kg/ha) and a, b and c are constants. Constant a is known as intercept which indicates the yield level without fertilizers. Constant b, otherwise known as slope, provides the response rate (kg grain obtained per kg N applied). Constant c represents the curvature of the response line which indirectly indicates the adverse effect of excess dose of nitrogen. Generally, constant c has a negative sign.

The constants a, b and c can be found by the following procedure:

On summation, $Y = a + bN + cN^2$ becomes

$\sum Y = na + b\sum N + c\sum N^2$ ….(1)

By multiplying the equation with N

$\sum YN = a\sum N + b\sum N^2 + c\sum N^3$ ….(2)

By multiplication with N again

$\sum YN^2 = a\sum N^2 + b\sum N^3 + c\sum N^4$ ....(3)

Thus, for obtaining three constants, there should be three equations. The small 'n' in the equation is the number of observations recorded. The other quantities, N, N, N3 ,N4, Y, YN, YN^2 and their summation can be obtained from the data.

By solving the simultaneous equations, the constants a, b, and c can be obtained. One such equation to calculate physical and economic optimum is given. The response equation is for rice variety Co 33.

$Y = 1813.25 + 25.93\ N - 0.0661\ N^2$

From this equation, amount of N required to obtain highest grain yield which is called physical optimum can be calculated. It is also possible to estimate economic optimum which is the nitrogen level at which highest net return can be obtained.

To calculate physical and economic optimum, the equation has to be differentiated. Simple rules of differentiation are: (1) if there is only a constant in a term, on differentiation it becomes zero, and (2) if a term contains a constant and a factor, the power of the factor becomes multiplier of the term and the power is reduced by one.

It can be explained with simple equation where $Y = 3 + 4\ N - 0.6\ N^2 + O.OO2N^3$. This equation has four terms. The first term contains only a constant i.e. 3, hence on differentiation, it becomes zero. The second term 4N, consists of a constant 4 and factor N. Since the power of N is one, its power on differentiation becomes zero. Any number to the power of zero is one. The term is multiplied by one, hence, it becomes 4. The third term consists of a constant 0.6 and a factor N^2. On differentiation, the power of N is reduced by one ($N^{2-I} = N^I = N$) and the term is multiplied by 2. Hence, it becomes $2 \times 0.6\ N^{2-1} = 2 \times 0.6\ N = 1.2\ N$. The last term $0.002\ N^3$ becomes: $= 3 \times 0.002\ N^{3-1}$

$= 3 \times 0.002\ N^2$

$= 0.006\ N^2$

The present equation, $Y = 1813.25 + 25.93N - 0.0661N^2$ on differentiation becomes

$dY/\ dN = 0 + (1 \times 25.93) - (2 \times 0.0066\ N^{2-1})$

$= 25.93 - (2 \times 0.066 \times N)$

$= 25.93 - 0.1322\ N$

dY/dN indicates the response rate ie. for a very small change In N level, there is change in grain yield.

Estimation of Physical Optimum. The response rate dY/dN is higher at lower doses of N. Gradually, it decreases and will be zero at some point and as the N level still increases; it becomes negative (Fig. 6). Maximum grain yield can, therefore, be obtained at N level where responses rate is zero. That is dY/dN = 0 where grain yield is maximum.

dY/dN $= 25.93 - 0.1322\ N = 0$

or $25.93 = 0.1322\ N$

or $N = 25.93/0.1322 = 196.14$

The dose, 196.14 kg/ha is physical optimum level of N for CO-33 rice variety. The maximum grain yield can be calculated by substituting N = 196.14 in the equation.

$$Y = 1813.25 + 25.93\ (196.14) - 0.0661\ (196.14)^2$$

$$= 1813.25 + 5085.91 - 2542.93 = 4356 \text{ kg/ha.}$$

Calculation of Economic Optimum. It depends on the price of fertilizer and grain. If the price of paddy is Rs. 2 per kg and that of nitrogen Rs. 5 per kg, then the price of grain can be denoted as PY and price of nitrogen as PN. The price ratio is PN/PY, that is 5/2 = 2.5. It implies that if a kg N is applied, at least 2.5 kg of grain should be obtained to off-set the cost of fertilizer. It follows that dY/dN = PN/PY for economic optimum dY/ dN = 25.93 - 0.1322 N = PN/PY

$= 25.93 - 0.1322\ N = 2.5$

$= 25.93 - 2.5 = 0.1322\ N$

$N=23.43/0.1322=177.23$

The economic optimum dose of N is 177.23 kg/ha. The grain yield at economic optimum dose can be calculated by substituting the value of economic optimum in the response equation.

$$Y = 1813.25 + 25.93\ (177.23) - 0.0661\ (177.23)^2$$

$$= 4332.59 \text{ kg/ha}$$

The advantage of recommendation of economic optimum dose of N can be seen by estimating the net return.

Yield at physical optimum = 4,356.23 kg/ha

Value of the produce at Rs. 2 per kg

= 4356.23 x 2 = Rs. 8,712.46

The cost of fertilizer applied at physical optimum

=196.14 x 5.00 = Rs. 980.70

Yield at economic optimum level of N = 4332.59 kg/ha

Value of the produce = 4332.59 x 2 = Rs. 8,665.18

Cost of the fertilizer applied at economic optimum level

= 177.23 x 5.00 = Rs. 886.15

Net profit at physical optimum = 8712.46 - 980.70 =7731.76

Net profit at economic optimum = 8665.18 - 886.15 = Rs. 7779.03

Advantage of recommending economic optimum dose = 7779.03 - 7,731.76 = Rs. 47.27

The drawbacks in the responses equation approach are: (1) soil contribution is not considered, (2) the level of production, which is low with the farmer, is not taken into account, and (3) response equations have to be different for each variety tested.

Soil Test Crop Response (STCR) Approach

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

1. Nutrient requirement (kg/q) $= \dfrac{\text{Total uptake of nutrient (kg/ha)}}{\text{Grain yield (q/ha)}}$

2. Efficiency of soil available nutrients (CS %) $= \dfrac{\text{Uptake in control plot (kg/ha)}}{\text{Soil test value (STV) of nutrient (kg/ha) in control plots}} \times 100$

3. Efficiency of fertilizer nutrient (CF %) $= \dfrac{\text{Total uptake of nutrient in fertilized plots – (STV in fertilized plot x CS)}}{\text{Nutrient applied through fertilizer (kg/ha)}} \times 100$

After calculating these three basic parameters from the yield and uptake data from the well conducted test crop experiment, these basic parameters, in turn, are transformed into workable fertilizer adjust equations as below,

$$\text{Fertilizer nutrient dose (kg/ha)} = \frac{\text{NR}}{\text{CF\%}} \text{ x 100 x T} - \frac{\text{CS\%}}{\text{CF\%}} \text{ x STV}$$

Thus equations for nitrogen, phosphorus and potassium are of the type

FN $= X\,T - Y\,SN$

F P_2O_5 $= X_i\,T - Y_i\,SP$

F K_2O $= X_j\,T - Y_j\,SK$

Where SN is soil nitrogen (N kg/ha); SP soil phosphorus (P kg/ha); SK soil potassium (K kg/ha); FN fertilizer N to be applied (N kg/ha); FP fertilizer P_2O_5 to be applied (P_2O_5 kg/ha); K_2O fertilizer K_2O to be applied (K_2O kg/ha) and T is targeted yield (q/ha).

Based on this approach, fertilizer recommendations are developed for different regions (Table 2). One such equation developed to recommend N, P, K fertilizers for rice is given below:

$FN = 4.39\ T - 0.6723\ SN$
$F\ P_2O_5 = 2.83\ T - 6.110\ SP$
$F\ K_2O = 1.41\ T - 0.329\ SK$

It is to be remembered that in the equations, soil phosphorus and potassium are considered in elemental form while fertilizer phosphorus and potassium are in oxidized form (P_2O_5 and K_2O).

The prescription based fertilizer recommendations method avoid wide variation in soil rating limits used in the previous method as it substitutes the exact values for soil available N, P and K. This method ensures the balanced nutrition of crops besides the maintenance of soil fertility.

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

TABLE 2 Soil-test crop response equations for rice for different regions

Variety and soil	S T C R equations	Suitable region
IR 20 Black soil	$FN = 2.54\ T - 054\ SN$	Tamilnadu
	$F\ P_2O_5 = 2.27\ T - 3.00\ SP$	
	$F\ K_2O = 2.64\ T - 1.32\ SK$	
IR 20 Kharif Black soil	$FN = 7.94\ T - 0.46\ SN$	Madurai Parts of Tirunelveli
	$F\ P_2O_5=1.46\ T - 3.73\ SP$	
	$F\ K_2O = 3.01\ T - 0.11\ SK$	
IR 20 Kharif Alluvial soil	$FN = 7.36\ T - 0.66\ SN$	Thanjavur
	$F\ P_2O_5= 2.15\ T - 6.46\ SP$	
	$F\ K_2O = 3.07\ T - 0.18\ SK$	
IR8 Kharif Alluvial soil	$FN = 3.45\ T - 0.29\ SN$	Parts of Bellary, Raichur Chirtradurga, Dharwar
	$F\ P_2O_5= 2.80\ T - 3.88\ SP$	
	$F\ K_2O = 2.00\ T - 0.11\ SK$	
Black soil	$FN = 6.28\ T - 0.40\ SN$	Kurnool Cuddapah of Andhra Pradesh
	$F\ P_2O_5=3.47\ T - 5.09\ SP$	
	$F\ K_2O = 2.06\ T - 0.08\ SK$	
IR8 Kharif Red soil	$FN = 2.78\ T - 0.27\ SN$	Eastern Madhya Pradesh
	$F\ P_2O_5= 5.45\ T - 11.03\ SP$	
	$F\ K_2O = 1.88\ T - 0.23\ SK$	
IR8 Kharif Chesnut	$FN = 3.02\ T - 0.63\ SN$	Several Districts of Punjab
	$F\ P_2O_5= 1.77\ T - 5.99\ SP$	
	$F\ K_2O = 2.75\ T - 1.39\ SK$	
Raina Kharif	$FN = 3.28\ T - 0.18\ SN$	West Bengal
	$F\ P_2O_5= 4.80\ T - 5.02\ SP$	
	$F\ K_2O = 2.82\ T - 0.54\ SK$	
IR8 Kharif Alluvial soil	$FN = 3.44\ T - 0.31\ SN$	Delhi
	$F\ P_2O_5 = 2.76\ T - 4.18\ SP$	
	$F\ K_2O = 2.02\ T - 0.24\ SK$	

Basic parameters and fertilizer adjustment equations for important crop in different agro-climatic zones of HP

A. **Mid hill wet temperate zone**: In Himachal Pradesh, almost every farmer domesticates animal which are mainly used for ploughing of land and milk production. Therefore, they have enough FYM which is applied to crops. The FYM contributes substantially to the nutrition of the crops. Besides, a lot of emphasis is given to the use of bio-fertilizers. In order to account for the nutrients supplied through FYM and bio-fertilizers, AICRP on STCR Correlation, Palampur Centre worked out the basic parameters for the contribution of nutrients from soil, fertilizer, FYM and PSB as shown in the Table 3. The adjustment equations for fertilizer recommendations have been given in Table 4. The fertilizer recommendation equations based on inorganics only have also been developed for some crops in this zone (Table 5).

Table 3 Basic parameters-IPNS based fertilizer adjustment equations (mid hills wet temperate zone)

Crop	Parameter												
	NR (kg q^{-1})			CS (%)			CF (%)			CFYM (%)			CPSB (%)
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	P_2O_5
Maize	3.08	1.58	3.13	12	39	42	42	32	86	49	26	43	-
Wheat	2.40	0.94	2.26	10	9	12	46	23	81	48	22	45	-
Raya	5.23	1.75	1.53	7	11	10	86	32	61	70	60	80	54
Soybean	5.23	2.75	2.93	21	21	17	83	62	72	70	41	57	26
Wheat (HPW 89)	0.94	0.27	0.83	16	5	15	18	18	19	36	34	20	54
Linseed (DPL-1)	3.07	0.91	1.52	8	6	4	55	20	57	91	48	40	37

Table 4. IPNS based fertilizer adjustment equations (mid hills wet temperate zone)

Crop	Fertilizer adjustment equation
Maize	F N = 5.88 T – 0.23 SN- 0.93 ON
	F P_2O_5 = 4.87 T - 1.22 SP - 0.81 OP
	F K_2O = 3.66 T - 0.49 SK - 0.51 OK
Wheat	F N = 5.27 T - 0.25 SN- 1.06 ON
	F P_2O_5 = 4.13 T - 0.38 SP - 0.98 OP
	F K_2O = 2.87 T - 0.15 SK - 0.55 OK
Raya	F N = 6.11 T –0.08 SN- 0.81 ON
	F P_2O_5 = 5.51 T - 0.36 SP - 1.88 OP – 1.69 PBP
	F K_2O = 5.81 T – 0.16 SK – 1.31 OK
Soybean	F N = 6.32 T – 0.25 SN- 0.85 ON
	F P_2O_5 = 4.40 T – 0.34 SP - 0.66 OP – 0.41 PBP
	F K_2O = 4.05 T – 0.23 SK – 0.80 OK
Wheat (HPW-89)	F N = 5.20 T – 0.90 SN- 1.0 ON
	F P_2O_5 = 4.36 T – 0.20 SP - 0.47 OP – 1.71 PBP
	F K_2O = 4.36 T – 0.78 SK – 0.26 OK
Linseed (DPL-1)	F N = 5.55 T – 0.15 SN- 0.09 ON
	F P_2O_5 = 5.36 T – 0.32 SP - 0.13 OP - 0.16 PBP
	F K_2O = 2.68 T – 0.08 SK – 0.11 OK

Table 5 Basic parameters and fertilizer adjustment equations
(Mid hills wet temperate zone)

Crop	Parameter	Nutrients			Fertilizer adjustment equation
		N	P_2O_5	K_2O	
Rice	NR (kg q^{-1})	1.71	0.48	2.96	F N = 5.46 T – 0.32 SN
	CS (%)	10.0	22.0	59.0	F P_2O_5 = 2.50 T – 2.67 SP
	CF (%)	31.0	19.0	105.0	F K_2O = 2.82 T – 0.68 SK
Potato	NR (kg q^{-1})	1.84	0.55	1.31	F N = 4.72 T – 0.21 SN
	CS (%)	8.0	36.0	13.0	F P_2O_5 = 3.24 T – 4.35 SP
	CF (%)	39.0	17.0	69.0	F K_2O = 1.90 T – 0.28 SK
Lentil	NR (kg q^{-1})	4.73	1.15	1.81	F N = 3.94 T – 0.04 SN
	CS (%)	15.0	22.0	7.0	F P_2O_5 = 3.22 T – 2.72 SP
	CF (%)	75.0	18.0	58.0	F K_2O = 3.41 T – 0.16 SK
Gram	NR (kg q^{-1})	4.32	0.92	1.85	F N = 1.69 T – 0.01 SN
	CS (%)	13.0	14.0	5.0	F P_2O_5 = 5.02 T – 2.32 SP
	CF (%)	76.0	18.0	168.0	F K_2O = 1.10 T – 0.04 SK

These equations have been developed involving improved varieties and can be successfully used in part of Kangra (Palampur, Dharamshala, Baijnath), kullu and Shimla district where the soils in general are acidic in reaction, loam to clay loam in texture, deficient in N and P and poor water and nutrient holding capacity.

B. Mid hills sub humid zone: the basic parameters and fertilizer adjustment equations for maize and wheat are given in Table 6. These equations can be successfully used where the soils are shallow in depth, acidic in reaction and silt loam to loam in texture (parts of Kangra, Kullu Chamba, Solan and Shimla) taking improved varieties and following proper management practices.

Table 6 Basic parameters and fertilizer adjustment equations (Mid hills sub humid zone)

Crop	Parameter	Nutrients			Fertilizer adjustment equation
		N	P_2O_5	K_2O	
Rice	NR (kg q^{-1})	2.29	0.92	1.44	F N = 3.48 T – 0.20 SN
	CS (%)	13.00	36.00	26.00	F P_2O_5 = 2.32 T – 2.09 SP
	CF (%)	66.00	39.00	67.00	F K_2O = 2.16 T – 0.48 SK
Potato	NR (kg q^{-1})	3.24	1.10	3.17	F N = 3.26 T – 0.20 SN
	CS (%)	7.00	35.00	26.00	F P_2O_5 = 5.47 T – 4.72 SP
	CF (%)	35.00	17.00	74.00	F K_2O = 3.28 T – 0.48 SK

C. Sub-montane low hills sub tropical zone: Basic parameters and fertilizer adjustment equations for rice, maize, wheat and toria have been given in Table 7. These equations are applicable for areas upto the altitude of 650 m altitude possessing shallow soil depth, light texture and low fertility, neutral soil reaction with pH 6.5 to 7.5, having average annual rainfall as low as 100 cm.

Table 7 Basic parameters and fertilizer adjustment equations (Mid hills wet temperate zone)

Crop	Parameter	Nutrients			Fertilizer adjustment equation
		N	P_2O_5	K_2O	
Rice	NR (kg q^{-1})	1.68	1.28	3.34	F N = 5.90 T – 0.43 SN
	CS (%)	90.00	57.00	137.00	F P_2O_5 = 3.22 T – 3.29 SP
	CF (%)	21.00	40.00	234.00	F K_2O = 3.14 T – 0.71 SK
Maize	NR (kg q^{-1})	2.72	1.57	1.89	F N = 5.82 T – 0.24 SN
	CS (%)	11.00	37.00	19.00	F P_2O_5 = 2.58 T – 0.31 SP
	CF (%)	47.00	40.00	73.00	F K_2O = 3.91 T – 2.11 SK
Wheat	NR (kg q^{-1})	2.85	0.91	2.03	F N = 5.75 T – 0.27 SN
	CS (%)	13.00	17.00	20.00	F P_2O_5 = 3.74 T – 1.64 SP
	CF (%)	49.00	24.00	89.00	F K_2O = 2.28 T – 0.28 SK
Toria	NR (kg q^{-1})	4.45	0.66	3.72	F N = 5.33 T – 0.06 SN
	CS (%)	5.00	13.00	38.00	F P_2O_5 = 3.67 T – 0.78 SP
	CF (%)	34.00	18.00	66.00	F K_2O = 4.63 T – 0.69 SK

Using fertilizer adjustment equations

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

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

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

Let the prescription equations be

FN = 4.39 T - 0.6723 SN

F P_2O_5 = 2.83 T - 6.110 SP
F K_2O = 1.41 T - 0.329 SK

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

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

Soil P = 35 x 0.43 = 15.05
Soil K = 350 x 0.83 = 290.5
Targeted yield = 5 t/ha = 50 q/ha.
Substitute T, SN, SP and SK in the equation
FN = 4.39 T - 0.6723 SN = (4.39 x 50) - (0.6723 x 250) = 219.50 - 168.07 = 51.43 kg N/ha
F P_2O_5 = 2.83 T - 6.11 SP = (2.83 x 50) - (6.11 x 15.05) = 141.50 -91.95 = 49.55 kg P_2O_5/ha
F K_2O = (1.41 x 50) - (0.329 x 290.5) = 70.50 - 95.57 = - 25.07 kg K_2O /ha

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

Problem 2:

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

DRIS Approach

Recently Diagnosis and Recommendation Integration System (DRIS) approach is suggested for fertilizer recommendation. In this approach, plant samples are analyzed for nutrient content and they are expressed as ratios of nutrients with others. Suitable ratios of nutrients are established for higher yields from experiments and plant samples collected from farmer's fields. The nutrients whose ratios are not optimum for high yields are supplemented by top dressing. This approach is generally suitable for long duration crops, but it is being tested for short duration crops like soybean, wheat etc.

Modeling Approach

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

$Y = K [(T - 15) \times D]^n$

Where Y is amount of mineralized nitrogen; T soil temperature (^oC); K coefficient related to the potential of mineralized nitrogen; n constant relating to the pattern of nitrogen mineralization, 15 threshold temperature and D is incubation period.

The N use efficiency for applied fertilizers ranges from 30 to 40 per cent depending on the nature of the fertilizers, source and management practices. Based on the mineralizable N during the crop period, the balance amount of nitrogen is supplied through fertilizer after considering nitrogen use efficiency.

Calculation of fertilizer dose

Fertilizer recommendations are made in elemental or oxidized form of nutrients, but not as fertilizers themselves since different fertilizers are available with the same nutrient but with different contents. Based on the nutrient content of a particular fertilizer, the amount of material to be applied has to be calculated.

Problem: Let the recommended fertilizer dose for lowland rice be 120, 60, 40 kg N, P_2O_5 and K_2O per hectare, respectively. The amount of fertilizer required in the form of urea, superphosphate and muriate of potash is calculated as shown below:

To supply 46 kg N/ha, 100 kg urea is necessary (Urea contains 46% N)

To supply 120 kg N/ha 100/46 x 120 = 260.9 kg or 261 kg urea is required.

Similarly:

To supply 60 kg P_2O_5 = 100/16 x 60 = 375 kg of superphosphate is required (Superphosphate contains 16% P_2O_5).

The amount of muriate of potash required to supply 40 kg K_2O per hectare is 100/58 x 40 = 68.9 kg/ha or 69 kg/ha (Muriate of potash contains 58% K_2O)

Therefore,

The amount of fertilizer to be applied = [100/(Nutrient content)] * [recommended dose].

Relative performance of organic and inorganic manures

Organic cannot meet nutrient requirement of crops. For example a 5 t grain yielding rice crop removes about 98 kg N, 45 kg P_2O_5 and 150 kg K_2O and 55 kg Ca. Assuming that the farm yard manure (FYM) contains 0.5% N, 0.2% P_2O_5 and 0.5% K_2O (contents vary with source, method of production etc) such a crop will need 19.6 t FYM per ha. Quantities of nutrients contained in organics are not completely available in the first year of

Nutrient application rates recommended for non-irrigated conditions (kg/ha)						
Particular	N		P_2O_5		K_2O	
	Range	Mean	Range	Mean	Range	Mean
Rice	40-80	60	0-40	30	0-30	15
Wheat	30-90	50	0-40	25	0-45	10
Jowar	30-90	60	0-40	30	0-20	2
Bajra	30-75	50	0-40	20	0-20	5
Maize	40-100	65	20-60	35	0-40	20
Other millet	0-25	15	0-50	35	0-25	5
Pulses	0-25	15	0-50	35	0-25	5
Legume oilseed (ground nut, soybean)	10-25	20	0-80	40	0-40	20
Non-legume oilseeds	10-60	40	0-60	25	0-40	5

application. About 30% N, 60% P_2O_5 and 80% K_2O is likely to be available in the first year. So, to meet N need about 59 ton FYM is to be applied per ha (5.9 kg/m^2) which is not possible under general farming conditions. While thinking of nutrient requirements focus is usually laid on field crop (creals, pulses, oilseeds) and that of non-traditional crops, fish pond, pasture grounds, fodder crops, lawns, flower crops, plantation crops, medicinal and aromatic crops, fortification of compost, animal feed etc I generally lost sight off. Even after harnessing all the irrigation sources, 50% of agricultural lands will remain rainfed. Rainfed crops also respond to fertilization and quantities of nutrients to be applied to these crops have been indicated in Table.

Average concentration of N, P, K in fishes is reported to be 3%, 0.82% and 2.5%., respectively. Based on these figures nutrients removal per t fish comes 30 kg N, 8.2 kg P and 2.5 kg k, respectively. India produces 5.4 t fishes and thus needs 162000 t N, 44280 t P and 13500 t K. The CIFRI suggests 50% nutrient requirement should be met through organics and the rest through inorganics.

Requirement of nutrients for pasture and grassland is also high. Forage crops are highly responsive to fertilizers N, P, K and S. Area under fodder crops in India is 8.5 m ha. In addition area under pastures is 12 m ha. One t dry fodder removes 9.4 kg N, 1.45 kg P, 14.2 kg K, 4.6 kg Ca, 2.65 kg Mg and 1.95 kg S. All grain legumes (pulses) grown for grain purposes (black gram, green gram, horse gram, cicer, groundnut, soybean etc) deplete soil nitrogen. They meet 40-60% of their nitrogen requirement through symbiotic nitrogen fixation.

All experiments involving organic and/or inorganic sources indicate that 50% of the requirement should come from organics and 50% from the inorganics for sustained high production. Hence, a judicious combination of both is desirable rather than dependence on either organic or inorganic alone. To find out suitable combination need long term field experiments. The job of the agricultural scientist is to see that these combinations are fully efficient and the waste is the least. The food they produce should be good and often better than that they produce under organics alone. New farming methods must not degrade the soil fertility and productivity. Newer methods must be effective and clean.

Economics of fertilizer use

Use of fertilizer by the farmer for increased crop production depends almost entirely on its economics. This is usually done by reporting response per unit area or per unit nutrient applied. With a view to convince the farmer about the profitability of fertilizer use, cost-benefit ratio is worked out. Almost all such calculations are based on evaluating the estra produce at the support/market price and deducting the cost of fertilizer only at the statutory prevailing rates.

P’=R’-E’

Where P’ is additional profit; R’ is the value of additional return and E’ is additional expenses incurred consequent to fertilizer use.

It is obvious that the additional income (P’) due to fertilizer use consists of a number of components, some of which are a) value of extra grain or main produce, b) value of secondary produce if it has commercial value, e.g. straw in wheat, c) residual effect, if significant, leading to increased yield of subsequent crop; and d) premium or discount in the price of the procedure due to use of fertilizer.

It is conceded that the computation of residual effect calls for data for which reliable statistics are not available and as such is conveniently left out in extensive studies. It may further be said that the difference arising out of premium or discount due to variation in quality is not a common feature and may therefore, be ignored. However, whenever secondary produce has a commercial value, it should be positively considered while working out economics of fertilizer use. As regard the value of the additional produce, it is an over-simplification to work out the same at the support/market price without taking into account the variable cost of production of the crop.

Regarding expenses (E') it is to be noted that the application of fertilizer to a crop usually entails additional expenses by way of extra irrigation, extra interculture, additional plant protection measures etc. it would also be correct to say that the additional yield consequent to the use of fertilizer is the combined result of the effect of fertilizer and these additional inputs. Any attempt to properly evaluate the economics of fertilizers only should deduct the increase due to other associated inputs.

Cost of production of a crop has two well recognized components viz. Fixed costs (the cost which does not vary with the level of yield or output like cost of seed, preparatory tillage operations, post sowing inter-cultivations etc. and Variable cost (the cost which varies directly with the level of produce, like cost of harvesting, threshing, winnowing, marketing etc.

When cost-benefit ratio (CBR) is worked out without considering value of secondary produce and variable cost of cultivation, it is known as gross CBR and when value of secondary produce and variable cost are considered, the ratio is known as net CBR. One cost benefit ratio represents the break-even point where the extra yield just pays for fertilizer cost (a no profit no loss situation). A CBR 2 means 200% gross return or 100% net return over investment.

CBR or fertilizer application (economics of fertilizer use) is a variable factor, changing directly with value of extra main and secondary produce and fertilizer cost.

Another ratio commonly used in working out economics of fertilizer use is incremental cost benefit ratio (ICBR). In this analysis, the incremental costs of applying fertilizers and the incremental benefits through additional farm output are compared. As per FAO standard, the value of net ICBR should be better than 1:2.5.

Integrated nutrient management

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

In literature three terminologies are used to convey the same meaning – Integrated Plant Nutrition Systems (IPNS), Integrated Plant Nutrient Supply Systems (IPNS Systems) and Integrated Nutrient Management (INM). Although these terminologies may look the same, yet they convey somewhat different connotations.

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

The IPNS approach aims to:

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

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

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

Key concept of IPNS

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

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

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

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

Veritable Nutrient Sources

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

A. Internal (farm) nutrient sources

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

B. External nutrient sources (from farm surroundings)

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

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

C. Imported nutrient sources (usually bought)

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

Use of vermicompost and residue wastes in crops

There is good potential of wastes available in India for recycling/use as a source of plant nutrients with very attractive economic implications. The available agricultural and industrial wastes could either be converted to manure by composting/vermicomposting or be directly utilized for soil improvement and crop production. The wastes/byproducts include

1. Agricultural waste [crop wastes (crop residues and oil cakes), animal wastes (animal urine, excreta and laughter house waste) and agro-industrial wastes].
2. Rural and Urban solid waste
3. Sewage sludges and bio solids
4. Industrial byproducts
5. Mining byproducts

Nutrient potential of crop residues, agricultural and industrial wastes

Residues	Quantity (m. t)	Nutrients/year (000 t)			
		N	P_2O_5	K_2O	Total
Crop residues	273.3	1283.1	1965.6	3903.9	7152.6
Potato haulms	12.0	294.0	12.0	225.0	531.0
Sugarcane trash	30.0	56.0	15.0	99.0	170.0
Forest litter	18.7	99.7	37.4	99.7	236.8
Non-edible oil cakes	0.4	12.0	5.0	12.0	29.0
Sewage sludge	0.5	5.1	2.9	2.8	10.8
Press mud	3.2	33.3	79.4	55.4	168.1
Water hyacinth	73.0	72.0	14.0	84.0	170.0
Domestic waste water	6351.0*	317.6	139.7	190.5	647.8
Industrial waste water	66.2*	2.9	0.9	1.3	5.1

* Million cubic meters/ annum Hegde and Dwivedi (1993)

Of the nutrients taken by cereal crop, on a average, 25% N and P, 50% S and 75% of K is retained in crop residues making them valuable nutrient sources. Guar and Mukherjee (1979) observed 95.5% increase in pod yields of growundnut over control, with the application of 5 t/ha of wheat straw which also improved the seed oil content. Application of coir pith inoculated with Pleuroteus sp + NPK increased the pod yield whereas uninoculated coir pith was not effective (Nagarajan et al., 1986).

Crop residues apart from supplying nutrients to current crop leave substantial residual effect on succeeding crops. Organic N is slowly mineralized and about 30% N is generally available to the first crop and 60-70% P and 75% K is likely to become available to the first crop and rest to the subsequent crops. The quantity and quality of crop residues will clearly influence the build up of soil organic matter and the subequent availability and timing of release of nutrients to following crops. Cereal straw for example, contains only around 35 kg N/ha compared to more than 150 kg N/ha for some vegetable residues. Besides supplying nutrients crop residues and wastes have favourable effect on soil physical, chemical and biological properties. Residue also contain variable amount of lignin and polyphenols, which influence decomposition and mineralization rates. Incorporaion of N rich, low C:N ratio residues leads to rapid mineralization and a large rise in soil mineral N, while residue low in N such as cereal straw can lead to net immobilization of N in the short to medium term. The latter can be advantageous in preventing N leaching between crops. The inclusion of crops with a diverse range of C:N ratios can help to conserve N within the system (Watson et al., 2002). The inconsistence crop responses to incorporation of crop residues under different situations may well be expected due to varying pace of immobilization mineralization cycle, particularly that of N.

While they are good source of manure and needed for soil building, there is a danger of contamination from bacteria and heavy metal. It is therefore suggested that crop residues should be used only after composting which will deactivate the bacteria like salmonella and/or Aflotoxin. In cases where composting cannot be done, crop residues should be washed with water and then dried before they are used.

Vermicomposting is one method of composting farm wastes, employing earthworms to do the hard work. It is somewhat labour intensive and requires some infrastructure but all this pays off, as the end result is an extremely high quality compost. While a small farm can use this method to compost all its wastes, a larger farm may find it economical to compost only part of its wastes this way. An extra benefit of vermicomposting is the production of vermiwash, which can be collected after a weekly or biweekly watering over the bed if there is a tap at its base. Vermiwash can be used as a prophylactic for pests for their repelling and as a foliar spray. An important point to note in case of vermicomposting but widely ignored is to carry out proper seiving of the compost before applying it in the fields. The most efficient and widely used earthworms are not indigenous. They are exotic.

Practicals

Soil sampling

Obtaining representative soil sample is the most important aspect of soil testing. Soil testing service starts with the collection of representative soil samples. Soil samples must be collected at the right time using right method with utmost care. The tools used, the area sampled, depth and correct mixing, packaging and labeling all influence the quality of soil test data. Consider each of the following before obtaining a soil sample:

1. Field area (acreage) per sample
2. Sampling technique to be followed
3. Sampling tools
4. Sampling depth
5. Sampling time
6. Taking the representative soil sample
7. Information label to be sent with the sample
8. Submitting the soil sample in a soil testing laboratory

Sampling time

Take soil samples well before owing of the crop or establishing a new orchard. Sufficient time is required between soil sample collection and sowing of the crop because if the soil test report recommends liming of the area then one should have enough time to apply it as per recommendation. For agricultural crops, the best time of sampling is when the field is free of crops. For horticultural crops, the best time to collect a soil sample is during autumn. As a general rule, it is best to go for soil sampling a couple of weeks prior to the start of any seed ed preparation. In case of perennial crops like forages and fruit trees, soil sampling should be done prior to the beginning of a new flush of growth.

Sampling equipments

1. Probe/auger/specially designed soil sampling tubes/spade or a khurpi. Specially designed soil sampling tubes can be used for moist soils. All sampling tools and storage bags should be perfectly clean.
2. Polythene/plastic bucket for collecting and mixing the soil samples.
3. Sampling cloth bags preferably of about 25 cm x 25 cm size.
4. Scale (12inches) or measuring tape for profile sampling.
5. Ball point pen/Lead pencil
6. A sheet of thick paper
7. Polythene sheet of about 2ft x 2 ft size.

Sampling units

Divide the area into sampling units based on visual observations on crop growth, appearance of the soil, soil colour, field slope, past crop management practices like manuring, fertilization techniques and cropping pattern etc. Collect one composite sample from each block or unit as explained in the following step:

1. Remove the litter from the surface by scraping it away at each spot selected for soil sampling.
2. If probe auger/specially designed soil sampling tubes are available, then take about 15-20 surface oil samples (0.15 cm) from each block (sampling unit) of about ½ acre area in random zigzag manner. Avoid sampling near houses, roads, bunds, channels, marshy spots, trees, recently fertilized area, compost pits any other abnormal spots and other non-representative locations. Collect these in a clean dry container or cloth bag.
3. If a khurpi or kassi (spade0 is used, first dig a V shaped hole (15 – 20 cm) and hake out the soil slice (like bread slice) of ½ inch thickness from one of the exposed surface.
4. Mix the oil sample collected in the step 2 or 3 thoroughly on a clean piece of cloth or polythene sheet. Put the sub-sample on a clean piece of cloth or polythene sheet.
5. Level and divide into four quarters with the help of fingers or wooden stick. Discard the soil in the opposite quarters.
6. Mix rest of the soil and continue quartering till about ½ kg of representative soil is obtained. Dry the ample in shade and fill in the cloth or polythene bag. Label the sample. The soil ample I now ready for submitting/sending to the soil testing laboratory for its analysis.
7. If the sample is to be analyzed for micronutrients, a stainless steel probe auger or stainless steel khurpi must be used.

Practical 1: Determination of soil pH

Soil reaction is an indication of acidity, neutrality or salinity of the soil. It is expressed in pH units. pH is the negative logarithm of the hydrogen ion activity. Mathematically pH= -log 10 (H^+). Where (H^+) is the activity of hydrogen ions in moles/litre. The pH scale for an aqueous system extends from 0 to 14. Water is a very weak electrolyte which ionizes to give H^+ and OH^- ions and can be expressed by the following:

$$H_2O = H^+ + OH^-$$

$$\frac{(H^+) * (OH^-)}{H_2O} = 10^{-14} = kw$$

The value of water can be taken as unity. So, $(H^+) * (OH^-) = 10^{-14}$ moles/litre at 25°C. In pure water at 25°C, the concentration of ions, i.e. $(H^+) = (OH^-)$ = 10-7 moles/litre. Therefore, pH = 7. So, pure water is neutral in reaction. When there is increase in hydrogen ion activity, the pH value decreases. However, when there is an increase in OH^- activity, there is decrease in H^+ ions resulting in increase in pH.

Potentiometric method:

Principle

In this method, determination of pH is based on the measurement of electrical potential developed by an electrode, whose potential depends on the concentration of the H+ ions in the solution. A measure of the electrical potential is therefore, a measure of the H+ concentration or pH of the solution. It is not possible to measure the emf of a single electrode alone. The potential of any single electrode is measured in conjunction with the second electrode (reference electrode) dipping into the same solution. The reference electrode commonly used is the saturated calomel electrode. Glass electrode is the indicator electrode for measuring soil pH.

Requirements:

Beakers (100 ml), balance, weight box, measuring cylinder, glass rod, buffer solution, pH meter, ordinary filter paper, wash bottle.

Procedure

1. Take 10 g soil into a 100 ml beaker and add 25 ml distilled water and stir it with a glass rod at least five times over a 30 minutes period. This time is sufficient for the soil and water to reach at equilibrium. This equilibrium can also be attained, if we shake the sample on a mechanical shaker for five minutes.
2. Switch on the pH meter and set the temperature compensation knob at the buffer-solution temperature and warm up the pH meter for 30 minutes.
3. After the warm up period, bring the galvanometer's pointer to zero reading with the help of zero set knob.
4. Rinse the electrodes with distilled water and dry them with filter paper. Now dip the electrodes into a buffer solution of known pH and turn the range selector. Adjust the pH meter to the pH of the buffer solution with the help of buffer set knob.
5. Turn the selector to zero, press the key stand and take out the electrodes. Wash them with distilled water and dry them with filter paper.
6. Now shake the soil suspension and dip the electrodes into it. Turn the selector in the proper pH range and read the pH on the dial or the digital scale of the pH meter. Turn back selector to zero.
7. Take out the electrodes and rinse them with distilled water and put them back into a beaker of distilled water. Switch off the pH meter.

Precautions:

1. Instrument should always be warmed up for about half an hour.
2. Adjust the temperature compensation knob at the buffer-solution temperature.
3. The pH meter should be calibrated with two buffers, commonly pH 4.0 and pH 9.0 buffers.
4. Before removing electrodes, instrument should always be switched to standby position.
5. The electrodes should not be allowed to remain in the suspension for a long period.
6. The electrodes should not touch the sides of the beaker. After testing the sample, the electrodes should be washed with distilled water.
7. After cleaning, the electrodes should be suspended in distilled water. The drying out of the electrodes must be avoided.

Practical 2. Determination of Electrical conductivity

All soils contain varying amounts of soluble salt in the form of CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^- and NO_3^- of Ca^{++}, Mg^{++}, Na+ and K+. Excessive accumulation of these soluble salts in the soil results in harmful effect on plant growth, seed germination and intake of water by plant. The soluble salt are determined by measuring electrical conductivity. Solution containing salts offer some resistence to the passage of electric current depending upon the concentration and the type of salt (ions) present. Higher the salt content, lesser the resistance to the flow of electric current. Electrical conductivity or conductance (EC) if the reverse of resistance. So the EC is defind as the reciprocal of the resistance of a conductor 1 cm long and 1 cm 2 in cross sectional area. It I expressed as mho per cm. as the values of EC obtained for soil solution are very small, therefore, it is expressed in millimhos/cm or dS/m.

The conductivity of satuation extract is generally recorded, but it is difficult to obtain saturation extract of a large number of soil samples. Therefore, as a standard, the EC is generally measured in 1:2:: soil:water suspension.

Requirements:
Salt bridge, beaker (100 ml), electric balance, weight box, cylinder, glass rod, distilled water and filter paper.

Procedure:

- i) Take 25 g of 2 mm sieved soil sample in a 100 ml beaker and add ml distilled water.
- ii) Stir it with a glass rod and leave it overnight to obtain a clear supernatant solution.
- iii) Adjut the temperature compensation knob to the room temperature and connect the cell to the meter.
- iv) Connect the salt bridge to the power supply and switch on the bridge.
- v) Dip the cell in the supernatant olution so that the electrodes are well immersed.
- vi) Rotate the meter knob till the dark shadow in the electric eye is the widest.
- vii) Read directly the reading on the salt bridge and calculate the conductance.

Precsaution:

- i) Salt bridge should always be warmed up for about 30 minutes before taking the reading.
- ii) As EC is temperature dependent, so set the temperature to knob to room temperature.
- iii) Soil water suspension should be allowed to settle for sufficient time to obtain clear supernatant solution.
- iv) The electrodes of the conductivity cell should be completely dipped in the supernatant solution.
- v) After each reading, wash the cell with distilled water and dry it with filter paper and dip the cell in distilled water while not in use.
- vi) Since dilution affects the EC measurement, therefore, 1:2:: soil:water ratio must be maintained.

Observations and calculations:

Cell constant	:	K
Reading of the salt bridge	:	C dS/m
EC	:	K x c dS/m

Interpretation:

EC (1:2::Soil:water) dS/m (m mhos/cm)	Approx. salt concentration (%)	Suitability
0-0.8	0.05	Normal soil fit for most crops
0.8-1.6	0.05-0.15	Criticl for salt sensitive crops
1.6-2.5	0.15-0.20	Critical for salt tolarant crops
>2.6	0.20-0.25	Injuriou to all crops

Practical 2. Determination of organic carbon in soil

Principle: The commonly used method for estimation of organic carbon is wet digestion method. It is based on the reduction of chromic acid by organic matter, wherein unreduced amount of chromic acid is estimated by titration. This is a rapid method and it distinguished between elementary carbon and the soil organic matter as the heat is not strong enough to oxidize elemental carbon. The presence of $CaCO_3$ also does not interfere.

Organic carbon present in organic matter is oxidized by chromic acid in presence of conc. H_2SO_4. Potassium dichromate on reaction with H_2SO_4 provides nascent oxygen which combines with carbon and form CO_2. The H_2SO_4 enables easy digestion of organic matter by rendering heat of dilution. Only certain quantity of chromic acid is used for oxidation. The excess chromic acid left unused is determined by titration with standard $FeSO_4$ or ferrous ammonium sulphate using diphenylamine as indicator.

$2\ K_2Cr_2O_7 + 8\ H_2SO_4 \longrightarrow 2K_2SO_4 + 2\ Cr_2(SO_4)_3 + 8\ H_2O + 6O$

$3\ C + 6\ O \longrightarrow 3\ CO_2$

Requirements:

- i. Potassium dichromate ($K_2Cr_2O_7$) 1N solution 49.04 g of analytical grade $K_2Cr_2O_7$ (dried at 105°C) in distilled water and make the volume to 1 litre.
- ii. Concentrated H_2SO_4 (36 N)
- iii. Orthophosphoric acid (86%) or sodium fluoride
- iv. Diphenylamine indicator: Dissolve 0.5 g diphenylamine indicator salt in 100 ml con. Sulphuric acid and 20 ml distilled water.
- v. Ferrous ammonium sulphate ($FeSO_4.7\ H_2O$) N/2 solution. It is known as Mohr's solution. Dissolve 196 g analytical grade ferrous ammonium sulphate in distilled water, add 7.5 ml conc. Sulphuric acid and make the volume to 1 litre with distilled water.
- vi. 500 ml Erlenmyer (conical flask).
- vii. Pippette (10 ml)
- viii. Burette

Procedure:

- i. Weigh out accurately 1 g soil, sieved through 0.5 mm sieve in a 500 ml conical flask.
- ii. Add 10 ml of 1 N $K_2Cr_2O_7$ solution and shake gently to disperse soil in the solution.
- iii. Add 20 ml of concentrated sulphuric acid, shaking the flask slowly during addition. Since the reaction is exothermic, a lot of heat is produced when acid is added.
- iv. Keep the flask on a dry tile or asbestos sheet for 30 minutes at room temperature.
- v. Add about 0.5 g sodium fluoride or 10 ml of orthophosphoric acid, 200 ml of distilled/organic matter free tap water, 1 ml or 10 drops of diphenylamine indicator and shake vigorously to mix.
- vi. Titrate against N/2 ferrous ammonium sulphate from a burette till the colour changes from violet to bright green.
- vii. Note the volume of Mohr's salt.
- viii. Carry out a blank titration (without soil) in a similar manner.

Precautions:

- i. Add $K_2Cr_2O_7$ very carefully without touching the neck of the flask.
- ii. Be careful while adding sulphuric acid as it can spoil your clothes.
- iii. If the contents of the flask turn green with the addition of indicator before titration, repeat the sample with double the amount of standard potassium dichromate solution and sulphuric acid.
- iv. Read upper meniscus of potassium dichromate solution.
- v. Do not place the flask on a wet surface lest it will break.

Observations:

Weight of soil taken	=	t g
Volume of 1N K2Cr2O7 used	=	10 ml
Volume of N/2 ferrous ammonium sulphate used for blank titration	=	X ml
Volume of N/2 ferrous ammonium sulphate used to titrate	=	Y ml

excess nascent oxygen		
X ml of ferrous ammonium sulphate reduces	=	10 ml of 1 N $Kr_2Cr_2O_7$
X ml of ferrous ammonium sulphate reduces	=	10xY/X ml = Z ml
Hence actual quantity of 1N $K_2Cr_2O_7$ used for oxidation of carbon	=	10-Z ml = a ml
1 ml of 1 N $K_2Cr_2O_7$	=	3 mg or 0.003 g organic carbon
Percent organic carbon in soil	=	[(a x 0.003)/t] x100=A
Percent of organic matter in the soil	=	A x 1.724

It is presumed that soil organic matter contain 58 percent carbon

Interpretation

Organic carbon (%)	Rating
<0.40	Low
0.40-0.75	Medium
>0.75	High

Practical 3. Determination of total N (Kjeldahl,s method)

Discussion

The nitrogen of the nitrogenous substances is converted into ammonia by boiling the material with concentrated sulphuric acid, which is fixed by the excess of sulphuric acid as ammonium sulphate. To the solution containing fixed ammonium sulphate an excess of caustic alkali is added and the content is distilled off. The liberated ammonia is received in standard acid. By titrating the excess of standard acid with standard alkali actual volume of standard acid required to absorb the liberated ammonia is worked out. Using the factor:
1 ml of 0.1 N sulphuric acid = 0.0014 g nitrogen

the amount of nitrogen present in the substance can be calculated.
Various modifications have been suggested in the original Kjeldahl's process to increase the speed of the reaction. Potassium sulphate is added to raise the boiling point of the acid. Catalysts, such as anhydrous copper sulphate, selenium and ferrous sulphate etc. are also used. The simple process is suitable for nitrogen determinations in proteins and also in amines and amides, but is not applicable to nitro, azo, hydrazo, and cyano compounds without modification. The salicylic acid is added to the sulphuric acid (1 g to 30 ml H_2SO_4) to fix the nitric acid as nitrosalicylic acid to the amino-compound which can then be estimated by the Kjeldahl process.

Reactions:

During digestion

$2\,NaNO_3 + H_2SO_4$ Nitrates	$\longrightarrow$	$2\,HNO_3 + Na_2SO_4$ Nitric acid
$C_6H_4(OH)COOH + HNO_3$ Salicylic acid	$\longrightarrow$	$C_6H_3(OH)NO_2COOH + H_2O$ Nitro-salicylic acid
$Na_2S_2O_3 + H_2SO_4$ Sodium thiosulphate	$\longrightarrow$	$Na_2SO_4 + H_2SO_3 + S$
$C_6H_3(OH)NO_2.COOH + 3H_2SO_3 + H_2O$ Nitro-salicylic acid	$\longrightarrow$	$C_6H_3(OH)NH_2.COOH + 3H_2SO_4$ Amino salicylic acid

$2C_6H_3(NH_2)(OH)COOH + 27\ H_2SO_4 \longrightarrow (NH_4)_2SO_4 + 14\ CO_2 + 26\ SO_2 + 30\ H_2O$
Amino salicylic acid
During digestion
$(NH_4)_2SO_4 + 2NaOH \longrightarrow 2NH_4OH + Na_2SO_4$
$2NH_4OH + H_2SO_4 \longrightarrow (NH_4)_2SO_4 + 2H_2O$
And during titration
$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + H_2O$

Procedure

1. Weigh out accurately 10 g of soil (< 0.5 mm size) and transfer it into a dry pyrex kjeldahl flask. Moisten it with about 10 ml of water, shake well and allow it to settle for about 30 minutes.
2. Add about 30 ml of concentrated sulphuric acid containing 1 g salicyclic acid, shake and keep for 5 minutes.
3. Add 5 g Sodium thiosulphate and keep for 5 minutes after shaking.
4. Then add 10 g of salt mixture (K_2SO_4 : $FeSO_4$: $CuSO_4.5H_2O$:: 10 : 1: 0.5) and heat the mixture first at a low flame and then gradually raise the flame.
5. Continue the digestion, until the mixture is colourless or nearly so. Cool and add about 50 ml water. Swirl well, cool under a tap and transfer the liquid carefully, without loss and without transferring the sand, to a 800 ml distillation flask.
6. Wash the contents of the kjeldahl flask with water till acid free and transfer it by decantation to the distillation flask. Make up the volume to about 350 ml. Add a few pieces of porcelain or glass beads to prevent bumping.
7. Pour carefully about 100 ml of 45 percent pure caustic soda solution into the distillation flask (sufficient to make the contents alkaline) and immediately connect with the distillation apparatus. Open the water tap to circulate the water through condenser.
8. Distill as usual receiving ammonia in a known volume of 0.1 N sulphuric acid (normally 20 ml) kept in a beaker. A few drops of methyl red should also be added in the 0.1 N sulphuric acid of the receiving beaker.
9. After about 50 minutes boiling or when the distillation is over (test by litmus paper) that no more ammonia is released), put off the flame, disconnect the condenser and remove the receiving beaker.
10. Titrate the excess of acid with 0.1 N NaOH. Similarly, determine the blank value for reagents and calculate the net volume of 0.1 N H_2SO_4 used for absorbing ammonia.

Calculations:

Weight of soil taken = 10 g
Volume of 0.1 N H_2SO_4 taken in excess = A ml
Volume of 0.1 N NaOH consumed in titration = B ml
Actual volume of 0.1 N H_2SO_4 consumed = (A-B) ml
1 ml of 0.1 N H_2SO_4 = 0.0014 g N
(A-B) ml of 0.1 N H2SO4 = 0.0014 x (A-B) g of N
This is present in 10 g of soil
In 100 g N present = 0.0014 (A-B)x100/10

Exercise 4. Determination of available nitrogen

The available N in a soil represents a fraction of the total N susceptible to absorption by plants. N is generally taken up in the NO_3^- form under aerobic and as NH_4^+ ions under anaerobic conditions of plant growth. Nevertheless, the sum of ammonical and nitrate N is generally smaller than the total quantity of N, which becomes available to the plants during their entire growth period. The organic forms of N e.g. proteins, amino acids and amino sugars etc. gradually becomes available to the plants for absorption, depending upon their nature of combination and the soil conditions. Since the bulk of total N at any time is present in organic combinations (95 to 98%), a method that takes this reserve N into account is a better index of N supplying capacity of a soil.

Alkaline potassium permanganate method

Principle: A known weight of soil is treated with an excess of alkaline $KMnO_4$. Organic matter present in soil is oxidized by the nascent oxygen liberated by $KMnO_4$ in the presence of NaOH and thus ammonia is released. The ammonia liberated is absorbed in a known volume of boric acid containing mixed indicator, which is titrated against standard acid.

$$2\ KMnO_4 \xrightarrow{NaOH} 3O + K_2O + 2MnO_2$$

$$\text{Organic matter} \xrightarrow{[O]} \text{Release of } R.NH_2$$

$$R.NH_2 \longrightarrow ROH + NH_3$$

Requirements:

Reagents and chemicals

i. 0.32 per cent potassium permanganate solution i.e. 3.2 g in 1 litre distilled water.
ii. 2.5 percent sodium hydroxide solution i.e. 25 g in 1 litre distilled water.
iii. Liquid paraffin/wax.
iv. 0.02 N H_2SO_4/HCl solution standardized
v. 2% boric acid solution containing 5 ml mixed indicator per litre and adjusting the solution pH 4.5 with dilute NaOH or HCl.
vi. Mixed indicator solution. Bromocresol green (0.5%) and methyl red (0.1%). Mixed indicator is prepared by dissolving 500 mg of former and 100 mg of latter in 100 ml of 95 percent ethanol.
vii. Kjeldahl's distillation assembly
viii. Measuring cylinder 100 ml
ix. Pipette 5 ml/10 ml
x. Burette 25 ml/50 ml
xi. Conical flasks 100/125 ml

Procedure

1. Weigh accurately 20 g of soil sample. Wrap the sample carefully and put into kjeldahl's distillation flask.
2. Moisten the sample with distilled water and add 1 ml of liquid paraffin to avoid frothing. Add few pieces of glass beads to avoid bumping. Fix it in the kjeldahl's assembly.
3. Add 100 ml each of 0.32% $KMnO_4$ and 2.5% NaOH. Immediately fit the cork.
4. Pippette out approximately 25 ml of 2% boric acid solution in a 125 ml conical flask. Dip the end of delivery tube in it.
5. Distill the contents at a steady rate and collect the liberated ammonia in boric acid. Continue distillation until the release of ammonia from distillation take place (Test by bringing moist red litmus paper near the outlet of condenser which will turn blue as long as ammonia is being evolved).

6. Titrate the boric acid solution containing dissolved ammonia against 0.02 N H2SO4. The end point is reached when the colour changes from bluish green (above pH 4.9) to pinkish/wine red (around pH 4.5)

Observations and calculations

Volume of the soil taken	=	W g
Volume of 0.02 N H_2SO_4 used	=	V ml
100 ml of 1 N H_2SO_4	=	14 g N
1 ml of 1 N H_2SO_4	=	0.014 g of N
1 ml of 0.02 N H_2SO_4	=	0.02 x 0.014 g of N = 0.00028 g of N
One hectare furrow slice soils	=	2.24×10^6 kg
Available N (kg/ha)	=	$(V \times 0.02 \times 0.014 \times 2.24 \times 10^6)/W$

Interpretation:

Available N (kg/ha)	Rating
<112	Very low
112-224	Low
225-560	Medium
561-840	High
>840	Very high

Precautions:

i. The frothing during boiling is prevented by using liquid paraffin/wax and bumping by adding a few glass beads.
ii. Before adding sodium hydroxide solution to the distillation flask, the delivery end must be dipped in the boric acid solution.
iii. The mouth of Kjeldahl's flask should be closed immediately after the addition of sodium hydroxide so as to avoid loss of the ammonia produced as a result of alkaline reaction.
iv. The connections should be airtight lest ammonia is lost to the air.
v. The delivery end must be removed from the receiver to avoid back suction when the distillation is over.
vi. While titrating care must be taken so that end point is not surpassed. A blank titration should be kept for check.

Practical 5. Determination of available phosphorus

Soil phosphorus exists in many primary and secondary compounds. The apatite group of primary minerals is the original source of 95% or more of soil phosphorus.

The soluble phosphates ($H_2PO_4^-$ and HPO_4^{2-}) form heteropoly complex with molybdate ions, P being the central coordinating atom. The heteropoly complexes give faint yellow colour to their water solution which on reduction with stannous chloride/ascorbic acid give blue colour. The intensity of blue colour, which is proportional to the concentration of P, is read from a colorimeter at a wavelength of 660 nm using red filter.

Reaction:

(Soil colloidal complex) phosphate anion + bicarbonate $\longrightarrow$ (soil colloidal complex)bicarbonate + P in solution ($H_2PO_4^-$ and HPO_4^{2-})

$H_3PO_4^- + 12\ H_2MoO_4 = H_3P\ (Mo_3O_{10})_4 + 12\ H_2O$

Molybdate phosphomolybdate heteropoly complex (light yellow)

$H_3P(Mo_3O_{10})_4$ + stannous chloride = reduced phosphor molybdate complex (blue colour)

Requirements:

i. Conical flask, end-over-end shaker, funnel, Whatman No. 40 filter paper, pipette, volumetric flask.
ii. Spectronic 20 colorimeter
iii. Bicarbonate extract (0.5 N $NaHCO_3$; pH 8.5): Dissolve 42 g sodium bicarbonate (AR) in some water and make volume to 1 litre with distilled water and adjust the pH of the solution to 8.5 by addition of either NaOH or HCL. Filter the solution, if necessary.
iv. Activated charcoal (Darco-G-60 or any suitable discolouring carbon made free from soluble phosphorus by repeated washings with the bicarbonate extracting solution).
v. Molybdate reagent (1.5%): Dissolve 15 g ammonium molybdate in 300 ml distilled water and warm to about 50^oC. Allow this solution to cool. Add to this solution 410 ml of 10 N HCl gradually with constant stirring and dilute it to 1 litre with distilled water.
vi. Stannous chloride (Stock solution): Dissolve 10 g of $SnCl_2.H_2O$ in 25 ml of conc. HCl. Store this solution in brown colour bottle closed properly with a stopper to avoid oxidation in light.
vii. Stannous chloride (working solution): Dilute 0.5 ml of the stock solution to 66 ml with distilled water just before use with every determination.

Procedure:

i. Add 50 ml of bicarbonate extract to 100 ml conical flask containing 5 g soil. Add 1 g of Darco-G-60 and transfer the flask to the shaker. Shake the flask for 30 minutes on the mechanical shaker.
ii. Filter the solution by using Whatman filter paper No. 1.
iii. Take a 5 ml aliquot from the filtered soil-extract with a pipette and place it in a 25 ml volumetric flask. Add 5 ml of molybdate reagent with a pipette and shake the contents slowly. Dilute to about 20 ml with distilled water and shake again.
iv. Add 1 ml working solution of stannous chloride with pipette.
v. Make up the volume to 25 ml by adding distilled water and shake the solution thoroughly.
vi. Put red filters in the Spectronic-20 for this determination. Adjust the instrument to zero with the blank which is prepared simultaneous without soil. Read the blue colour of test solution after 10 minutes on the colorimeter.
vii. Colour intensity should be measured within 10 minutes of the addition of stannous chloride solution at 660 nm wavelength.

Measurement of colour intensity

1. Insert the red filter (660 nm wavelength in the colorimeter and put it on. Let the instrument warm up for about 10-15 minutes.
2. Adjust the pointer on the galvanometer to read zero transmittance.
3. Rinse the colorimeter tube with blank solution and pour a suitable volume of it in it. Place the tube in the cuvette and make the pointer read 100 with the 100-set knob.

4. Pour the test solution in another colorimeter tube and record the transmittance/absorbance reading in the scale.

Preparation of the standard curve

Standard curve shows the relationship between the concentration of an element in a given solution and the intensity of its colour. Primary P-standard solution of 50 ppm-P is prepared from potassium dihydrogen phosphate (KH_2PO_4) salt. For 50 ppm-P solution, 0.2195 g of KH_2PO_4 is dissolved in about 400 ml of distilled and then final volume is made to 1000 ml. From this primary standard, secondary standard solution of 5 ppm P is prepared.

Volume of secondary stock solution (5 ppm P) used for preparing different conc. ranges

Volume of 5 ppm P solution to be taken (ml)	Final volume to made (ml)	Conc (ppm P)
0.0	25	0.0
0.5	25	0.1
1.0	25	0.2
2.0	25	0.4
3.0	25	0.6
4.0	25	0.8
5.0	25	1.0

Preparation of standard curve

i. As given in the above table, pipette out requisite volume of 5 ppm –P solution in 25 ml measuring flask to have standard concentrations.
ii. To this add 5 ml of the extractant and 5 ml of Ammonium Molybdate solution. Mix well by shaking with hand until the evolution of CO_2 stops.
iii. Add 10 ml of distilled water washing the neck of the measuring flask.
iv. To this add 1 ml of working stannous chloride solution and make up the volume to 25 ml.
v. Measure the colour intensity at 600 nm wavelength using red filter. Note the transmittance/absorbance reading.
vi. Prepare the standard curve on semilog paper for transmittance reading or on simple graph paper for absorbance reading.

Calculations:

Weight of soil taken	=	w g
Volume of NaHCO3 used for extraction	=	50 ml
Volume of extracted solution used for P estimation	=	5 ml
Colorimeter reading	=	T
Concentration of P from the standard curve against X ppm	=	$X/10^6$ g/ml
Therefore, 25 ml of solution	=	$[X/10^6] \times 25$g
Available P_2O_5 in kg/ha	=	$[X/10^6] \times [25/5] \times [50/w] \times 2 \times 10^6$

Conversion factor for P2O5 to P is 0.43

Interpretations

Available P (kg/ha)	Rating
<4	Very low
4-10	Low
11-25	Medium
>25	High

Exercise 6. Determination of available potassium

Principle: An element when subjected to high temperature emits radiation at a characterstics wavelength. During emission, electrons in the inner shells are raised to high energy level by the flame and some electron move to outer shells of high energy. But they are not stable and return back to original shell releasing the absorbed energy in the form of photons (electromagnetic radiation). Excited atoms thus give radiation at a very definite wavelength. Intensity of flame/radiation is directly proportional to the concentration of element in solution which can be measured using photocell.

In neutral normal acetate method, the K^+ ions in exchangeable cites are replaced with NH^+ ions and K^+ is released. The concentration of K^+ ions in solution is determined by using flame photometer.

Requirements:

1 N CH_3COONH_4 (pH 7): dissolve 77 g solid ammonium acetate in distilled water, adjust the pH to 7.0 with dilute NH_4OH or acetic acid and make the final volume with distilled water to one litre.

Standard solution of K: Make a stock solution of 1000 ppm K by dissolving 1.908 g AR grade KCl (dried at 60°C for 1 hr) in distilled water and diluting to 1 litre. Prepare 100 ppm standard by diluting 100 ml of 1000 ppm K to one litre with distilled water.

Glassware: pH bottles, polyethylene bottle, measuring flask (1000 ml), funnel, pippetes

Standard curve:

Pippete 0, 5, 10, 15, 20, 40 ml of 100 ppm K solution into 100 ml volumetric flask and bring the volume to mark with distilled water. The solution contains 0, 5, 10, 15, 20 and 40 ppm K, respectively.

Procedure:

Weigh 2.5 g soil in a pH bottle. To it add 25 ml 1N Ammonium acetate (pH 7.0) with a pipette (1: 10 ratio). Keep it as such for about 10-15 minutes. In between shake it with hand. After this, shake it on an electric shaker for 5 minutes. Filter the suspension through Whatman No. 1 filter paper in another pH bottle. Prepare a standard curve by adjusting 40 ppm K solution to 100 and 0, 5, 10 15, 20 ppm K solution accordingly. Take the reading of the clear filtrate of the sample under test. Compare this reading with standard curve and note down the concentration of K from it. Calculate the available K (kg/ha). Also run a blank side by side.

Precautions:

i. Filtrate should be clear.
ii. Standard curve should be prepared carefully using right pipettes.

Calculations:

Weight of soil taken	=	2.5 g
Volume of 1N ammonium	=	25 ml

acetate
Dilution factor = 25/2.5=10 times
Reading of the sample from flame photometer = X (say)
Concentration of K standard curve = Y ppm (say)
Available K (kg/ha) = Y/100 x 25/2.5 x 2 x 10^6

Interpretation

Available K (kg/ha)	Rating
<47	Very low
47-116	Low
117-280	Medium
281-467	High
>467	Very high

Exercise 7. Determination of available sulphur

The most important fraction of sulphur absorbed by plants is SO_4-S. Its availability depends upon the S dynamics in the soil system. Sulphur is extracted with 0.15% $CaCl_2$ and the soluble sulphate is estimated turbidimetrically on a colorimeter using blue filter at 420 nm wavelength.

Requirements:

1. Calcium chloride dihydrate ($CaCl_2.2H_2O$) 0.15%. Dissolve 1.5 g of $CaCl_2.2H_2O$ (oven dried) in about 700 ml of water and make the volume one litre with distilled water.
2. Barium chloride dihydrate: $BaCl_2$. $2H_2O$ crystals, 20 to 30 mesh.
3. Darco G-60: This chemical should be sulphur free. It is used for removing the soil dispersed colour which is due to the organic matter. When this chemical is used it makes the solution clear.
4. Morgan's reagent (sodium acetate + acetic acid buffer) pH 4.8: Dissolve 100 g of pure sodium acetate in 500 ml of water. Add to this, 37 ml of glacial acetic acid (AR grade). Make the final volume one litre.
5. 0.25% gum acacia: Dissolve 250 mg gum acacia in warm water and make the volume 100 ml.
6. Standard sulphate solution: Dissolve 0.5434 g K_2SO_4 in one litre distilled water. This contains 100 mg S/ml. dilute 10 times to obtain 10 ppm solution. Transfer 0, 5, 10, 15 and 20 ml of 10 ppm solution into 50 ml volumetric flasks and to them add 10 ml Morgan's reagent and make the volume 50 ml. The solutions contain 0.1, 2, 3 and 4 ppm sulphur.
7. Measuring flask (1000 ml, 25 ml), Erlenmeyer flask (150 ml), graduated cylinder (100 ml), pipettes, Spectronic 20 colorimeter.

Procedure:

1. Transfer 10 g soil into a 150 ml Erlenmeyer flask.
2. Add 50 ml 0.15% $CaCl_2$ extraction solution.
3. Add 1 g sulphur gree Darco G 60.
4. Shake for half an hour.

5. Also run one blank with Darco-G-60 (without soil).
6. Filter the suspension through Whatman No. 42 filter paper.
7. Transfer 10 ml of aliquot to a 25 ml measuring flask and also add 10 ml of Morgan's reagent inot it.
8. Add 1 g $BaCl_2$ crystals and shake for one minute. To this add 1 ml (if S concentration in the solution is 20 ppm) or 2 ml (if S concentration in the solution is > 20 ppm) of 0.25% gum acacia solution.
9. Again shake the flask for 1 minute and make the volume upto the mark.
10. Take turbidity readings (blue filter at 420 nm) after 5 minutes but before 30 minutes. Sulphur is calculated with reference to a standard curve.

Calculations:

Weight of soil taken = 10 g
Volume of 0.15% $CaCl_2$ added = 50 ml
Dilution factor = 50/10= 5
Amount of aliquot taken = 10 ml
Final volume = 25 ml
Dilution factor = 25/10=2.5
Total dilution factor = 5 x 2.5= 12.5
Reading of sample from colorimeter = X (say)
Reading from standard curve = Y (say)
Available S (mg/kg) = Y x 12.5
Available S (kg/ha) = Y x 12.5 x 2.24

Exercise 8: Determination of nitrogen in plant residues

Principle

The nitrogen present in the plant residues is converted into ammonium sulphate by digestion with sulphuric acid in the presence of K_2SO_4 and CuSO4. Ammonium sulphate is distilled with NaOH and ammonia is liberated. It is collected in boric acid and is titrated against standard sulphuric acid.

$$(C_6H_{10}O_5)n + H_2SO_4 \longrightarrow 6n\ C + 2n\ H_2O$$
$$C + H_2SO_4 \longrightarrow CO_2 + H_2O + SO_2$$
$$R\text{-}COONH_2 + H_2SO_4 + 5\ H_2 \longrightarrow 2(NH_4)_2SO_4 + 2\ R.COOH$$

Requirements

Micro-Kjeldahl assembly, distillation assembly, digestion flask, conical flasks, burette, digestion mixture: K_2SO_4:$CuSO_4$, 10:1 (finally ground), Conc. H_2SO_4, NaOH 10 N (40%), H_2SO_4 0.1 N, boric acid 4% (prepared by heating; pH 4.5-4.8), mixed indicator (0.5 g bromocresol green + 0.1 g methyl red dissolved separately in 50 ml alcohol and then mixed –pH 4.5).

Procedure

1. Digestion: Take 0.5 to 1.0 g finally ground plant sample in Kjeldahl digestion flask. Add 20 ml conc. H_2SO_4 and 2.5-5.0 g digestion mixture. Keep it overnight.
2. Digest the material first on heater gently and at elevated temperature, till the material becomes white. Remove it and cool.

3. Add 10-15 ml water and shake the flask. Now make the volume 100 ml by mixing it well after cooling.
4. Distillation: Take 5 ml of aliquot in micro-Kjeldahl apparatus and add 10 ml of 40% NaOH slowly.
5. Distil it till 100 ml of distillate is collected in 10 ml of 4% working boric acid (with mixed indicator) in a conical flask. The colour changes from wine red to blue.
6. Remove the conical flask and titrate the contents against 0.02 H_2SO_4 till colour changes from blue to wine red again.
7. Note the reading.
8. Run a blank sample without adding aliquot and note that reading too.

Calculations

Weight of the sample = W g
Volume made = 100 ml (v)
Volume taken for distillation = 5 ml
Amount of acid used for titration = S ml
Amount of acid used for blank = B ml
Actual acid consumed for titration = (S-B) ml = X ml
1000 ml of 1 N H_2SO_4 = 14 g of nitrogen
1 ml of 1 N H_2SO_4 = 14/1000 g of nitrogen
1 ml of 0.02 N H_2SO_4 = 14/1000 x 0.02 = 0.00028 g of nitrogen
1 ml of 0.02 N H_2SO_4 = 0.00028 x X
This is present in 5ml of extract
In 100 ml 0.00028/5 x X x 100
This is present in W g of plant
In 100 g = [X x 0.00028 x 100 x 100]/(5 x W)

Note: the pH of the working boric acid solution should be adjusted between 4.5-4.8, the colour of boric acid at this pH will be wine red having little bluish tinge.
(In a solution of 1 litre of 4% boric acid contained in a measuring flask, add 8-10 ml of mixed indicator and adjust the pH between 4.5-4.9, which would impart a wine red colour with a bluish tinge).

Exercise 9: Determination of Phosphorus in plant residues

Principle

In an acidic medium, the phosphorus form a yellow-coloured complex with vanadomolybdate ions and the yellow colour is measured in a colorimeter at 470 nm wavelength using blue filter.

Requirements

Colorimeter, volumetric flasks (25 ml/50 ml), pipettes (5 ml/10 ml), ammonium molybdate, ammonium metavanadate, conc. HNO_3, standard phosphorus solution (50 ppm).

Preparation of HNO_3-vanado-molybdate reagents

1. Dissolve 25 g ammonium molybdate in warm 400 ml distilled water in a beaker. This is ‘a’ solution.

2. Dissolve 1.25 g ammonium metavanadate in 300 ml boiling water. Cool it and add 250 ml conc. HNO_3 and again cool it. This is ‘b’ solution.
3. Pour solution ‘a’ into solution ‘b’ and dilute the mixture to one litre.

Preparation of standard phosphorus (50 ppm) solution

Dry KH_2PO_4 at 40°C and dissolve 0.2195 g in about 400 ml distilled water in one litre volumetric flask. Then add 25 ml of 1 N H_2SO_4 (17.7%) and make the volume one litre. This gives stock solution of 50 ppm of phosphorus. 100 ml of 50 ppm stock solution is diluted to 1000 ml. this gives 5 ppm of P. From this various concentrations of P can be prepared as given below

Preparation of a standard curve

Volume of 5 ppm solution taken	Conc. (ppm) obtained when diluted to 25 ml	Percent transmittance	Absorbance
0	0	100	0
0.5	0.1		
1.0	0.2		
1.5	0.3		
2.0	0.4		
2.5	0.5		
3.0	0.6		
3.5	0.7		
4.0	0.8		
4.5	0.9		
5.0	1.0		

Take the concentrations of P (ppm) on X-axis of a semi-log paper and % transmittance n Y-axis and plot the reading on paper. Join these points to the nearest, in a straight line. If absorbance has been required, mark absorbance (O.D) on Y-axis on an ordinary graph paper and mark all the OD values against concentration and draw a straight line joining different points to the nearest. This would be a standard curve for P in plant residue/organic manure.

Procedure:

1. Digest the plant/organic residue samples in di-acid or tri-acid mixture and make the volume 100 ml.
2. Take 5 ml aliquot in 25 ml volumetric flask.
3. Add 10 ml distilled water.
4. Add 5 ml vanado-molybdate solution.
5. Make the volume to 25 ml with distilled water by mixing thoroughly.
6. After 20 minutes, the yellow colur develops. Note the reading either in transmittance or optical density at 470 nm wavelength. Warm the instrument for half an hour before taking the reading.
7. From the standard curve, determine P concentration.

Calculation

Reading from standard curve= X ppm

ppm P in solution = X * dilution factor = Y ppm

% P in plant/organic residue= $Y/10^4$

Exercise 10: Determination of Potassium in Plant samples

Principle

Potassium gives a characteristic colour due to emission of the flame. The intensity of colour during emission is proportional to the quantity of potassium in solution.

Standard potassium solution

Dissolve 1.9069 g of dried AR grade KCl in distilled water and make the volume 1 litre with distilled water. This solution contains 1000 ppm K. Prepare 100 ppm solution by diluting it 10 times (10 ml of 1000 ppm to 100 ml). Now prepare 0, 5, 10, 15, 20 and 40 ppm solution from 100 ppm K solution.

Standard curve

Set the instrument at 100 on the scale of galvanometer with highest concentration i.e. 40 ppm using a K filter. Then, take the reading with the remaining concentrations i.e. 5, 10, and 20 ppm and make a standard curve by plotting concentration on X- axis and reading on Y-axis.

Procedure

1. Take 1 g of dried and powdered sample and digest it with di-acid method and make volume to 100 to 250 ml.
2. After setting the instrument with standard solutions of K take a small quantity of aliquot and feed it to flame photometer.
3. Note the reading of unknown sample and compare it with the standard curve and calculate the concentration of K in the ample by multiplying it with dilution factor.

Calculations

Weight of plant sample taken = 1 g

Total volume of acid extract prepared = 100 ml

Volume of acid extract used for analysis = 5.0 ml

Flame photometer reading = T

Corresponding concentration from the standard curve = X ppm

K content in plant sample = $x/10^6 \times 100/5 \times 100/1$

Exercise 11. Determination of Sulphur in plant samples

A common procedure for determining total S in plant sample follows wet ashing of plant tissue sample. The sulphate content in the digest is then determined with barium sulphate by turbidimetry method.

Principle

During wet digestion, the entire plant sulphur of the sample is converted to sulphate form. When treated with $BaCl_2$, it is precipitated as $BaSO_4$. This provides turbidity to the solution, which is proportional to the amount of sulphate present. The measurement of this turbidity provides the means for quantitative determination of sulphur. The precipitation of $BaSO_4$ and the turbidity is a sensitive process and hence, it is necessary to standardize conditions, which should be strictly adhered to barium sulphate formation, which tends to precipitate if solution is not properly acidified. On the other hand, if the solution is too acidic, the precipitation of BaSO4 is low. Therefore, buffer salt solution is added to prevent the pH of the medium from wide fluctuation. The rate of precipitation should be controlled by the addition of pure $BaCl_2$ crystals of definite size and by its slow dissolution. Gum acacia solution is added to help in stabilizing the turbidity.

Requirements

1. Barium chloride ($BaCl_2$. 2 H_2O), 20-60 mesh crystals AR grade. Pass $BaCl_2$. 2 H_2O crystals through 20 mesh sieve and retain them on 60 mesh sieve.
2. Gum acacia solution: Dissolve 0.5 g powdered gum acacia in a mixture containing 50 ml glacial acetic acid and 50 ml distilled water, store the solution in a refrigerator in order to avoid growth of micro-organisms.
3. Salt Buffer solution: This solution contains 50 g $MgCl_2$. $6H_2O$, 4.1 g KNO_3 and 28 ml ethanol per litre.
4. 6 N HCl
5. Standard sulphur solution: To prepare 100 ppm S solution, 0.5434 g analytical grade K_2SO_4 is dissolved in distilled water and diluted to one litre.

Procedure

Preparation of standard curve

Pipette 0, 10, 20, 30, 40 and 50ml aliquot of 100 ppm S standard into 250 ml volumetric flasks. Add 25 ml buffer salt solution to each. The volume is made up with deionized water and mixed thoroughly. The resulting solutions provide 0, 4, 8, 12, 16 and 20 ppm S solution, respectively. Pipette ten ml each of the above solutions into 50 ml volumetric flask. Then add 1 ml of 6 N HCl and 1 ml of 0.5% gum acacia solutions. Mix the contents by swirling and add 0.5 g barium chloride crystals. Allow the flask to stand for one minute and then swirl the contents gently till the barium chloride crystals are dissolved. Make the volume of flask to 50 ml by adding distilled water and mix. The resulting solutions provide 0, 0.8, 1.6, 2.4 and 4 ppm S solution, respectively. Read the absorbance or transmittance of the solution on spectrophotometer at 470 nm in colorimeter using blue filter and draw the standard curve.

Estimation of Sulphur

Pipette ten ml aliquot from plant digest and then the procedure described for standard curve preparation is followed. Sulphur concentration is calculated from standard curve as follows.
Transmittance of the sample under test= X
Corresponding reading from standard curve = Y ppm
Total dilution = 100 x 5 = 500 times
Actual concentration of S in sample = Y x 500 ppm
% S content = Y x 500 x 10^{-4}

Exercise 12. Interpretation of interaction effect

Two or more growth factors are said to interact when their influence individually is modified by the presence of one or more of the others. An interaction takes place when the response of two or more inputs used in combination is unequal to the sum of their individual responses. Interactions among plant nutrients can have considerable influence on plant growth. The interplay of plant nutrients is best studied in factorial experiments that test each nutrient at three or more rates. There can be both positive and negative interactions in soil fertility studies. In addition, there can be circumstances where there is no interaction, with the action of factors being only additive. In negative interactions, the two factors say nutrients combined increase yields less than when they are applied separately. This kind of interaction can be the result of substitution for and/or interference of one treatment with the other. Lime x P, lime x Mo, Mo x P, and Na x K are common negative interactions involving apparent substitution effects. Changes in soil pH will result in numerous interactions where one ion or nutrient interferes with or competes with the uptake and utilization of other nutrients by plants. Positive interactions are in accordance with Liebig's law of the minimum. If two factors are limiting, or nearly so, addition of one will have little effect on growth, whereas provision of both together will have a much greater influence. In severe deficiencies of two or more nutrients, all fertilizer responses will result in strong positive interactions.

Yield increases from an application of one nutrient can reduce the concentration of a second nutrient, but the higher yields result in greater uptake of the second nutrient. This is a dilution effect, which should be distinguished from an antagonistic effect.

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

Some data along with their interpretation have been given in following paragraphs for making abreast ourselves.

Effects of N levels on response of rice to K

Potassium (kg K_2O/ha)	Rice yield (t/ha)	
	30 kg N/ha	90 kg N/ha
30	3.4	6.8
60	3.5	7.6
90	3.5	8.5

Interpretation: N-K and N-P interactions are commonly observed. For example, under low yield conditions when other nutrients are limiting or management practices are inadequate, plant growth is slow, and unless K is seriously limiting, some soils will release K at a rate adequate to meet the needs of the crop. With adequate N and P and improved management practices, there is more rapid growth and the potential response to K, S, and other nutrients is greater. With 30 kg/ha of N there was little response by rice to K; however, when 90 kg/ha of N was applied, the response to K was linear up to the highest rate applied.

Interaction of P and Zn fertilization on corn yield (lb/acre)

P_2O_5 (lb/a)	0 lb Zn/acre	20 lb Zn/acre
0	130	110
80	120	175

Interpretation: Interactions with micronutrients can be dramatic. On a low-P, low-Zn soil leveled for irrigation, adding P or Zn separately decreased corn yields. When both were applied a substantial positive interaction occurred.

Soil pH and row P_2O_5 interaction on corn yield (bu/A-15.5%)

Row P_2O_5 (lb/A)	pH 5.1	pH 6.1
0	105	129
35	120	130
70	130	132

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

Students are to scan relevant research articles from Indian Journal of Agronomy having interaction effects studied between different nutrients and between nutrients and other growth factors. Students will learn how the integrated effects are elucidated by the authors.

Some more exercises

1. Interpret the following interaction effect of nutrient levels and biofertilizers on seed yield of cluster bean as per the data shown below,

Biofertilizer	Percent recommended dose of fertilizers				
	0	50	75	100	Mean
Control	649	801	806	1113	842^d
Rhizobium	767	1003	1264	1179	1053^b
PSB	682	940	1159	1120	975^c
Rhizobium + PSB	802	1187	1376	1223	1147^a
Mean	725^c	983^b	1151^a	1159^a	
LSD (P=0.05)		Fertilizers		93	
		Bio-fertilizers		93	
		Interaction		186	

Sammauria *et al*. 2009. IJA 54 (3): 319-323.

Exercise 13: Computation of economic yield optima

Exercise: From the following data on response of rice (HRI 152) to different levels of N, calculate the toxic level and recommend economic optimum dose to the farmers of mid hills of Himachal Pradesh. (given price of N Rs 10/kg; price of rice Rs 8/kg).

N level (kg/ha)	0	40	80	120	160
Yield (kg/ha)	1000	3000	6000	7000	5500

Solution:

	N dose	Rice yield					
		Y	N^2	N^3	N^4	YN	YN^2
	0	1000	0	0	0	0	0
	40	3000	1600	64000	2560000	120000	4800000
	80	6000	6400	512000	40960000	480000	38400000
	120	7000	14400	1728000	207360000	840000	100800000
	160	5500	25600	4096000	655360000	880000	140800000
∑=	400	22500	48000	6400000	906240000	2320000	284800000
n=	5						

22500 = 5 a + 400 b + 48000 c (1)

2320000 = 400 a + 48000 b + 6400000 c (2)

284800000 = 48000 a + 6400000 b + 906240000 c (3)

From 1
5 a = 400 b + 48000 c - 22500
- a = 80 b + 9600 c - 4500 (4)
From 2
400 a = 48000 b + 6400000 c - 2320000
- a = 120 b + 16000 c - 5800 (5)
From 3
48000 a = 6400000 b + 906240000 c - 284800000
- a = 133.3 b + 18880 c - 5933.3 (6)

Equating 4 and 5
40 b + 6400 c = 1300 (7)
Equating 5 and 6
13.3 b + 2880 c = 133.3 (8)
From 7
b = 32.5 - 160 c (9)
From 8
b = 10 - 216 c (10)
Equating 9 and 10
56 c = -22.5
c = -0.402

Put in the value of c in equation 9
b = 32.5 - 160 x (-0.402)
b = 96.8
Put in the value of b and c in equation 4
- a = 80 x 96.8 + 9600 x (-0.402) - 4500
- a = - 614.3
or a = 614.3

Therefore, $Y = 614.3 + 96.8\ N - 0.402\ N^2$

On differentiation,
$dY/dN = 96.8 - 0.804\ N$
Therefore, the toxic level (Maximum dose) is,
$N = 96.8/0.804 = 120.4$ kg/ha
Optimum dose
$96.8 - 0.804\ N = 10/8$
or $96.8 - 0.804\ N = 1.25$
or $N = (96.8 - 1.25)/0.804$
or $N = 118.8$ kg/ha